STAND DYNAMICS OF UNTHINNED AND THINNED SHORTLEAF PINE PLANTATIONS

Glendon W. Smalley[1/]

ABSTRACT

Growth and yield information about unthinned and thinned shortleaf pine (*Pinus echinata* Mill.) plantations established mostly on old-fields in the Coastal Plain, Piedmont, Ridge and Valley, Cumberland Plateau, and Highland Rim physiographic provinces is covered in this paper. The growth and yield pattern of shortleaf pine is more suited to the production of sawlogs at long rotations than to the production of pulpwood at short rotations. Thinning is needed to capture mortality and to concentrate growth potential on fewer trees. The efficacy of thinning shortleaf plantations depends on planting density, site, quality, rotation age, and availability of markets for small-diameter trees. A management scenario proposed by Williston (1983) should be applicable to most plantations. The paper concludes with some thoughts on the adequacy of existing growth and yield information for shortleaf plantations.

INTRODUCTION

I was asked by the program committee to discuss density management in shortleaf pine plantations. Density management is the manipulation and control of growing stock to achieve specific management objectives. Although the actual control of growing stock is relatively easy to achieve through initial spacing and intermediate cuttings, the determination of appropriate levels of growing stock at the stand level is a complex process involving biological, technological, and economic factors specific to a particular management situation.

There is limited published information about density control of shortleaf pine plantations; there are no economic analyses. Consequently, I found it impossible to pattern this paper after similar ones in the East and West symposia on loblolly pine (*P. taeda* L.) (Hughes and Kellison 1982, Hughes and Herschelman 1984).

In consulation with Dr. Willett and other speakers, particularly Dr. Murphy, I changed my topic to "Stand Dynamics of Thinned and Unthinned Shortleaf Pine Plantations." Published information about the growth and yield of shortleaf plantations is limited in quantity and in coverage of the range of the species (Williston 1975, Smalley 1978), and nearly all is concerned with plantations established on old-fields.

1/ Dr. Smalley is principal soil scientist at the Silviculture Laboratory, maintained at Sewanee, TN, by the Southern Forest Experiment Station, USDA Forest Service, in cooperation with the University of the South.

Information in this paper about unthinned plantations was gleaned from accounts of localized silvicultural tests, such as species trials and spacing trials, and from regional growth and yield studies located in the Ridge and Valley, Piedmont, Coastal Plain, Shawnee Hills, Cumberland Plateau, and Highland Rim physiographic provinces (Fenneman 1938). Information about thinned plantations comes from three well-documented studies located in (a) the Highland Rim in southern Indiana, (b) the Shawnee Hills section of the Interior Low Plateau in southern Illinois, and (c) the East Gulf Coastal Plain of northern Mississippi (Fenneman 1938). All ages in this report are plantation ages unless otherwise noted.

UNTHINNED PLANTATIONS

Localized Silvicultural Tests

Ridge and Valley

In upper east Tennessee, shortleaf pine was one of 14 species planted on abandoned fields in a series of experiments begun in 1938 and 1939 by Leon S. Minckler. At plantation age 20, Burton (1964) reported that total height and diameter of experiment-2 plantations were remarkedly uniform within and between aspects (north and south) and soil parent material (shale, dolomite, and limestone) (table 1). However, survival, and hence merchantable volume, was half again as great on south slopes as on north slopes. Poor survival on north slopes was attributed to dense competition from grasses, forbs, shrubs, and trees.

At plantation age 30, shortleaf pines on soils derived from carbonate materials were significantly taller than those on soils derived from shale (table 1). Other stand attributes were not affected by aspect or soil parent material.

Piedmont

Near Union, SC, 13-year-old shortleaf pines established at a spacing of 8 by 8 feet grew reasonably well (table 1) but were exceeded in height and diameter growth by loblolly pine and slash pine (*P. elliottii* Engelm.) (Branan and Porterfield 1971). Virginia pine (*P. virginiana* Mill.), longleaf pine (*P. palustris* Mill.), and eastern white pine (*P. strobus* L.) did so poorly that they were not recommended for timber production.

In Buckingham County, VA, 16-year-old shortleaf pines established at a spacing of 6 by 6 feet did not grow as well as expected (table 1) (Kormanik and Hoekstra 1963). The poor growth might be due to seed source. Although shortleaf pine is native to the area, planting stock came from northern Alabama. Adjacent loblolly and eastern white pine plantations grew much better. Virginia pine growth was similar to shortleaf pine.

In Clarke County, GA, shortleaf pine plantations were established at spacings of 4 by 4, 5 by 5, 6 by 6, 7 by 7, and 8 by 8 feet (Jackson 1958). The seed source was unknown and no details of the site were reported. Spacing appreciably affected survival and growth after 14 years (table 2). Only at the 8 by 8 foot spacing were 50 percent or more of the surviving trees in the 5-inch or larger diameter classes (345 out of 648 trees).

Table 1.--Stand characteristics of shortleaf pines planted on old-fields in the Ridge and Valley of east Tennessee and in the Piedmont of South Carolina and Virginia

Location	Original spacing	Planatation age	Survival	D.B.H.	Basal area	Height	Merchantable volume
	ft	yrs	percent	in	ft^2ac^{-1}	ft	ft^3ac^{-1}
East Tennessee	6 by 6	20[1/]	57	5.3	127	39	860
		30[2/]	61	6.3	166	55	3,996
South Carolina[3/]	8 by 8	13	92	5.3	96	51	-----
Virginia[4/]	6 by 6	16	80	4.6	124	35	-----

1/ From Experiment 2 (Burton 1964). Basal area based on all trees $\geq$ 0.6 inch d.b.h.; merchantable volume is inside bark to a 3.0-inch top i.b., all trees $\geq$ 4.6 inches d.b.h.

2/ From Experiments 2 and 3 (unpublished data on file at Silviculture Laboratory, USDA Forest Service, Sewanee, TN). Basal area based on all trees $\geq$ 0.6 inch d.b.h.; merchantable volume is outside bark to a 4.0-inch top o.b. for all trees $\geq$ 5.0 inches d.b.h.

3/ From Branan and Porterfield (1971).

4/ From Kormanik and Hoekstra (1963).

Table 2.--Stand characteristics of planted shortleaf pines in the Piedmont of Georgia at plantation age 14 as affected by initial spacing (from Jackson 1958)

Spacing	Survival	D.B.H.	Basal area	Merchantable volume
ft	percent	in	ft^2ac^{-1}	ft^3ac^{-1}
4 by 4	86	3.2	131	772
5 by 5	87	3.8	122	1,236
6 by 6	92	3.9	94	913
7 by 7 2/	94	4.1	77	779
8 by 8	95	4.7	79	1,042

1/ Cubic volume outside bark to a 3.0-inch top outside bark, all trees $\geq$ 4.6 inches d.b.h.

