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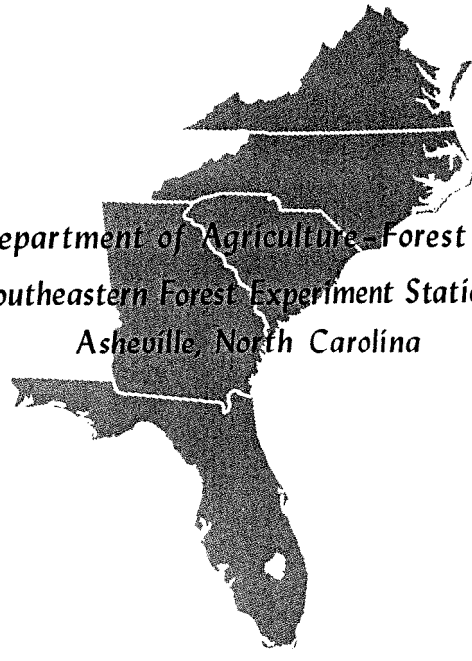

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Growth and Yield of *Slash* Pine *Plantations*

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INTRODUCTION

Although slash pine has the most limited range of the major southern pines, more has been planted than any other southern pine, or for that matter, than any timber species in North America. More acres of planted slash pine are also approaching a merchantable condition than any other species, even though the bulk of the plantings has been in the last 20 years.

Because most planting is so recent, there has been a lack of information on the growth and yield of slash pine plantations. Until 1955 the information was piecemeal and only then did the first major contribution on growth and yield appear. Since then, such information has been accumulating at an ever increasing rate until today, there is considerable data available on slash pine plantation growth and yield within the species' natural range, scattered as it is.

It is the purpose of this paper to bring together this information into a single summary bulletin based on the best experience and knowledge to date.

HEIGHT GROWTH

Slash pine planted on an average old-field site (index 65, 25-year basis) will grow about three feet annually for the first 15 years. The first year after planting, growth is only one-half to three-quarters of a foot, the second year about two feet, the third year about three feet; then, for a period, as much as four feet per year may be realized. This growth pattern is illustrated by records from a spacing study on the George Walton Experimental Forest, near Cordele, Georgia (table 1). Note that during the fifth, sixth, and seventh years, 4 feet or more in height growth was added, while growth declined to about 3.5 feet during the eighth and ninth years.

Poor growth during the fourth year is ascribed to the drought of 1954 and 1955. Although rainfall in 1954, the third growing season, was about 50 percent of normal, the height growth of 2.8 feet was about average. This is explained by a surplus of ground water resulting from 63 inches of rainfall in 1953, 10.5 inches falling in December of that year. This surplus apparently sustained growth during the extreme drought of 1954, when only 26.84 inches fell throughout the year but the combined effect of the 1954-1955 drought took its toll in the fourth year. Height growth is not correlated with stand density.

Table 1. --Annual height growth by age from seed and spacing for planted slash pine

Spacing	Trees per acre	Age from seed								Mean
		2 year* (1953)	3 years (1954)	4 years (1955)	5 years (1956)	6 years (1957)	7 years (1958)	8 years (1959)	9 years (1960)	
		Feet								
6 by 6	1,210	2.0	2.9	2.6	3.9	3.8	4.4	2.9	3.8	3.3
6 by 8	908	2.3	2.8	2.2	4.5	4.4	4.2	3.1	3.9	3.4
5 by 10	871	2.2	2.9	2.1	5.1	3.6	4.3	2.8	2.7	3.2
a by a	681	1.6	3.0	2.1	4.6	4.6	4.1	3.3	3.4	3.3
6 by 12	605	2.1	2.6	2.4	4.3	5.1	3.4	3.4	3.7	3.4
10 by 10	436	2.1	2.9	2.4	4.3	4.6	4.2	3.7	3.1	3.4
7½ by 15	387	2.1	2.1	2.6	4.5	4.3	3.8	4.1	3.5	3.4
15 by 15	194	2.1	2.7	2.4	4.2	4.2	3.8	3.7	3.9	3.4
Mean		2.1	2.8	2.3	4.4	4.3	4.0	3.4	3.5	

Further records from 19 plantations on the Forest that ranged from 14 to 18 years in age show height growth of the average tree to be about 3.0 feet annually (table 2). It is also interesting to observe that the tallest trees averaged 25 percent taller than the average tree. With a mean height of 45 feet, attained at age 15, this amounts to two 5-foot pulpwood bolts.

Height growth of the dominant stand only, up to age 25, can be calculated from existing site index curves (fig. 1).

Over a lo-year period, growth declines about 50 percent. For example on site 65, growth on a typical old field in the middle coastal plain of Georgia declines from more than 3 feet during the 10- to 15-year period to about 1.5 feet during the 20- to 25-year period. During the same period, growth on site 80 declines from 3.9 feet to 1.9 feet. Although sufficient. data from plantations older than 25 years are not available for analysis, records from natural stands indicate this rapid decline can be expected to continue until little effective height growth is realized after age 35 (Bennett, 1960a).

Table 2. --Height growth in 19 plantations of slash pine on the George Walton Experimental Forest

Age (years)	Plantation basis	Site index 1/	Mean height	Annual growth	Tallest trees
	Number	Feet			
14	5	66	41	2.9	50
15	11	69	45	3.0	57
16	2	69	48	3.0	61
18	1	63	48	2.7	60
Mean 15	--	68	45	3.0	56

1/ 25-year basis.

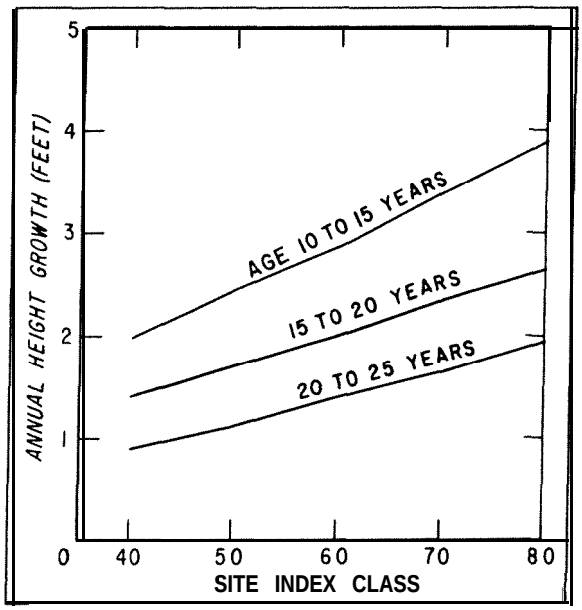

Figure 1.--Slash pine periodic annual height growth by site classes for 5-year periods as calculated from site index curves.

The **time** of year when growth **occurs is another point of interest. Records from the second, third,** and fourth growing seasons show that 25 percent of the height growth of young slash pine was completed by the end of March; by the end of April about 52 percent of the growth was completed (fig. 2). By the end of June about 85 percent of all growth was completed, and by mid-August 95 percent of all growth had occurred. No measurements were made after October 31 and that date was taken as the point of completion for height growth. Only about 1 percent of the total growth occurred in October.

These figures for slash pine are quite similar to data on loblolly pine reported by Williston (1951). He found 86 to 88 percent of loblolly height growth complete by July 4, and 93 to 96 percent complete by August 1.

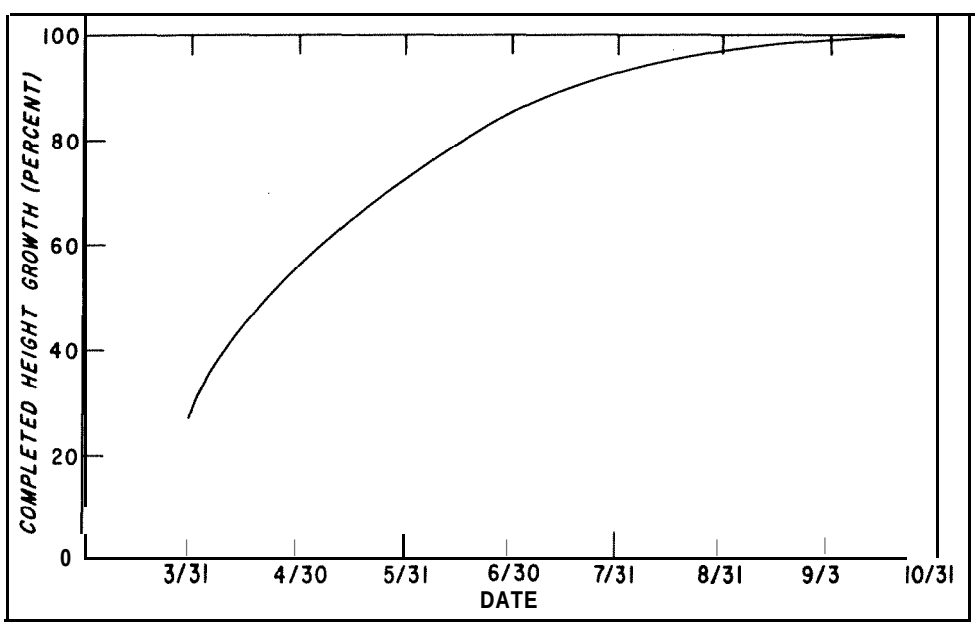

Figure 2.--Cumulative height growth for field-planted slash pine.