2/ Data not highly reliable because of excessive soil erosion on two of four plots.

Jackson did not recommend spacings of 4 by 4 and 5 by 5 feet because of the small average diameter and the large number of trees in the 2- and 3-inch diameter classes. Despite the increased percentage of larger trees, the 8 by 8 foot spacing was not recommended because of poor wood quality resulting from large branches associated with retarded natural pruning. Also, the relatively low number of trees would reduce the yield of the first thinning. The 6 by 6 or possibly a 6 by 8 foot, spacing was recommended as the best compromise considering survival, growth, wood quality, and expected yield of pulpwood from the first thinning. However, these recommendations, based on 14-year results, seem to be premature.

Coastal Plain

In Benton County, MS, Williston (1958) reported that dominant and codominant shortleaf pines averaged 48 feet in height at age 22 (table 3). The deep, brown loam soils on the study site were considered fair for shortleaf pine. Original spacing was 5 by 5 feet. Early height growth was retarded by tip moths (*Rhyacionia frustrana* Comst.).

In Madison County, TN (Williston 1959), reported that dominant and codominant shortleaf pines averaged 45 feet in height at age 29 (table 3). These plantations were established at a 6 by 6 foot spacing on an eroded ridge. Early height growth was retarded by tip moths. At age 29, many of the crowns had an unhealthy color and unusually short needles. Stagnation appeared imminent unless the plantation was thinned.

In Lafayette County, MS, annual spraying of insecticides for 6 years to prevent tip moth attack had only a minor impact on stand development (Williston 1985). These shortleaf pines were planted at a 7 by 9 foot spacing in a creek bottom. The somewhat poorly drained, nearly level soils had formed in silty alluvium; the site appeared to be too wet for shortleaf pine to make its best growth. Even at the wider spacing, basal area growth slowed after age 15. Mean annual volume increment at age 25 was 158 cubic feet per acre (table 3). These plantations were overstocked and should have

Table 3.--Stand characteristics of shortleaf pines planted on old-fields in the East Gulf Coastal Plain region of west Tennessee and north Mississippi

Location	Original spacing	Plantation age	Survival	D.B.H.	Basal area	Height of dominants and co-dominants	Site index (50 years)	Merchantable volume
	ft	yrs	percent	in	$ft^2 ac^{-1}$	ft	ft	$ft^3 ac^{-1}$
Benton County MS 1/	5 by 5	12	63	4.7	132	23	--	623
		22	61	6.3	231	48	73	3,369
Madison County TN 2/	6 by 6	19	89	4.4	116	29	50	701
		29	74	5.7	158	45	60	2,080
Lafayette County MS 3/	7 by 9	10	100	5.1	99	32	--	765
		15	99	6.3	147	44	--	1,995
		25	72	7.7	162	67	108	4,120

1/ From Williston 1958.

2/ 19-year data from Huckenpahler 1950; 29-year data from Williston. 1959.

3/ From Williston 1985.

4/ For Benton County, MS and Madison County, TN plantations, merchantable volume is inside bark to a 3.0-inch top i.b., all trees ≥ 4.6 inches d.b.h.; for the Lafayette County, MS plantation, merchantable volume is inside bark to a 3-inch top i.b., all trees ≥ 4 inches d.b.h.

been thinned at about age 15. It may be difficult for the crowns of residual trees to recover if thinned.

According to Williston, yields such as these on formerly cultivated creek bottoms indicate the attractiveness of converting similar sites encumbered with cut-over, low-value hardwoods to shortleaf pine, particularly north of the range of loblolly pine. These creek bottoms are also excellent hardwood sites as attested by a rating of site index 100 to 110 (base age 50 from seed) for bottom land hardwoods.

In 1957, a survey of pulpwood-size, CCC-established pine plantations in north Mississippi showed that the average survival of shortleaf plantations was 48 percent, mean stocking was 633 trees per acre, and mean annual increment was 0.58 cords per acre (Williston and Dell 1974). Form class for the shortleaf pines was 2 to 3 percentage points lower than for loblolly pines. Most of these plantations were established on eroded old-fields at a spacing of 6 by 6 feet. Common soils were Loring, Providence, Grenada, and Ruston. Only 19 percent of the plantations needed any release from hardwood competition at the time of the survey. Most of those needing release were along intermittent streams, in minor stream bottoms, or in dense growths of kudzu (*Pueraria lobata* (Willd.) Ohwi.), muscadine (*Vitis rotundifolia* Michx.), or cow-itch vines (*Campis radicans* (L.) Seem.). Twenty-nine percent of the study plots had been thinned prior to 1959, but the work had been done haphazardly. Loblolly pine plantations were thinned 4 or 5 years sooner than shortleaf pine plantations.

Volume growth rates between ages 20 and 35 were increased by retaining high densities. Thinning could reduce growth as well as increase the risk of loss to *Fomes annosus* (Fr.) Cke. Across the range of ages sampled (17-29), cordwood growth rates increased with age and site index (fig. 1A and B). Across the range of ages sampled (23-29), sawtimber growth rates culminated at all site indexes (fig. 1C and D), because merchantability limits are more stringent for sawtimber than for pulpwood. At a given age, sawtimber growth rates culminated at a higher basal area as site index increased.

Shawnee Hills

In Pope County, IL, shortleaf pine seedlings from an unknown seed source were planted at spacings of 4 by 4, 6 by 6, 8 by 8, and 10 by 10 feet on fields abandoned from cultivation about 10 years earlier (Gilmore and Gregory 1974; Arnold 1978, 1981). The soil, classified as Grantsburg silt loam, developed under forest cover in 50 to 100 inches of loess over sandstone or shale residuum. A moderately well-developed fragipan occurs at a depth of 24 to 30 inches or at a shallower depth if the soil is eroded. Both root penetration and moisture movement are impeded by the fragipan.

Here at the northern limit of its range, shortleaf pine grew satisfactorily for 31 years (table 4). The 6 by 6 and 8 by 8 spacings produced about equal cubic volumes. The 10 by 10 spacing produced about 700 cubic feet per acre less, and the 4 by 4 spacing lost volume in the last 6 years because of excessive mortality. Statistically, there are no significant differences in merchantable cubic volume among the three widest spacings. Arnold (1981) concluded that the 10 by 10 spacing was too wide to

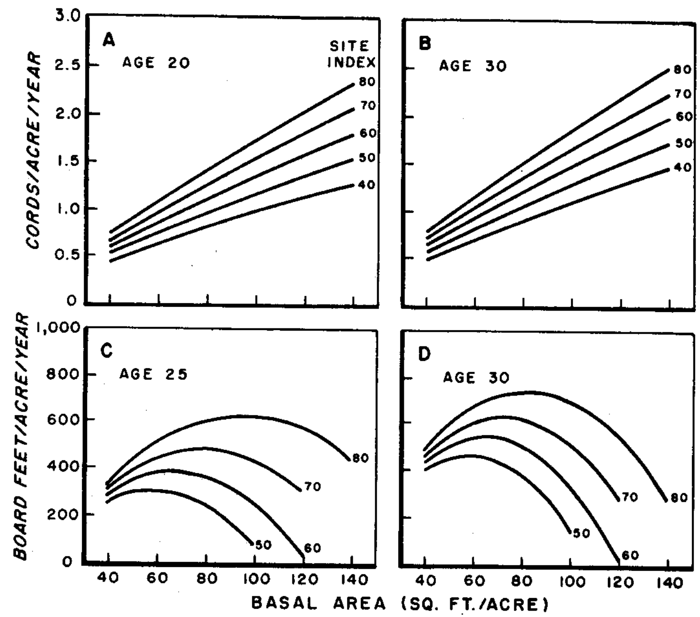

Figure 1.--Effect of plantation age, basal area, and site index (base age 50 from seed) on periodic annual volume increment of CCC-established shortleaf pine plantations in north Mississippi. Basal area is calculated on trees of all sizes (from Williston and Dell 1974).

produce optimal quantities of pulpwood at age 20, but he was encouraged by the production of over 4,600 fbm per acre of sawtimber at age 31.

However, it seems to me that the 10 by 10 foot spacing data supports the idea of managing shortleaf pine plantations for sawlogs. A commerical thinning (mostly from below) for pulpwood seems possible by age 30 when the mean diameter is approaching 9 inches. Probably another thinning of pulpwood and small sawlogs could be made about age 40 when the mean diameter should be close to 10 inches.

Arnold (1981) did not recommend planting any more shortleaf pine in southern Illinois because it was outproduced by loblolly pine. He did feel though that the slower growth and higher survival rates of shortleaf pine should enable owners of plantations to keep posts and poles "on the stump" longer, a definite advantage in the uncertain post and pole market. Because the post and pole market is very limited, early thinning of plantations for these products is not an option for most owners of shortleaf pine plantations.

Regional Growth and Yield Studies

Piedmont

Ralston and Korstian (1962) developed a system of equations for predicting pulpwood yields in the lower Piedmont of North Carolina based on variations in stocking, average stand diameter, and volume-basal area ratios developed from multiple regressions. This analytical system was intended to solve such growth and yield problems as (a) preparation of yield tables for well-stocked stands, (b) growth predictions for nonmerchantable stands, (c) yield estimates for merchantable stands of variable density, and (d) growth

Table 4.--Continued

Plantation age (yrs)	Spacing (ft)			
	4 by 4	6 by 6	8 by 8	10 by 10
	Merchantable volume (fbm $acre^{-1}$)2/			
25	0	0	884	1,862
31	94	483	3,090	4,638

1/ Volume outside bark, total stem, all sizes of trees.

2/ International 1/4" kerf.

projections for thinned stands. However, the system received only limited application.

Interior Uplands

Smalley and Bailey (1974) developed variable-density yield tables for the Ridge and Valley, Cumberland Plateau, and Highland Rim physiographic provinces in Alabama, Tennessee, and Georgia. They presented detailed schedules of trees per acre, basal area, mean tree height, and cubic-foot yields in eight volume categories by 1-inch diameter classes for all combinations of four site indexes at base age 25 years from seed (30, 40, 50, and 60), seven ages from seed (10, 15, 20, 25, 30, 35, and 40 years), and six planting densities (750, 1,000, 1,250, 1,500, 1,750, and 2,000 trees per acre). These results depict the early development of unthinned shortleaf pine plantations on old-fields throughout the Interior Uplands. Predictions were extended 5 years beyond the oldest sampled stands, and all relationships appeared biologically valid. Stand development can best be understood by plotting the various stand characteristics with respect to age, site index, and number of trees planted per acre. Figures 2, 3, 4, and 5 are examples of these plottings. A summary of trends follows.

Survival--On all sites, survival percentage decreased as planting density and age increased (fig. 2A). With an increase in site index, however, survival was slightly higher at early ages and, because competition intensified on better sites, lower at older ages.

Diameter distribution--Diameter distributions (fig. 3) form bell-shaped curves the peaks of which flatten and the widths of which gradually widen with time. The largest diameter trees were on the best sites at the lowest planting density at age 40. Maximum size of tree decreased with both an increase in planting density and/or a decrease in site. By age 25 some sawlog-size trees are obtained on the best sites even at a planting density of 2,000 trees per acre (equivalent to a spacing of 4 by 5 feet). Very few trees reach sawlog-size in 40 years on poor sites.

Quadratic mean diameter--As planting density increased, mean diameter declined for all ages and sites, but improvement in site always resulted in diameter increases (fig. 2B). On sites 30 and 40 at all planting densities, diameter growth was nearly linear past age 20. On sites 50 and 60 at all planting densities, diameter growth accelerated slightly beyond age 20.

Table 4.--Stand characteristics of shortleaf pines planted on old-fields in southern Illinois as affected by initial spacing and plantation age (from Gilmore and Gregory 1974; Arnold 1978, 1981)

Plantation age (yrs)	Spacing (ft) 4 by 4	6 by 6	8 by 8	10 by 10
	Survival (percent)			
11	86	92	95	93
13	82	91	95	93
18	73	86	91	92
20	73	86	87	92
25	52	79	82	88
31	25	55	64	71
	D.B.H. (in)			
11	2.8	3.8	4.1	4.4
13	3.2	4.3	4.8	5.3
18	3.9	5.1	6.0	6.9
20	4.0	5.3	6.3	7.3
25	4.6	5.7	7.1	8.2
31	5.9	6.7	8.1	8.9
	Basal area ($ft^2 acre^1$)			
11	110	93	62	45
13	132	115	85	63
18	164	151	123	102
20	196	173	137	122
25	164	170	153	140
31	128	164	156	134
	Height (ft)			
11	22	20	20	20
13	25	25	24	24
18	33	38	38	33
20	39	45	45	46
25	42	47	50	51
31	55	60	63	62
	Merchantable volume ($ft^3 acre^{-1}$)1/			
11	1,032	870	567	406
13	1,403	1,230	951	641
18	2,363	2,353	1,995	1,701
20	2,884	3,206	2,726	2,383
25	3,408	3,803	3,477	3,190
31	3,197	4,455	4,382	3,707