Old Field Versus Cutover Lands

Early height growth on old fields is about double that for cutover untilled sites (Bennett, 1956). Numerous plantings in and near the Experimental Forest confirm this (table 3). In this comparison, soils of the old-field areas are similar, being sands and loamy sands 10 to 30 inches deep. The cutover areas are generally of the same series but with a slightly lower elevation, giving them an advantage from the standpoint of available moisture. No comparison of soil properties between the two sites has been made other than percolation rate. One test of this feature indicates the cutover areas have a slightly faster rate. This agrees with Lutz and Chandler (1946), who state that "The infiltration capacity of a forest soil is usually decreased as a result of cultivation. . ."

Table 3 also indicates a correlation between growth and length of time since cultivation--the more recent the tillage, the better the growth.

Table 3. --A comparison of slash pine height growth on old-field and cutover areas

Site and years idle	Time since planting	Mean height
	Years	Feet
Area 1		
Field (2 years)	3	5.6
Cutover area	3	2.6
Area 2		
Field (2 years)	5	11.6
Cutover area	5	3.5
Area 3		
Field (5 years)	5	10.5
Cutover area	5	4.5
Area 4		
Field (10 years)	5	9.5
Cutover area	5	4.5

DIAMETER GROWTH

Data from the slash pine spacing study on the Experimental Forest indicate that stand density first affected diameter growth during the fifth year, when competition of a significant degree developed at a density of approximately 500 to 550 trees per acre (table 4) (Bennett, 1960b). The 15 by 15 spaced tree was significantly larger in the fifth year than the 6 by 12 spaced tree, while the difference between the 15 by 15 tree and the 10 by 10 tree was not significant.

The increase in density effect during the fifth year (fig. 3) is significant. At the end of 4 years, the line of average diameter plotted over stand density is almost horizontal. A decided slope develops in this line in the fifth year and it intensifies with each succeeding year,

Diameter growth of all spacings decreased markedly during the sixth year (table 5) and to a lesser extent in subsequent years. The decline was continuous even in the 15 by 15 spacing. In percentage, this reduction between the fifth and ninth year was about as much in the 15 by 15 spacing as in the 6 by 6 spacing.

Spacing configuration --that is, square versus rectangular--has shown no correlation with tree size as yet.

Table 4. --Mean diameters by spacing at the end of each growing season

Spacing (feet)	Trees per acre	Year					
		4	5	6	7	8	9
		Inches					
6 by 6	1,210	1.49	2.45	2.97	3.39	3.79	4.17
6 by 8	908	1.39	2.70	3.37	3.96	4.34	4.68
5 by 10	871	1.38	2.69	3.34	4.02	4.28	4.48
8 by 8	681	1.31	2.55	3.49	4.37	4.47	4.82
6 by 12	605	1.40	2.67	3.59	4.11	4.60	5.02
10 by 10	436	1.62	2.93	3.86	4.47	5.00	5.45
7½ by 15	387	1.52	2.82	3.73	4.45	5.03	5.50
15 by 15	194	1.55	3.02	3.96	4.74	5.44	6.09

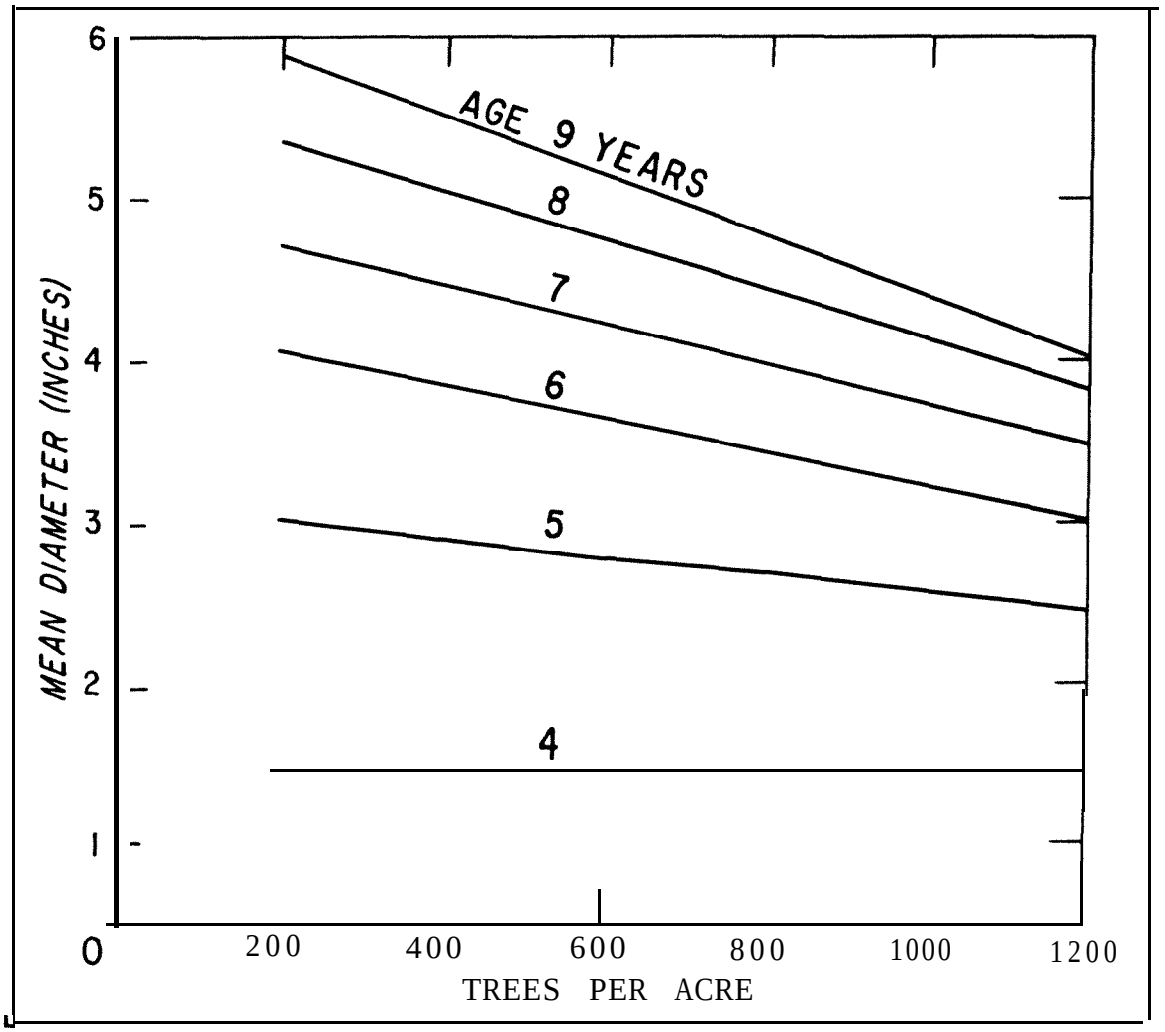

Figure 3. --Regression of d. b. h. on stand density.

Table 5. --Annual diameter growth by spacings

Spacing (feet)	Year				
	5	6	7	8	9
	Inches				
6 by 6	0.96	0.52	0.42	0.40	0.38
6 by 8	1.31	.67	.59	.38	.34
5 by 10	1.31	.65	.68	.26	.20
8 by 8	1.24	.94	.58	.40	.35
6 by 12	1.27	.92	.52	.49	.42
10 by 10	1.31	.93	.61	.53	.45
7½ by 15	1.30	.91	.72	.58	.47
15 by 15	1.47	.94	.78	.70	.65

Table 6. --Basal areas at the end of the ninth growing season

Spacing (feet)	Basal area per acre 1/
	Square feet
6 by 6	113
6 by 8	105
5 by 10	94
8 by 8	83
6 by 12	79
10 by 10	70
7½ by 15	63
15 by 15	39

1/ Number of surviving trees per acre multiplied by the basal area of the average tree.