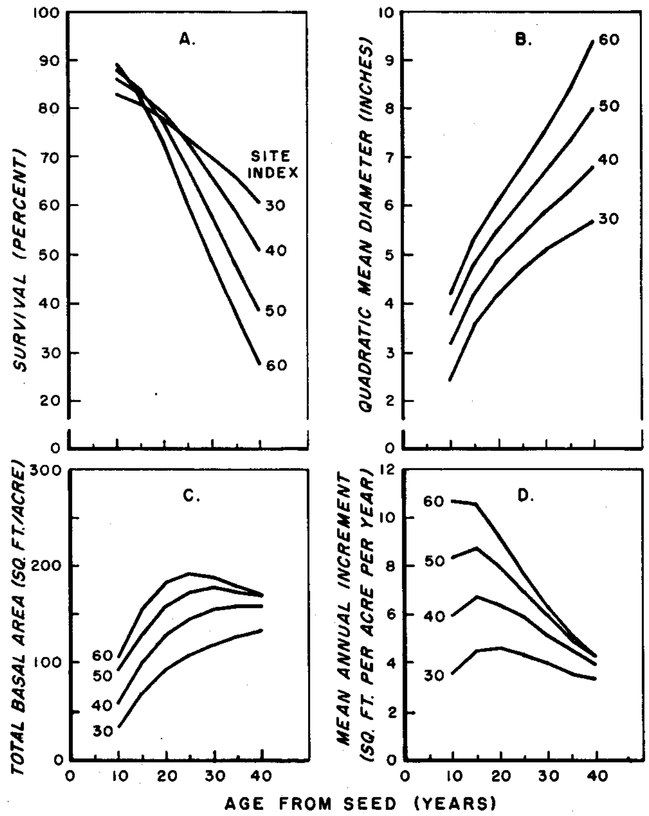

Figure 2.--Effect of age from seed and site index on (A) survival, (B) quadratic mean diameter, (C) total basal area, and (B) mean annual increment - total basal area of shortleaf pine plantations In the Interior Uplands at a planting density of 1,250 trees per acre (from Smalley and Bailey 1974).

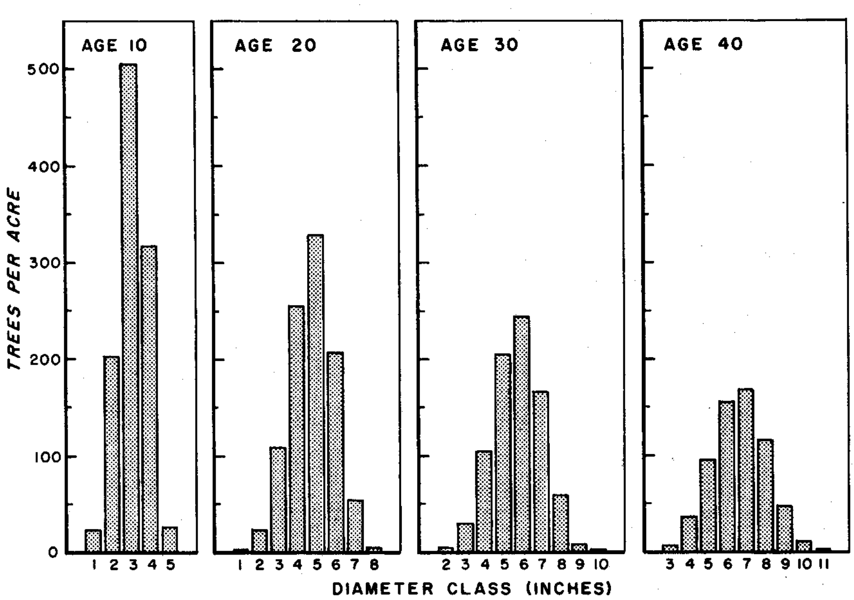

Figure 3.--Effect of age from seed on diameter distribution of shortleaf pine plantations in the Interior Uplands at a planting density of 1,250 trees per on site 40 (from Smalley and Bailey 1974).

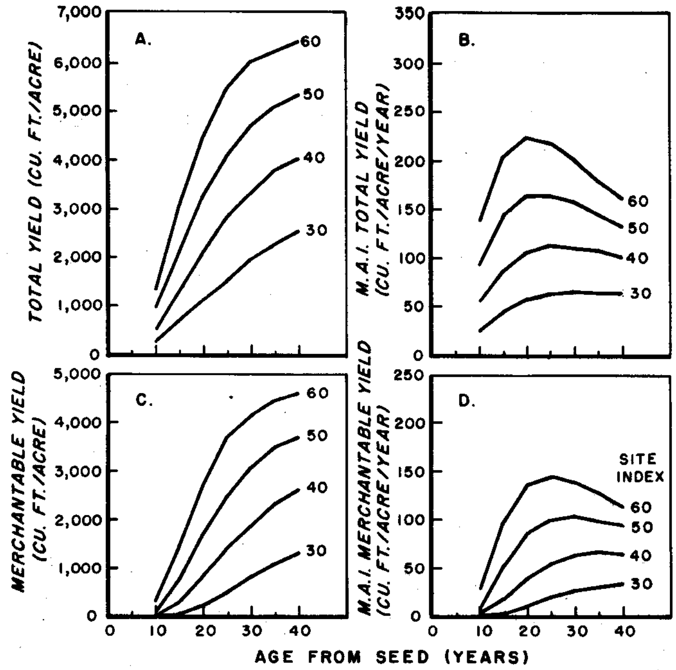

Figure 4.--Effect of age from seed and planting density on (A) total yield - VOBTOT, (B) mean annual increment (MAI) - total yield, (C) merchantable yield - VIB4INOB, and (D) mean annual increment (MAI) - merchantable yield of shortleaf pine in the Interior Uplands at a planting density of 1,250 trees per acre (from Smalley and Bailey 1974).