After nine growing seasons, the 6 by 6 spacing has about three times more square feet of basal area than the 15 by 15 spacing (table 6). These data were derived by multiplying the tree of average basal area by the number of surviving trees per acre. To that extent the figures are an approximation but they illustrate the high densities to be expected from close spacings even with a small average diameter.

Diameter growth in older stands has not been measured directly and can be determined only from measurements taken at various ages. Analysis of such data shows that at a given age the average annual growth rate of the 6 by 6 spacing is nearly 68 percent of the 15 by 15 spacing (table 7). Between the tenth and twentieth years the growth rate of both spacings declined about 28 percent. This corresponds with the trend found in the spacing study, where the growth rate of the 6 by 6 spacing declined about 60 percent from the fifth to the ninth year and the 15 by 15 spacing dropped about 56 percent. For the first 20 years, mean annual diameter growth on an average old-field site will be about one-half inch for the 15 by 15 spacing and about one-third inch for the 6 by 6 spacing. Intermediate spacings will be within these extremes.

Table 7. --Average annual diameter growth rate for two spacings of planted slash pine at different ages on an average old-field site (site 65, 25-year basis), after Bennett, McGee, and Clutter (1959)

Spacing (feet)	Age period		
	0 to 10 years	0 to 15 years	0 to 20 years
	Inches		
6 by 6	0.46	0.37	0.33
15 by 15	.67	.55	.48

CUBIC AND CORDWOOD YIELDS

Prior to 1955, isolated and more or less piecemeal yield studies of slash pine plantations indicated that yields are influenced by age, site, and spacing, of which only spacing can be controlled directly (table 8). The closer spacings produce the greatest total cubic and cordwood yield and, with one exception, these cordwood yields are in proportion to spacing. The Auburn, Alabama, test showed less yield at age 14 for the 4 by 4 spacing than for the 6 by 6. These yields, however, are from small test plots, and although there are spacing replications in some instances, age and site were not replicated.

Since that time, three rather comprehensive yield plantation studies have been completed within the slash pine belt. These studies, in Florida, Georgia, and Alabama provide a base for yield and growth predictions.

Florida

The work of Barnes (1955) and Barnes and Ralston (1955), who reported on planted slash pine yields in Florida, was the first comprehensive study of slash pine plantation yields in relation to age, site, and spacing (tables 9 to 12). These yields are presented by spacing and number of surviving trees per acre in tables 9 and 10. Survival percentages are presented in table 11, and the relation of average diameter to age, site, and stand density is illustrated in table 12.

Table 8. --Slash pine cordwood yields in relation to spacing

Location	Age	Spacing	Survival	Volume per acre
	Years	Feet	Percent	Cords
Johnson Tract, Louisiana (Muntz, 1947)	12	4.3 by 4.3	53	11.9
		5.2 by 5.2	59	10.0
		6.2 by 6.2	63	9.6
		13.1 by 13.1	68	4.1
Lake City, Florida (Florida Forest and Park Serv., 1944)	13	8 by 8	90	25.9
		10 by 10	90	19.5
		12 by 12	90	18.1
Tallahassee, Florida (Florida Forest and Park Serv., 1944)	13	8 by 8	90	34.8
		12 by 12	90	20.2
		16 by 16	90	10.8
Auburn, Alabama (Ware and Stahelin, 1948)	14	4 by 4	73	28.6
		6 by 6	77	31.0
		6 by 8	84	22.9
		8 by 8	76	17.3
		9.6 by 9.6	79	17.5
		12 by 12	76	15.5
		18 by 16	82	10.6
Bogalusa, Louisiana (Bull, 19471	15	5 by 5	85	18.6
		6 by 6	91	16.2
		8 by 8	90	13.2
Bogalusa, Louisiana (Bull, 1947)	20	5 by 5	--	1/ 30.0
		6 by 6	--	1/ 27.0
		8 by 8	--	1/ 26.0

1/ Includes volume removed in a thinning at age 15.

Table 9. --Volume yields of slash pine in Florida in cords per acre by site quality, age, and spacing at time of planting (Barnes, 1955)

Age	Original spacing	Site quality (height at 25 years)					
		30	40	50	80	70	80
		Cords per acre					
10	8 by 8	--	--	1.3	5.3	10.8	11.7
	8 by 8	--	--	.6	3.8	8.1	13.8
	10 by 10	--	--	.3	2.3	8.0	10.9
	12 by 12	--	--	.1	1.3	5.2	8.5
15	8 by 8	--	1.4	9.8	19.7	31.3	43.9
	8 by 8	--	1.4	8.1	18.2	25.7	37.8
	10 by 10	--	1.5	8.7	12.9	20.7	31.5
	12 by 12	--	1.8	5.7	10.4	17.4	28.1
20	6 by 6	2.7	8.0	17.2	30.3	45.2	81.4
	8 by 8	3.1	8.0	15.4	28.0	40.0	53.1
	10 by 10	3.1	8.1	13.3	21.9	32.3	44.3
	12 by 12	3.3	8.3	11.4	18.1	28.9	37.8
25	6 by 6	5.5	9.7	22.9	37.7	53.8	71.5
	8 by 8	5.5	9.8	20.8	33.7	48.3	83.9
	10 by 10	5.8	9.8	17.8	27.8	40.4	53.0
	12 by 12	5.8	9.8	18.1	24.2	33.9	44.9

Table 10. --Volume (cords per acre) of slash pine in Florida by age, number of surviving trees per acre, and site quality (Barnes, 1955)

Age	surviving trees per acre	Site quality (height at 25 years)					
		30	40	50	80	70	80
	Number	Cords per acre					
10	200	--	--	--	1.2	5.0	7.8
	400	--	--	0.4	2.8	8.3	11.8
	800	--	--	.8	3.9	a.5	14.5
	800	--	--	1.2	4.9	10.0	18.5
	1,000	--	--	1.5	5.8	11.1	17.9
15	200	--	1.8	5.7	10.2	18.4	24.4
	400	--	1.5	7.8	15.8	24.7	35.3
	800	--	1.4	9.1	18.1	28.8	40.4
	800	--	1.4	9.8	19.5	30.8	43.1
	1.000	--	1.4	10.2	20.4	32.0	44.8
20	200	3.2	8.2	11.4	18.1	28.3	38.1
	400	3.0	8.0	15.1	25.7	37.7	51.1
	800	2.8	5.9	18.8	28.7	42.1	58.8
	800	2.7	8.0	17.4	30.2	44.4	59.8
	1,000	2.5	8.0	17.9	31.2	45.8	61.7
25	200	5.8	9.8	18.2	24.3	33.9	44.9
	400	5.5	9.8	20.8	32.8	'48.7	81.7
	600	5.5	9.7	22.2	36.0	51.3	87.0
	800	5.8	9.8	23.1	37.7	53.7	71.0
	1,000	5.7	9.9	23.8	38.7	55.1	72.9

Table 11. --Survival percentage of slash pine in Florida by age and site quality (Barnes, 1955)

Age	Site quality (height at 25 years)					
	30	40	50	60	70	80
	Survival percentage					
10	63	70	74	77	79	81
15	56	63	68	71	73	74
20	53	60	65	68	70	71
25	51	58	63	66	68	69

Yield in Relation to Stocking

On sites 50 and above, the closer spacings give the greatest cordwood yield. Below site 50, spacing has little effect on yields, Apparently on these poor sites only a few trees can efficiently utilize the site potential.

Table 12. --Average d. b. h. of entire stand of slash pine in Florida by site quality, age, and spacing at time of planting (Barnes, 1955)

Age	Original spacing	Site quality (height at 25 years)					
		30	40	50	60	70	80
		D. b. h. (inches)					
10	6 by 6	1.7	1.8	3.0	3.8	4.4	4.6
	8 by 8	1.7	1.8	3.2	4.3	5.0	5.4
	10 by 10	1.9	2.1	3.5	4.6	5.4	6.0
	12 by 12	2.1	2.3	3.7	4.9	5.9	6.4
15	6 by 6	2.2	2.9	4.1	4.9	5.5	5.7
	8 by 8	2.3	3.4	4.0	5.7	6.5	7.0
	10 by 10	2.5	4.1	5.4	6.5	7.4	8.0
	12 by 12	2.6	4.3	5.8	7.0	8.0	8.6
20	6 by 6	2.4	3.8	4.9	5.8	6.4	6.6
	8 by 8	3.0	4.5	5.8	6.8	7.6	8.0
	10 by 10	3.5	5.2	6.5	7.6	8.4	9.0
	12 by 12	3.8	5.6	7.0	8.3	9.2	9.8
25	6 by 6	3.0	4.4	5.5	6.4	7.0	7.4
	8 by 8	3.6	5.2	6.5	7.5	8.3	8.9
	10 by 10	4.3	6.1	7.4	8.5	9.2	9.8
	12 by 12	4.7	6.5	7.8	9.1	10.0	10.7

Yields on the better sites indicate a stocking limit beyond which little growth can be realized on additional stocking levels (table 13). Use of table 13 is as follows: From the 16- to 20-year growth period note that on site 70 and for a stocking of 400 trees there are 24.7 cords, and that during the 16- to 20-year period annual growth on this stocking is 2.60 cords. Now, for 600 trees per acre there is a stocking of 28.6 cords, or 3.9 cords more than the 400-tree stocking level; annual growth on the 28.6 cords equals 2.70 cords for the 16- to 20-year period. Thus the additional stocking of 200 trees and 3.9 cords increased the annual growth by only 0.10 cord. This amounts to 2.6 percent growth on the added stocking of 3.9 cords. For the 16- to 20-year period, growth on stockings beyond 400 trees per acre is generally less than 3 percent. For the 21- to 25-year period, growth on stocking levels beyond 200 trees per acre is usually less than 2 percent.

Table 13. --Periodic annual growth by age, site, and stand density, and growth added by additional stockings beyond given base stockings

GROWTH PERIOD 16 TO 20 YEARS

Site	Tree stocking at age 15		Periodic annual growth	Annual growth on additional stocking units of--							
				200 trees		400 trees		600 trees		800 trees	
	Number	Cords	Cords	Cords	Percent	Cords	Percent	Cords	Percent	Cords	Percent
50	200	5.7	1.14	0.32	15.2	0.36	10.6	0.36	9.3	0.40	8.9
	400	7.8	1.46	.04	3.1	.06	3.0	.08	3.3	--	--
	600	9.1	1.50	.02	2.9	.04	3.6	**	--	--	**
	800	9.8	1.52	.02	5.0	--	**	**	--	--	**
	1,000	10.2	1.54	--	--	**	**	--	--	**	**
60	200	10.2	1.58	.44	8.1	.55	7.0	.56	6.0	.58	5.7
	400	15.6	2.02	.11	4.4	.12	3.1	.14	2.9	--	--
	600	18.1	2.13	.01	.7	.03	1.3	--	--	--	
	800	19.5	2.14	.02	2.2	**	**	--	--	--	**
	1,000	20.4	2.16	**	--		**	**	**	**	**
70	200	16.4	1.98	.62	7.5	.72	5.9	.78	5.5	.78	5.0
	400	24.7	2.60	.10	2.6	.16	2.7	.16	2.2	**	--
	600	28.6	2.70	.06	3.0	.06	1.8		--	--	**
	800	30.6	2.76	.00	-0.4	**	**	**	--	--	--
	1,000	32.0	2.78	--	--	--	--	**	--	--	--
60	200	24.4	2.34	.82	7.5	.94	5.9	1.00	5.3	1.04	5.1
	400	35.3	3.16	.12	2.3	.18	2.3	.22	2.3		
	800	40.4	3.28	.06	2.2	.10	2.3	--	--		
	800	43.1	3.34	.04	2.3	--	**	**	--	**	
	1,000	44.8	3.38	--	**	--		**	--	**	

	(Tree stocking at age 20)		GROWTH PERIOD 21 TO 25 YEARS								
50	200	11.4	.96	.14	3.8	.16	3.1	.18	3.0	.18	2.8
	400	15.1	1.10	.02	1.3	.04	1.7	.04	1.4	--	--
	600	16.6	1.12	.02	2.5	.02	1.5	--	--	--	--
	800	17.4	1.14	.00	-0.2	--	--	--	**	--	--
	1,000	17.9	1.14	--	**	--	--	--	--	--	--
60	200	18.1	1.24	.18	2.4	.22	2.1	.26	2.1	.26	2.0
	400	25.7	1.42	.04	1.3	.08	1.8	.08	1.4	--	--
	600	28.7	1.46	.04	2.7	.04	1.6	**	--	--	--
	800	30.2	1.50	.00	-0.2	**	--	--	--	--	--
	1,000	31.2	1.50	--	--	--	--	**	--	--	**
70	200	26.3	1.52	.28	2.5	.32	2.0	.34	1.9	.34	1.7
	400	37.1	1.80	.04	.9	.06	.9	.06	.7	--	**
	600	42.1	1.84	.02	.9	.02	.5	--	--	--	--
	800	44.4	1.86	.00	-0.1	--	--	--	--	--	--
	1,000	45.0	1.86	--	--	--	**	**	--	**	--
80	200	36.1	1.76	.36	2.4	.44	2.1	.48	2.0	.48	1.9
	400	51.1	2.12	.08	1.4	.12	1.4	.12	1.1	--	--
	800	56.8	2.20	.04	1.3	.04	.a	**	--	--	--
	800	59.8	2.24	.00	-0.1	--	--	--	**	--	**
	1,000	61.7	2.24	--	--	--	**	--	--	--	--

Two hundred trees per acre will produce 5'7 to 64 percent of the yield of 1,000 trees at age 20, and 60 to 69 percent of the 1,000-tree yield at age 25. One thousand trees per acre yield 55.1 cords at age 25, while 200 trees yield 33.9 cords, or 62 percent of the 1,000-tree yield. Further, four hundred trees produce 46.7 cords, or 85 percent of the 1,000-tree yield; this leaves 60 percent of the trees producing 15 percent of the yield. Production by 200-tree units is outlined in figure 4. Beginning with the first 200 trees, production drops drastically through the third 200-tree unit, but the decline is more gradual thereafter.

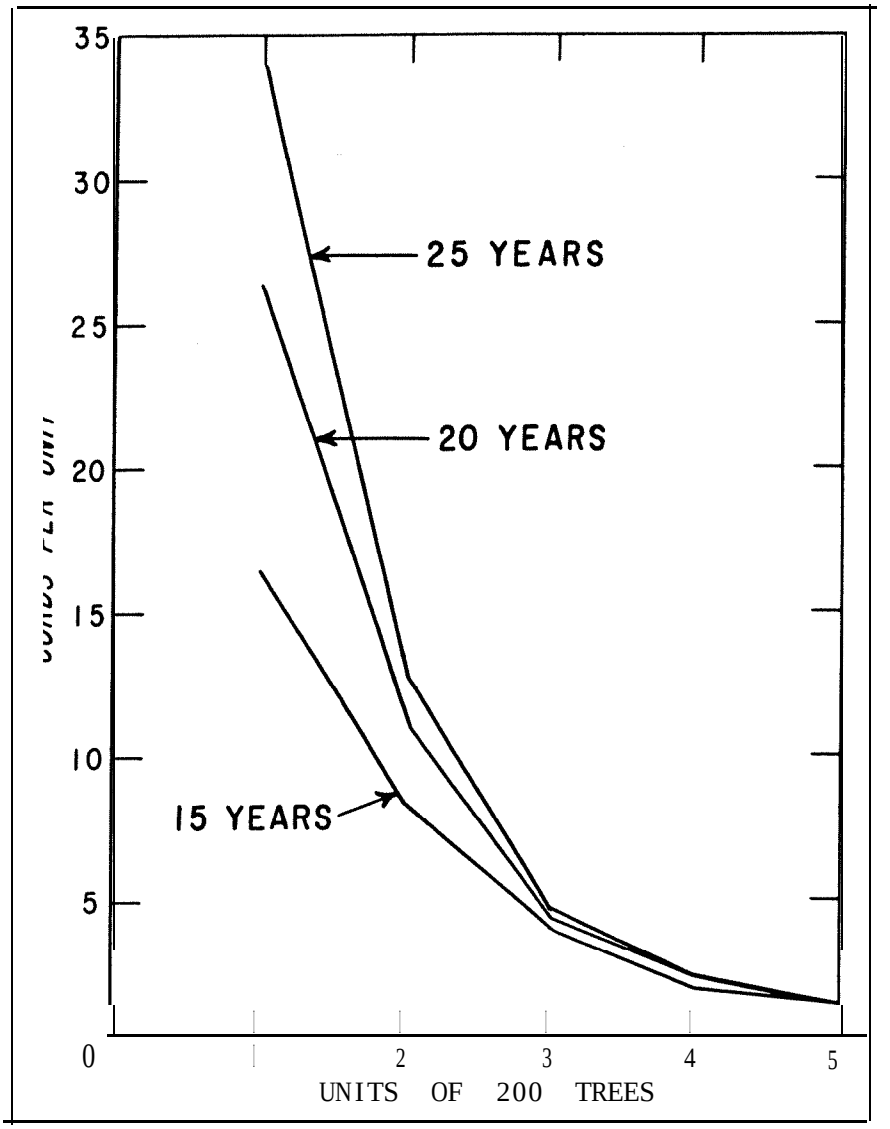

Figure 4.--Comparison of yields by 200-tree units.