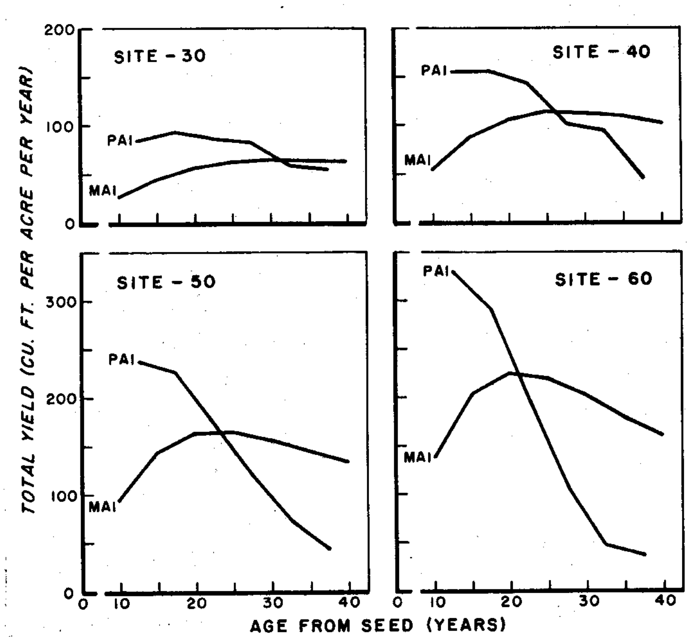

Figure 5.--Effect of age from seed and site index on mean annual (MAI) and periodic annuals increments (PAI) - total yield of shortleaf pine plantations in the Interior Uplands at a planting density of 1,250 trees per acre (from Smalley and Bailey 1974).

Basal area--Total basal area (trees of all sizes) for sites 50 and 60 culminated before age 40 for all planting densities (fig 2C). On site 40, culmination occurred at densities greater than 1,250 trees per acre. On poor sites culmination was projected at about age 50 for all planting densities except for 750 trees per acre where culmination will be closer to age 55.

Basal area increment--For total basal area, mean annual increment (MAI) culminated by age 20 for all sites and planting densities (fig. 2D). At low planting densities on best sites, MAI culminated before age 10. Increment at culmination increased with planting density up to 2,000 trees per acre on all sites. All periodic annual increment (PAI) curves for total basal area were descending within the range of data.

Yield--Total and merchantable cubic-foot yields increased with site and planting density, but the effect of density was small on poor sites (figs. 4 A and C). Yield increased with age for all planting densities on sites 30, 40, and 50. For a planting density of 2,000 trees per acre on site 60, yield culminated at about age 35 as the loss of volume from mortality had begun to exceed growth on the remaining trees.

Yield increment--For total volume, MAI culminated for all sites and planting densities (figs. 4B and 5). Age at culmination ranged from 30 years on poor sites to about 20 years on the best sites, regardless of planting density. Increment at culmination increased with planting density up to 2,000 trees per acre on all sites. By age 20, PAI culminated on sites 30 and 40 at all planting densities. All other PAI curves were descending within the range of data. Merchantable-volume increment culminated on sites 40, 50, and 60 at all planting densities (fig. 4D), but at older ages than for total volume--for example, age 35 to 40 for site 40 and age 25 for site 60.

THINNED PLANTATIONS

Highland Rim

Two thinning tests were made in southern Indiana on the Hoosier National Forest (Williams 1959, Phipps 1973), one on the Crawford Upland near Tell City in Perry County and the second on the Norman Upland near Houston in Jackson County. Initial spacing was 6 by 6 feet. Average height of dominants and codominants in both plantations was about 48 feet at age 25, which indicates a site index of 80 at 50 years from seed (USDA Forest Service 1929). The Tell City plantation was thinned at ages 14 and 21 by removing trees in all crown classes to basal areas of 80, 100, and 120 square feet per acre. Average basal area before thinning was 127 square feet per acre. Final age was 32. The Houston plantation was thinned at ages 17 and 22 by removing trees in all crown classes to basal areas of 70, 90, 110, and 130 square feet per acre. Average basal area before thinning was 165 square feet per acre. Final age was 29. Thinned trees were marketed as 7-foot fenceposts.

Stands lightly thinned to 110 square feet of basal area increased basal area growth rates and total merchantable yield over unthinned stands (fig.

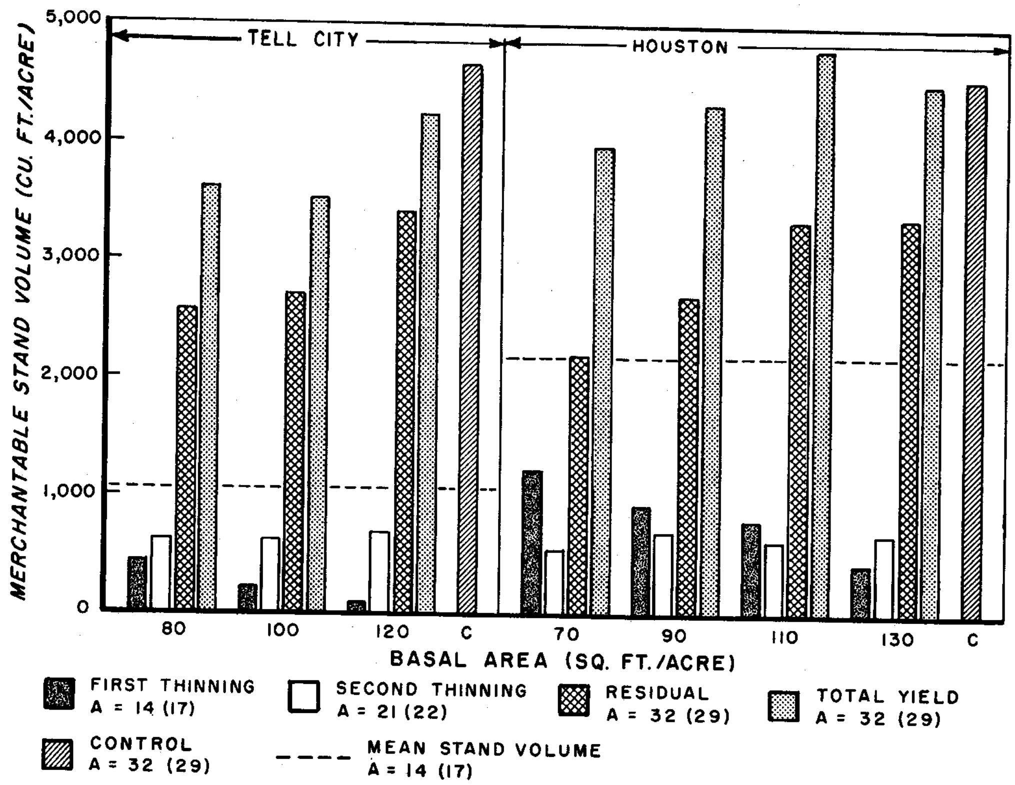

Figure 6.--Yield of two free-thinned shortleaf pine plantations established on old-fields of medium site quality in southern Indiana. Yield is expressed as merchantable cubic-foot volume inside bark to a 3-inch top inside bark. No minimum threshold diameter was given. Numbers in the residual and control bars are mean stand diameter in inches at final age. Ages in the legend are for the Tell City and Houston plantations respectively (from Williams 1959 and Phipps 1973).

6). Figure 6 varies somewhat from figure 1 in Phipps (1973) because of discrepancies in the data. Maintaining higher residual basal areas of 120 and 130 square feet increased basal area growth rates, but total merchantable yield was about the same as in unthinned stands. Thinning stands to residual densities of 100 square feet or less resulted in increased basal area growth, but total merchantable yields were 250 to 1,100 cubic feet per acre less than those in unthinned stands. At the conclusion of the tests, basal area of the unthinned plots exceeded 200 square feet per acre. Phipps suggested that free-thinning of shortleaf pine plantations before age 30 was of questionable value in improving growth rates and yields on medium-quality sites. Diameter distributions would have provided a more definite assessment of the merits of thinning these plantations.

Shawnee Hills

The effect of crown-thinning (thinning from above) was determined in two experiments in southern Illinois. The first (Boggess and others 1963) involved residual basal areas of 60, 80, and 100 square feet per acre and unthinned controls on three upland old-field sites. Good sites consisted of deep, well-drained loessial soils with no fragipan. Medium sites consisted of moderately well-drained and somewhat poorly drained loessial soils with a fragipan. Poor sites consisted of eroded phases of soils similar to those on medium sites.

The plantations were thinned once at ages 15 through 17, and results were reported only for the ensuing 5-year periods. At the time of thinning, basal area ranged from 100 to 155 square feet per acre, and merchantable cubic-foot volume (outside bark to a 3-inch top inside bark) ranged from 1,200 to 2,400 cubic feet per acre. No planting density was given. Site indexes based on average height of dominants and codominants at age 15 for good, medium, and poor sites were 85, 75, and 65 respectively at a base age of 50 years from seed determined from curves developed for second-growth natural stands (USDA Forest Service 1929) or 53, 45, and 37 respectively, at a base age of 25 years since planting determined from a regression developed for similar old-field plantations in southern Illinois (Gilmore and Metcalf 1961).

The second experiment (Burkhart and Gilmore 1967) involved residual basal areas of 70, 80, and 90 square feet per acre and unthinned controls on supposedly similar old-fields. Four crown-thinnings were made at ages 13, 16, 21, and 26. The study was terminated at age 30. Original planting density was given as 8 by 8 feet, but average number of trees and survival data indicated a spacing of 7 by 7 feet or closer. Because no information on tree height was given, it is impossible to estimate site index. However, the quality of these sites was rated as medium. The thinned trees were marketed as 7-foot fenceposts and small poles.

Based on the results of these two experiments, Burkhart and Gilmore recommended that crown-thinning on good and medium sites should be delayed until plantations are at least 20 years old. However, they cautioned not to delay the first thinning on these sites much beyond age 25, particularly if the trees are planted at spacings of 6 by 6 feet or closer (figs. 7 and 8). Although shortleaf pine will grow and persist in fairly dense stands, live-crown ratios become so small that residual trees will not respond to thinning. About 40 percent of the basal area was recommended for removal in the first crown-thinning.

On poor sites, they recommended that plantations be thinned 2 or 3 years earlier because net volume growth decreases sooner on poor sites than on better sites. This recommendation is valid only if a market for small-diameter trees, such as posts, is available. The consensus is to delay thinnings on poor sites up to 10 years until tree diameters are large enough to support a commercial pulpwood operation.

In the unthinned plantations, basal area culminated between ages 26 and 29. However, cubic volume was still increasing.

A row-thinning experiment was established in the same plantation as the second crown-thinning experiment (Gilmore and Boggess 1969). Advantages of row-thinning are lower marking and administrative costs, lower felling costs, and easier access into plantations for logging. A disadvantage of row-thinning is that no choice is made in the removal of trees--good quality trees are cut along with poor quality trees.

In the first thinning at age 14, every fourth row was cut and basal area reduced from 101 to 80 square feet per acre. In the second thinning at

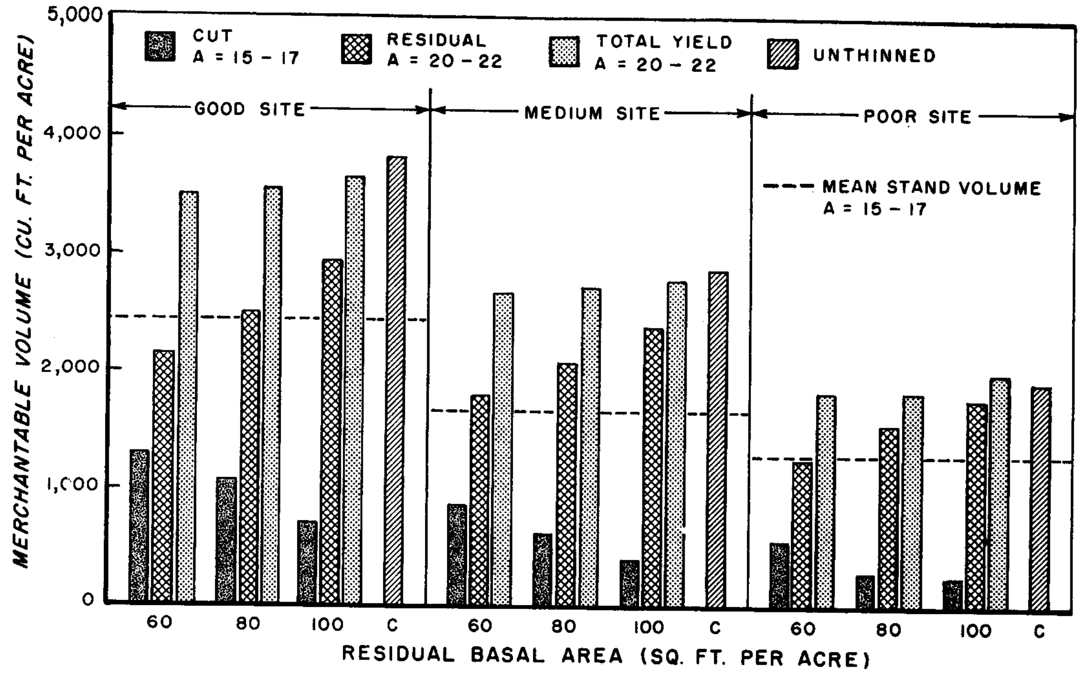

Figure 7.--Yield of crown-thinned shortleaf pine plantations established on old-fields of varying site quality in southern Illinois. Yield is expressed as merchantable cubic-foot volume outside bark, of trees $\geq$ 3.6 inches d.b.h., to a 3-inch top inside bark (from Boggess, Minckler, and Gilmore 1963).