Yield in Relation to Site

For each lo-foot increase in site index there is a sizable yield increase. The percentage increase in yield per unit increase in site is much larger for the lower sites, but the numerical increase in cords, of course, is larger on the better sites. For example, looking at the 6 by 6 spacing, the increase in yield at age 25 of site 40 over that of site 30 is 4.2 cords, or 76 percent, while the increase in yield of site 80 over site 70 is 17.7 cords, or an increase of only 33 percent.

Barnes (1955) suggests the site index of a given soil type with a history of cultivation will be7 feet higher at age 25 than that of a forest soil of the same physical characteristics. Accordingly, old-field sites of 50 or more will yield 5 to 12 cords more per acre at age 25 than forest sites of the same soil classification. Presumably cultivation has reduced vegetative competition for soil moisture and nutrients, and residual fertilizer may have beneficial effects. These are the same general effects produced by site preparation and fertilization. Thus, using old-field yields as a basis of comparison, a rough guide to the profitability of site improvement can be set up (table 14). Assuming a forest site can be raised to the old-field level (7 feet), site preparation would not pay on site 30 at an interest charge of 3 percent or more if the cost were ten dollars or more. In slash plantings, these very low sites are usually associated with deep sands, such as the Kershaw series, which are low in organic content. Ralston and McGee (1962) suggest that soils with an Al horizon of less than six inches (the depth to which organic matter is incorporated into the soil) be assigned a low priority for site preparation treatment. Their work showed that response to complete site preparation on low forest sites, principally deep sands with shallow A_1 horizons, was not sufficient to justify the expense.

Table 14. --Net returns from site preparation expenditures at various interest charges when the quality of a forest site is raised 7 feet to the old-field level at 25 years 1/

cost per acre (dollars)	Site class 30	40	50	60	70
		Net return in dollars			
3 PERCENT INTEREST					
10	X1--	26.00	37.56	46.01	48.61
15	--	15.39	27.09	35.54	38.14
20	--	4.92	16.62	25.07	27.67
25	--	--	6.16	14.61	17.21
30	--	--	--	4.14	6.74
35	--	--	--	--	--
4 PERCENT INTEREST					
10	--	20.14	31.84	40.29	42.89
15	--	6.81	18.51	26.96	29.56
20	--	--	5.18	13.63	16.23
25	--	--	--	.31	2.91
30	--	--	--	--	--
35	--	--	--	--	--
5 PERCENT INTEREST					
10	--	12.94	24.64	33.09	35.69
15	--	--	7.70	16.15	18.75
20	--	--	--	--	1.82
25	--	--	--	--	--
6 PERCENT INTEREST					
10	--	3.88	15.58	24.03	26.63
15	--	--	--	2.51	5.17
20	--	--	--	--	--
25	--	--	--	--	--

1/ Based on yields from an 8 by 8 spacing and a stumpage price of $6.50 per standard cord. The figure would vary slightly for other spacings.

2/ Dashes represent negative values.

Table 15. --Maximum allowable expenditure for site preparation with stumpage at $13.00, a rotation of 25 years, and a site increase of 7 feet

Interest charge percent	Initial site class (feet)				
	30	40	50	60	70
	Dollars				
3	20.00	44.00	55.00	63.00	66.00
4	15.00	35.00	43.00	50.00	52.00
5	12.00	27.00	34.00	39.00	41.00
6	--	21.00	27.00	31.00	32.00

With costs compounded at 3 percent for 25 years, the maximum profitable expenditure on any site would be $30 per acre unless the site quality were increased by more than 7 feet; at 4 percent, it would be $25; at 5 percent, $20; and at 6 percent, $15. Note also the indicated maximum expenditure applies to sites 60 and 70.

The figures in table 14 are relative to the returns from site preparation based on today's stumpage prices. However, stumpage has about doubled in the past 15 years, and if stumpage prices double again in the next 25 years, the maximum allowable expenditure for site preparation will increase accordingly (table 15). Likewise, if measures increasing the site quality by more than 7 feet can be developed, expenditures can be increased in proportion.

Yield in Relation to Age

Depending on stocking, mean annual growth culminates on sites of index 50 or more at 18 to 25 years of age (fig. 5). Growth does not culminate by age 25 on sites below 50. Growth culminates earlier where spacing is close than where it is wide.

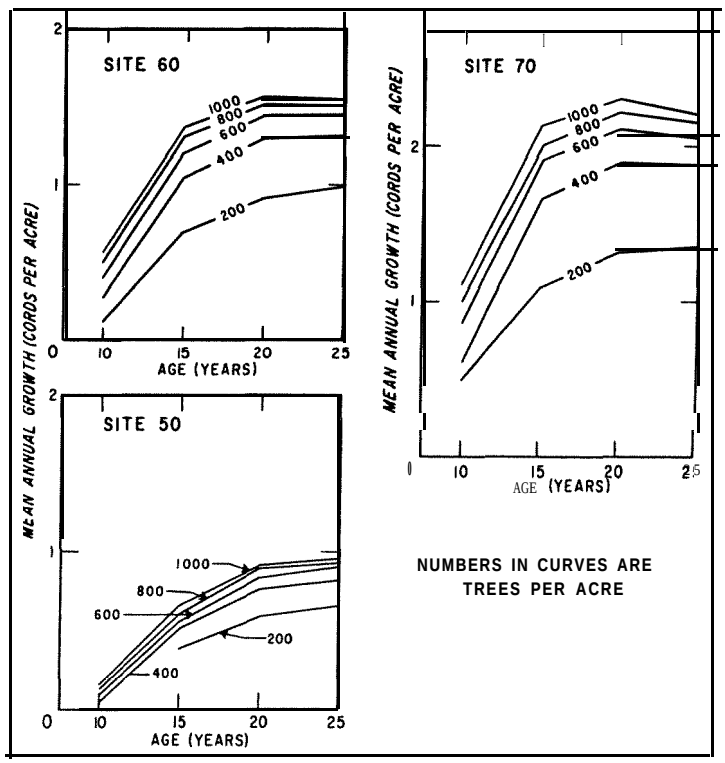

Figure 5. --Mean annual cordwood growth for the 50-, 60-, and 70-foot site classes.

Georgia and the Carolinas

Yields for the middle coastal plain of Georgia and the sandhills of the Carolinas were published in 1959 (Bennett, McGee, and Clutter, 1959). Volume data from 308 plots were correlated with age, site, and stand density through regression analysis. These variables accounted for 86 percent of the variation in yields. The following functions of these variables were established as highly significant:

The reciprocal of plantation age

Site (height of dominant stand at age 25)

The logarithm of effective space per tree (original space per tree divided by percent survival)

The reciprocal of site index

Tables 16 and 17 present volume yields in cubic feet for the various age, site, and stand density combinations. Survival percentages used in computing these yields are listed in table 18. The effect of age, site, and stand density on diameter growth is illustrated in table 19.

When the tables are used to estimate the actual yield obtainable from plantations where mortality occurs in clusters, some adjustment of the tabular yields may be required. Such adjustments are necessitated because the sample plots contained no openings or voids of measurable size. Trees often tend to die in groups, however, leaving openings or voids of measurable size within the plantation. To arrive at a reasonable yield estimate, these voids must be accounted for in the total plantation acreage. Use of the yield tables is explained in detail by Bennett, McGee, and Clutter (1959).