age 18, the middle row of the remaining three rows was cut and basal area reduced from 104 to 71 square feet per acre. A third free-thinning was made at age 23, and the basal area was reduced from 116 to 80 square feet per acre. The study was terminated at age 30.

Row-thinned plots did not produce as much merchantable cubic volume as crown-thinned or unthinned plots, although row-thinning did provide an adequate number of crop trees of good form and size (fig. 8). Stand volume and growth rates were related to site quality differences in the test plantation, but stand density and site quality did not appreciably affect basal area growth.

Diameter distributions at age 30 of row-thinned, crown-thinned, and unthinned shortleaf pine plantations all displayed reasonable bell-shaped curves (fig. 9). Unthinned plantations had the highest peak (6-inch class) because of the much larger number of surviving trees (645). Row-thinned plantations had a lower peak (8-inch class) with 301 surviving trees. Crown-thinned plantations had the lowest peak (9-inch class) with 188 surviving trees. In row-thinnned plantations, 33 trees were 10 inches d.b.h. and larger, representing 11 percent of the total trees and 17 percent of total basal area. Comparable data are 95 trees, 50 percent, and 44 percent for crown-thinned plantations and 46 trees, 7 percent, and 13 percent for unthinned plantations. At age 30, crown-thinned plantations had twice as many sawlog-size trees as unthinned plantations and nearly three-times as many as row-thinned plantations.

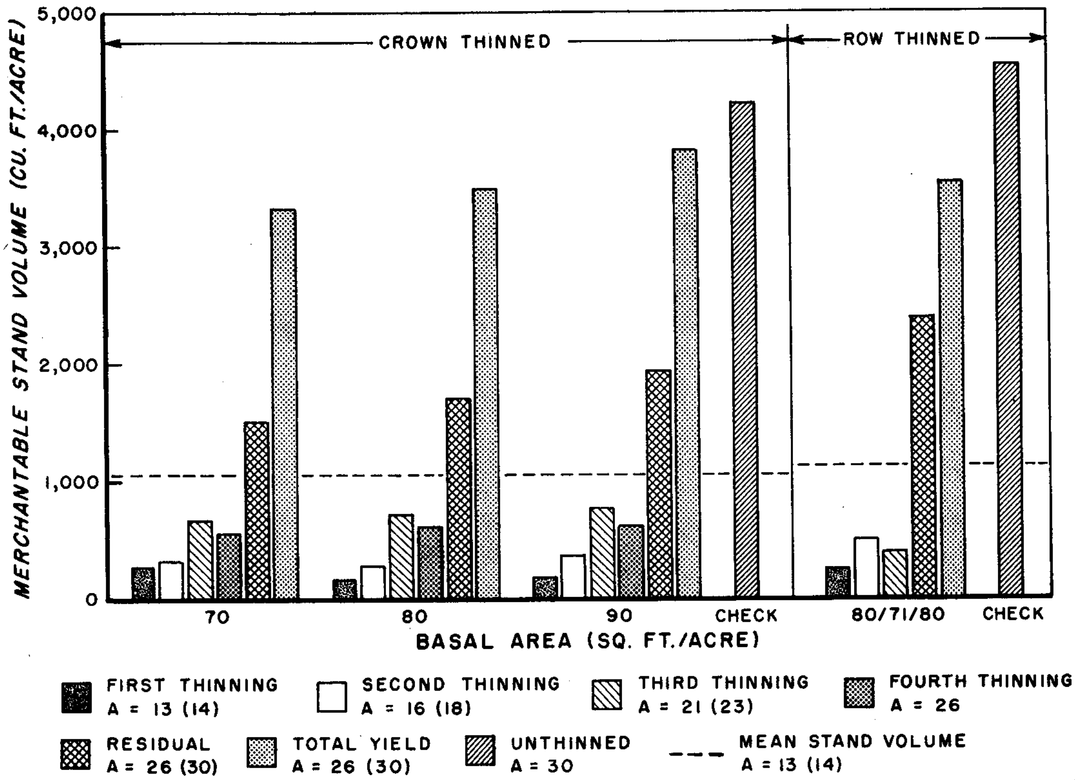

Figure 8.--Yield of crown- and row-thinned shortleaf pine plantations established on old-fields in southern Illinois. Yield is expressed as merchantable cubic-foot volume outside bark, of trees ≥ 3.6 inches d.b.h., to a 3-inch top inside bark. Numbers in the residual and control bars are mean stand diameters in inches. Ages in the legend are for the crown- and row-thinned experiments respectively (from Burkhart and Gilmore 1967 and Gilmore and Boggess 1969).

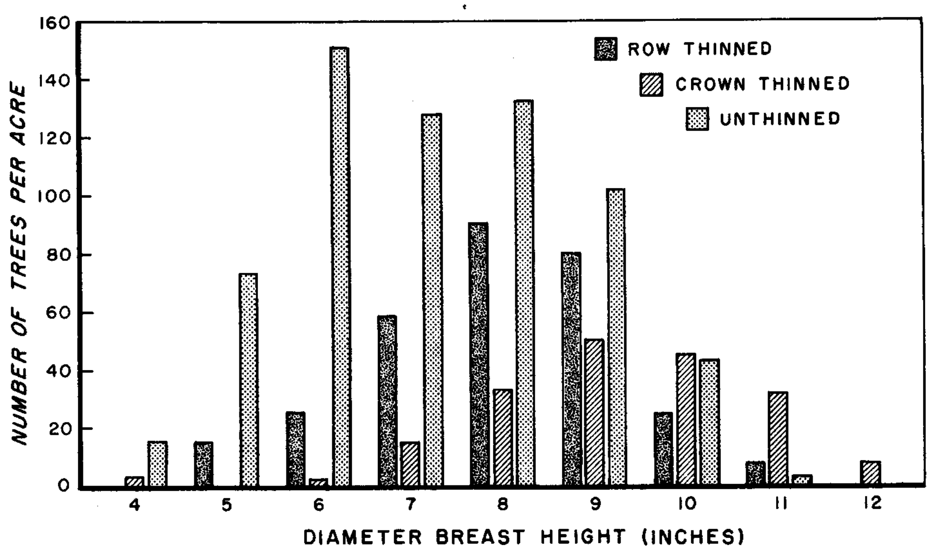

Figure 9.--Diameter distributions of row-thinned, crown-thinned (80 sq ft per acre of residual basal area), and unthinned shortleaf pine plantations in southern Illinois at age 30 (from Gilmore and Boggess 1969).