Yield in Relation to Stocking

Growth in Georgia and the Carolinas, unlike that in Florida, does not culminate in relation to spacing on any site by age 20. Data were insufficient for a valid analysis of yields at age 25. Cordwood yields for the closer spacings are somewhat higher in Georgia than in Florida, while yields for the wider spacings are about the same for the two states. A difference in average diameter accounts for most of the variation in yields (table 20). For the 6 by 6 spacing, the Georgia mean diameter is 0.3 to 0.7 inch larger than that of the Florida planting, but except for site 70, the wider spacings have about the same average diameter.

As in Florida, plantation density can be reduced without a proportionate reduction in yield (table 21). The 15 by 15 spacing has only 16 percent as many trees as the 6 by 6, but it produces 47 percent of the yield of the closer spacing. The 12 by 12 spacing, with 25 percent as many trees as the 6 by 6 spacing, produces 57 percent of the 6 by 6 yield. This is because volume does not vary directly with diameter, but rather in proportion to the square of diameter. The average diameter of the 6 by 6 spacing at age 20 on site 70 is 7.1 inches, while that of the 12 by 12 spacing is 9.6 inches. This is a 35 percent increase in average diameter, but the volume increase for this average tree is about 100 percent.

Table 16. --Yields (outside bark) of slash pine plantations of the middle coastal plain of Georgia and the Carolina Sandhills 1/ (Bennett, McGee, and Clutter, 1959)

TOP DIAMETER 4.0 INCHES OUTSIDE BARK

Age (years)	Original spacing	Site index (age 25)							
		40	45	50	55	60	65	70	75
	Feet	Cubic feet per acre							
10	6 by 6	61	135	240	369	511	657	788	912
	6 by 8	54	119	212	327	451	582	697	809
	8 by 8	48	106	188	289	400	515	617	712
	10 by 10	40	88	156	241	333	428	514	593
	15 by 15	29	65	115	177	244	315	377	435
15	6 by 6	237	522	926	1,426	1,972	2,539	3,042	3,526
	6 by 8	209	461	819	1,262	1,745	2,246	2,691	3,120
	8 by 8	186	409	726	1.118	1,546	1,989	2,384	2,761
	10 by 10	155	340	605	931	1,287	1,657	1,986	2,303
	15 by 15	114	250	443	684	946	1,218	1,459	1,699
20	6 by 6	463	1,020	1,812	2,790	3,858	4,967	5,952	6,800
	6 by 8	410	902	1,603	2,468	3,412	4,393	5,230	5,990
	8 by 8	363	799	1,419	2,185	3,022	3,891	4,595	5,260
	10 by 10	302	666	1,183	1,822	2,519	3,210	3,800	4,315
	15 by 15	222	490	871	1,341	1,834	2,310	2,790	3,275
	TOP DIAMETER 3.0 INCHES OUTSIDE BARK								
10	6 by 6	127	252	414	599	789	976	1,134	1,291
	6 by 8	112	221	363	525	692	856	994	1,125
	8 by 8	98	194	318	460	607	751	872	981
	10 by 10	81	159	262	379	499	617	727	824
	15 by 15	57	114	188	272	358	443	545	654
15	6 by 6	389	772	1,267	1,835	2.417	2,989	3,473	3,918
	6 by 8	342	677	1,111	1.608	2,119	2,621	3,045	3,436
	8 by 8	300	595	975	1,413	1,860	2,302	2,675	3.014
	10 by 10	247	489	802	1,161	1,529	1,892	2,199	2.480
	15 by 15	177	351	577	835	1,099	1,360	1.580	1,787
20	6 by 6	679	1,344	2,206	3,193	4,206	5,204	6,046	6,905
	6 by 8	595	1,178	1,934	2,799	3,687	4,532	5,300	6,120
	8 by 8	522	1,035	1,698	2,458	3,238	4,005	4,654	5.300
	10 by 10	430	851	1,397	2,022	2,664	3,296	3,886	4,410
	15 by 15	309	613	1,006	1,456	1,917	2,387	2,860	3,369
	TOP DIAMETER 2.0 INCHES OUTSIDE BARK								
10	6 by 6	153	300	487	697	908	1,112	1,279	1,431
	6 by 8	134	262	426	609	793	971	1,117	1,263
	8 by 8	117	229	372	532	694	849	977	1,088
	10 by 10	96	187	304	435	567	694	798	889
	15 by 15	68	133	216	309	403	493	600	700
15	6 by 6	441	863	1,399	2,002	2,609	3,195	3,676	4,103
	6 by 8	386	753	1,222	1,748	2,279	2,790	3,209	3,585
	8 by 8	337	660	1,069	1,530	1,994	2,441	2,809	3,133
	10 by 10	276	539	874	1,251	1,630	1,996	2,296	2,563
	15 by 15	196	384	622	890	1.160	1,420	1,634	1,829
20	6 by 6	744	1,454	2,357	3,374	4,397	5,384	6,212	7,000
	6 by 8	650	1,270	2,059	2,948	3,840	4,702	5,500	6,200
	8 by 8	568	1,110	1,801	2,577	3,359	4,112	4,780	5,410
	10 by 10	465	908	1,473	2,108	2,748	3,387	3,980	4,512
	15 by 15	331	648	1,050	1,503	2,000	2,490	2.980	3,470

1/ Includes all trees 4.6 inches in diameter and larger.

Table 17. --Yields (inside bark) of slash pine plantations of the middle coastal plain of Georgia and the Carolina Sandhills 1/ (Bennett, McGee, and Clutter, 1959)

TOP DIAMETER 4.0 INCHES INSIDE BARK

Age (years)	Original spacing	Site index (age 25)							
		40	45	50	55	60	65	70	75
	Feet	Cubic feet per acre							
10	6 by 6	25	62	118	193	260	376	464	552
	6 by 8	23	55	106	172	250	334	413	493
	8 by 8	20	49	94	153	222	297	368	437
	10 by 10	17	41	79	129	187	250	310	367
	15 by 15	13	31	59	96	139	186	231	298
15	6 by 6	122	297	570	930	1,346	1,802	2,228	2,655
	6 by 8	109	265	507	830	1,197	1,603	1,981	2,382
	8 by 8	97	236	451	737	1,068	1,428	1,766	2.120
	10 by 10	82	198	380	619	897	1,200	1,484	1,783
	15 by 15	81	148	283	462	869	835	1,106	1,330
20	6 by 6	268	650	1,243	2,028	2,938	3,931	4,700	5,480
	6 by 8	238	578	1,106	1,804	2,813	3,487	4,200	4,900
	8 by 8	212	515	985	1,607	2,328	3,091	3,718	4,328
	10 by 10	179	433	828	1,351	1,958	2,587	3,173	3,683
	15 by 15	133	323	819	1.009	1,439	1,897	2,360	2.175
		TOP DIAMETER 3.0 INCHES INSIDE BARK							
10	6 by 6	62	130	225	340	462	587	696	800
	6 by 8	54	115	199	300	408	518	615	708
	8 by 8	48	102	178	265	360	458	543	622
	10 by 10	40	85	146	220	299	380	451	516
	15 by 15	29	62	107	180	218	277	350	414
15	6 by 6	220	468	808	1,218	1,657	2,104	2,497	2,870
	6 by 8	195	413	714	1,075	1,462	1,857	2,204	2,533
	8 by 8	172	365	631	950	1,293	1,642	1,949	2,237
	10 by 10	143	303	524	789	1,074	1,363	1,618	1,859
	15 by 15	105	221	383	576	785	997	1,183	1,372
20	6 by 6	416	881	1,523	2.295	3,121	3,965	4,760	5,510
	6 by 8	367	778	1,344	2,025	2,755	3,510	4,225	4,950
	8 by 8	324	687	1,188	1,790	2,435	3.093	3,760	4.393
	10 by 10	270	571	987	1,488	2,023	2,620	3,239	3,750
	15 by 15	197	418	722	1,089	1,481	1,956	2.418	2,890
		TOP DIAMETER 2.0 INCHES INSIDE BARK							
10	6 by 6	79	164	278	418	551	689	806	914
	8 by 8	70	144	244	362	485	607	710	807
	8 by 8	81	127	215	319	427	534	824	706
	10 by 10	51	105	178	263	352	441	515	582
	15 by 15	37	76	129	191	255	319	400	465
15	6 by 6	259	537	911	1,349	1.806	2,260	2,644	2,397
	8 by 8	227	472	801	1,186	1,588	1,988	2,326	2,637
	8 by 8	200	417	706	1,046	1,400	1,752	2,050	2,320
	10 by 10	166	344	583	864	1,157	1,447	1.693	1,918
	15 by 15	120	249	422	626	838	1,049	1,227	1,391
20	6 by 6	466	968	1,640	2,430	3,253	4,072	4,861	5,811
	6 by 8	410	851	1,443	2,138	2,861	3,581	4,309	5,000
	8 by 8	361	750	1,271	1,883	2,520	3,211	3,850	4,491
	10 by 10	298	620	1,051	1,556	2,084	2,680	3,297	3,840
	15 by 15	217	450	763	1,130	1,546	2,014	2,489	2.979

1/ Includes all trees 4.6 inches in diameter and larger.

Table 18. --Survival by age and stand density (Bennett, McGee, and Clutter, 1959)

Spacing (feet)	Age (years)		
	10	15	20
	Percent		
6 by 6	73	70	88
8 by 7	74	71	89
8 by 8	74	72	70
8 by 8	75	73	71
8 by 10	78	74	72
10 by 10	78	78	74
15 by 15	88	88	84

Table 19. --Average diameter at breast height of entire stand by age, spacing, and site index (age 25) (Bennett, McGee, and Clutter, 1959)

Age (years)	Original spacing	surviving trees per acre	Site index							
			40	45	50	55	80	85	70	75
	Feet	Number	Inches							
10	8 by 8	888	3.5	3.8	4.0	4.2	4.4	4.8	4.9	5.2
	8 by 8	672	3.8	4.0	4.3	4.5	4.7	4.9	5.2	5.5
	8 by 8	513	4.0	4.3	4.5	4.8	5.1	5.2	5.6	6.9
	10 by 10	341	4.4	4.7	5.0	5.3	5.6	5.7	8.2	6.5
	12 by 12	249	4.6	5.1	5.4	5.7	6.0	6.2	6.6	7.0
	15 by 15	171	5.2	5.6	5.9	6.2	6.6	6.7	7.2	7.6
15	8 by 6	858	4.0	4.3	4.8	4.9	5.2	5.8	5.9	8.3
	6 by 8	651	4.2	4.8	4.9	5.2	5.6	5.9	6.3	8.7
	8 by 8	497	4.5	4.9	5.2	5.8	5.9	6.3	6.1	7.1
	10 by 10	331	5.0	5.3	5.7	6.0	6.5	7.0	1.4	7.9
	12 by 12	243	5.3	5.7	6.2	6.6	7.0	7.5	8.0	8.4
	15 by 15	167	5.8	6.3	6.7	7.2	7.7	8.2	8.7	9.2
20	6 by 6	830	4.4	4.8	5.2	5.7	6.1	6.6	7.1	7.7
	6 by 8	631	4.7	5.1	5.6	8.1	6.5	7.1	7.6	8.2
	8 by 8	462	5.0	5.5	8.0	6.4	7.0	7.5	8.1	8.7
	10 by 10	322	5.5	6.0	6.5	7.1	7.7	8.3	8.9	9.5
	12 by 12	236	5.9	6.5	7.0	7.8	8.2	8.9	9.6	10.3
	15 by 15	182	6.5	7.1	7.7	8.3	9.0	9.7	10.4	11.2

Table 20. --Average diameters at age 20 for Georgia and Florida slash pine plantations 1/

Spacing (feet)	Site class					
	50		60		70	
	Florida	Georgia	Florida	Georgia	Florida	Georgia
	Inches					
6 by 6	4.9	5.2	5.8	6.1	6.4	7.1
8 by 8	5.8	6.0	6.8	7.0	7.6	8.1
10 by 10	6.5	6.5	7.6	7.7	8.4	8.9
12 by 12	7.0	7.0	8.2	8.2	9.2	9.6

1/ Georgia data from Bennett, McGee, and Clutter (1959) and Florida data from Barnes (1955).

Table 21. --Percentage *yields* at *age 20* of various spacings in relation to the 6 by 6 spacing as a standard

Spacing (feet)	Trees per acre	Stocking	*Yield*
	Number	Percent	Percent
6 by 6	1,210	100	100
8 by 8	680	56	77
10 by 10	436	36	64
12 by 12	305	25	57
15 by 15	194	16	47

Table 22. --Cordwood *yield* increases at age 20 by J-foot site increments

Site improvement (feet)	Spacing			
	8 by 6	8 by 8	10 by 10	15 by 15
	Cords			
40 to 45	6.1	4.7	4.0	2.9
45 to 50	8.6	6.7	5.6	3.8
50 to 55	10.8	8.3	6.9	5.1
55 to 60	11.6	9.1	7.6	5.4
60 to 65	12.0	5.4	7.6	5.2
65 to 70	10.7	7.7	6.4	5.2
70 to 75	9.2	7.2	5.8	5.2

Yield in Relation to Site

Yields at age 20 for a minimum top diameter of 4 inches increase about 1,370 percent from site 40 to site 75, with the biggest increases in the lower site classes. For example, the yield from site class 45 is 120 percent above that of site class 40, while the yield from site 75 is only about 14 percent above that of site 70. The larger yield increases occur, of course, on the better sites, with a peak at about site 60. Because of the larger yields indicated for Georgia, effective site improvement would pay even better dividends there than in Florida, especially in the closer spacings (table 22). Increasing the site quality of an 8 by 8 planting from 60 to 65 feet would result in a yield increase at age 20 of 9.4 cords, which is an increase of $61.10 in stumpage value at an average of $6.50 per cord. This stumpage increase will vary with both site and spacing, as indicated by volumes in table 22, but the potential profits from increases of 5 feet or more in site quality are substantial for all spacings on the better sites, i. e., those with index of 50 or more.

Yield in Relation to Age

Mean annual increment has not culminated at age 20 for any site or spacing (fig. 6), but the 6 by 6 spacing on site 70 does indicate an approaching culmination. In fact, curves for all spacings on site 70 are leveling somewhat by age 20, indicating that culmination will occur within a few years.

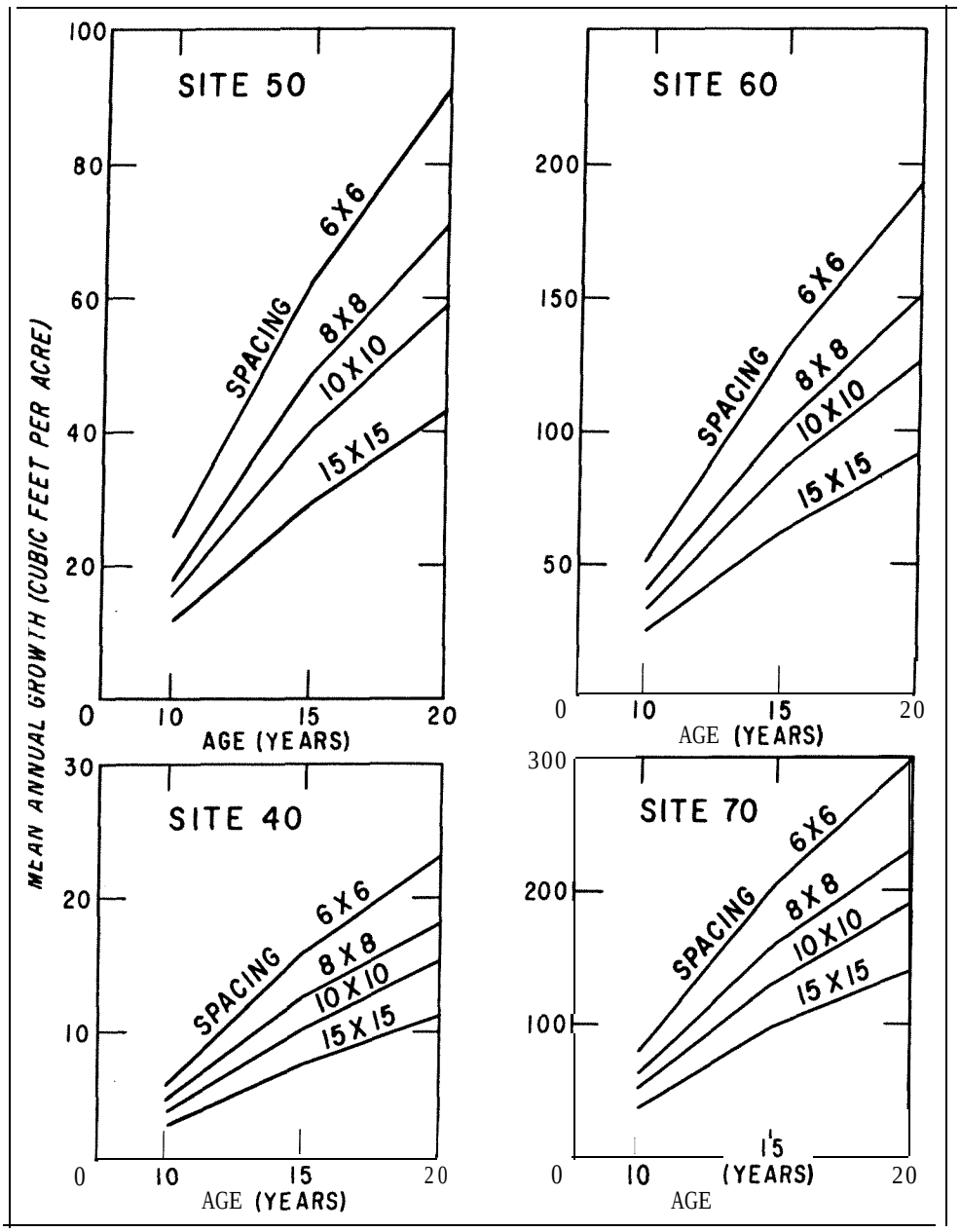

Figure 6. --Mean annual cubic-foot growth--by site and spacing.

Alabama

Goggans and Schultz (1958) related slash pine plantation yields in Alabama to stand density and dominant height. Data from 69 plots, averaging 54 percent in survival and 11 years of age, were subjected to regression analysis. The regression shows a 5-cord increase in yields for each 5-foot increase in dominant height (table 23). For each 100-tree increase in stocking, yields increase 1.32 cords. This constant increase in yields per unit increase in stocking is at variance with Barnes and Ralston's (1955) work in Florida, but the Alabama yields show the same pattern as the Florida and Georgia yields with respect to the high proportion of yield attributable to the first 400 trees.

A table of estimated heights in relation to age, surface soil depth, and silt plus clay content of the surface soil is useful in estimating yields from bare soils (table 24). Yields that accompany a dominant height of 50 feet can be attained from 12 to 16 years of age, depending on surface soil characteristics. Yields for a dominant height of 40 feet will be produced from 9 to 15 years of age, according to surface soil depth and silt plus clay content.

Table 23.--Estimated merchantable volume per acre of 9- to 16-year old slash pine plantations in Alabama's coastal plain (Goggans and Schultz, 1958)

Number of trees per acre	Height of tallest trees (feet)					
	25	30	1/35	40	45	50
	Cords					
400	go.30	5.33	**10.49**	**15.59**	20.69	25.78
500	1.82	8.71	11.81	18.91	22.01	27.11
3/600	2.94	8.04	4/13.13	18.23	23.33	28.43
700	4.28	3.38	14.48	19.55	24.85	29.75
800	5.58	10.68	15.78	20.87	25.97	31.07
900	**6.90**	12.00	17.10	22.20	27.29	32.39
1,000	8.22	13.32	18.42	23.52	g28.82	33.71

1/ Average height was 37.2 feet.
2/ Five percent confidence limits at this point are ± 1.49.
3/ Average number of trees per acre was 590.
4/ Five percent confidence limits at this point are ± 0.84.
5/ Five percent confidence limits at this point are ± 1.81.

BOARD-FOOT YIELDS

No formal analysis on board-foot yields similar to cubic and cordwood analyses is available. Records from individual plantations and plots supply the best, if not the only, estimate of sawtimber production in slash pine plantations. As one would expect, board-foot production varies directly with spacing (table 25). At 14 years of age the close spacings have produced very little sawtimber volume, while production in the wider spacings ranges from 800 to 2,808 board feet per acre at 15 years. At 20 years of age one 10 x 10 spacing shows 1,87 5 board feet per acre, with more than half of the total in dominant wildings. In contrast, the wider spacings show up to 6,296 board feet per acre at age 20, with little volume contributed by large volunteers. Variation in the wider spacings is the result of initial survival and site differences, defects in tree form, and fusiform infections. Although no special study has been made, observations indicate that repeated or severe burning in the early years tends to cause crook and sweep in the lower portion of the trunk. This directly affects the number of trees that will qualify as sawtimber. Form and quality are also influenced, no doubt, by genetically inherited characteristics,

Table 24. --Estimated heights of tallest trees in slash pine plantations 1/

Depth of topsoil	Silt plus clay content of topsoil	Age (years)											
		5	6	7	8	9	10	11	12	13	14	15	16
		Feet											
Shallow (6 inches)	Low (10%)	11.3	Y15.2	18.9	22.3	25.5	28.4	31.2	33.1	36.0	38.1	39.9	41.5
	Average (20%)	11.9	15.8	19.4	22.8	26.0	29.0	31.7	34.3	36.6	38.6	40.5	42.1
	High (35%)	12.7	18.6	20.2	23.7	28.9	29.6	32.6	35.1	37.4	39.5	41.3	42.9
Average (22 inches)	Low (10%)	12.8	16.7	20.4	23.8	27.0	29.9	32.7	35.2	37.5	39.6	41.4	43.0
	Average (20%)	14.9	18.8	22.4	25.8	29.0	32.0	34.7	37.2	39.5	41.6	43.4	45.0
	High(35%)[0]	17.9	21.8	25.5	28.9	32.1	35.0	37.8	40.3	42.6	44.7	46.5	48.1
Deep (50 inches)	Low (10%)	15.4	19.3	23.0	26.4	29.8	32.5	35.3	37.0	40.1	42.2	44.0	45.6
	Average (20%)	20.1	24.0	27.6	31.0	34.2	37.2	39.9	42.4	44.7	46.8	48.6	50.2
	High (35%)[0]	27.0	30.9	34.8	38.0	41.2	44.1	46.9	49.4	51.7	53.8	3/55.6	57.2

1/ Adapted from Goggans and Schultz (1958).
2/ Five percent confidence limits at this point are ± 2.0 feet.
3/ Five percent confidence limits at this point are ± 5.5 feet.

Table 25. --Board-foot volume production by slash pine plantations on the George Walton Experimental Forest

Plantation number	Spacing	Age	Survival	Sawtimber stand per acre			Total
				Trees	Planted trees	Wild trees	
	Feet	Years	Percent	Number	Board feet	Board feet	Board feet
132B	8 by 8	14	42	8	55	412	467
155A	10 by 10	14	70	13	74	709	783
		20	69	47	902	953	1,875
155E	10 by 10	14	63	16	65	765	830
155G	II by 11	14	64	11	254	69	323
101A	15 by 15	15	83	60	--	--	1,888
		20	83	63	--	--	4,090
132A	15 by 15	15	78	73	2,504	304	2,806
		18	--	89	--	--	4,548
132C	15 by 15	15	--	62	1.778	682	2,460
163B	15 by 15	15	85	55	1,876	414	2,290
188B	15 by 15	15	66	42	1,257	433	1,690
186A	15 by 15	18	75	69	3,047	68	3.115
		24	--	79	6,756	38	6,796
124A	16 by 16	14	81	46	--	--	1,481
		15	81	60	1,899	176	2,075
1551	16 by 16	15	86	52	1.623	159	1,782
155J	16 by 16	15	70	31	938	62	1,000
163C	16 by 16	15	86	44	1,527	133	1.660
167A	16 by 16	15	65	24	737	86	823
		16	--	33	--	--	1,275
		21	--	57	3,720	46	3,766
220A	17 by 17	15	--	77	2,716	51	2,767
		20	--	16	--	--	6,296

SUMMARY

The utility of this paper will be lost, for the most part, if the plantation manager views it as a series of case histories. But if he uses the information gathered here as prediction mechanisms on which he can base management decisions, he will have progressed from decision-making based on intuition to decision-making based on thorough, complete, and painstaking research.

Finally, the information contained in this paper will be less than complete on the date of issue. More and better data and analyses of slash pine plantation growth and yield are in progress; they will give more specific information for localized areas, for areas outside the natural range of slash pine, and for growth analyses obtained from re-inventories over a period of time. The plantation manager, because of the rapidity of growth and changing conditions, should keep continually up-to-date on publications in this field.

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