Coastal Plain

The thinning test in the North Central Hills Section of the East Gulf Coastal Plain was near Abbeville in Lafayette County, MS. Williston (1983) estimated the mean site index (base age 50 years from seed) of these test plantations to be about 75 according to Coile and Schumacher's (1953) curves developed for natural stands in the Piedmont. Eight thinning treatments were applied to 23-year-old shortleaf pine plantations. Although there were large differences in stand parameters among treatment regimes, differences were not statistically significant throughout most of the term of the test. Statistical analyses at age 48 were impossible because southern pine beetles (*Dendroctonus frontalis* Zimm.) had killed trees on several plots between 1976 and 1981 (ages 43 to 48). Consequently, only averages for all thinning regimes are reported (table 5).

Table 5.--Periodic annual growth and total yields per acre of thinned and unthinned shortleaf pine plantations in north Mississippi (from Williston 1983).

Treatment	Unit 1/	Period (plantation age-years)						Total yield 2/
		0-23	24-28	29-33	34-38	39-43	44-48	
Thinned	Cu ft	67	105	121	155	135	30 (46) 3/	4,285
Unthinned	Cu ft	63	117	81	169	77	-90 (35) 3/	3,212
Thinned	Fbm	--	38	240	850	1,390	563 (800) 3/	15,764
Unthinned	Fbm	--	140	345	700	924	-194 (549) 3/	9,577

1/ Pulpwood volumes are in cubic feet inside bark, of trees > 3.5 inches d.b.h., to a 3-inch top inside bark. Sawtimber volumes are in board feet, International 1/4-inch kerf.

2/ Total yield includes volumes removed in three thinnings at plantation ages 23, 28, and 33.

3/ Value of plot most heavily damaged by southern pine beetles is omitted.

Per acre production of all thinned plots averaged 4,285 cubic feet and 15,764 fbm. Periodic annual cubic volume growth culminated at about age 35. Among the plots not damaged by southern pine beetles, at age 48 the best per acre production of 5,402 cubic feet and 25,860 fbm occurred on a plot free-thinned successively to 120, 115, and 110 square feet of basal area per acre at ages 25, 28, and 33 respectively, with a site index of 84. At age 48, mean d.b.h. averaged 10.1 inches on thinned plots and 9.0 inches on unthinned plots, but crop trees averaged 11.3 inches and 10.5 inches respectively.

Total production on thinned plots was 4,122 cubic feet per acre; on check plots it was 3,685 cubic feet per acre. Since the first thinnings in 1957, the thinned plots grew 2,583 cubic feet, and the check plots grew 2,235 cubic feet--a difference of 348 cubic feet or about 17 cubic feet per acre per year.

Total production from the thinned plots was 13,070 fbm (International 1/4-inch kerf) per acre; from the check plots it was 10,547 fbm per acre. Comparative yields in the Doyle rule were 5,453 fbm and 4,380 fbm per acre.

PERSPECTIVES

The test plantings reported in this paper were established with seedlings grown from "woods run" seed that often was not collected locally. It is probably safe to assume that plantations established with genetically improved seedlings from best seed sources and on prepared sites would outproduce plantations described in this review.

Within the common range of shortleaf and loblolly pines, old-field plantations of loblolly pine grow better than shortleaf plantations for 40 to 50 years. Beyond 50 years, shortleaf pine yields apparently approach and perhaps exceed those of loblolly pine. Thus, when rotations are short and the main product is pulpwood, loblolly pine is the preferred species. In fact, the growth and yield pattern of shortleaf pine is not especially well suited to pulpwood rotations.

At longer rotations, when high-quality sawlogs are the management goal, shortleaf pine should be given more consideration than it has been accorded. Outside the common range of shortleaf and loblolly pines, shortleaf should be preferred. Shortleaf pine should certainly be preferred over loblolly where the frequency of glaze storms is high.

Shortleaf pine plantations grow better at higher basal areas than do loblolly plantations. However, overstocked shortleaf plantations, particularly those on poor sites, tend to stagnate. Results from studies reported in this paper are inconclusive concerning the best spacing. Spacings wider than the customary 6 by 6 feet used in many of the reported studies are necessary to concentrate production on as few trees as possible and to reduce planting and logging costs. In Illinois, Arnold (1981) was convinced that shortleaf pine did not fully occupy the site at spacings wider than 8 by 8 feet, and, consequently, he recommended moderate planting densities between 6 by 6 and 8 by 8 feet. However, with use of the best adapted seed sources, modest genetic gains in growth rate, and optimal site preparation, new plantations should probably be established at spacings of 8 by 8 feet or wider.

Even at wider spacings, thinning appears to be needed to capture mortality, to concentrate growth potential on fewer trees, and to meet an estimated goal of 14- to 16-inch trees in 60 years on medium and good sites. Trees removed in early thinnings would be suitable for posts, small poles, or pulpwood. Thinnings will probably reduce cubic yields below those of unthinned plantations but will maximize diameter growth on high-quality trees and provide periodic income. The first commercial thinning of shortleaf pine plantations on good sites can be made about age 20; on medium sites, between ages 20-25; and on poor sites, between ages 25-30. If a market for posts is available, thinning can be started 2 or 3 years earlier. But beware--thinning may increase the possibility of losses from *Fomes annosus*, particularly in plantations established on sandy soils low in organic matter.

Williston's management scenario for shortleaf pine plantations in north Mississippi seems apropos, with maybe slight modifications, to the entire range of the species. In order to attain a 60-year shortleaf pine rotation with a final harvest cut objective of trees averaging 16 inches d.b.h., Williston (1983) suggested that "the first two thinnings for pulpwood made 7 years apart when plantation are capable of growing 3 to 4 square feet of basal area per acre per year, would reduce the stand to a basal area equal to the site index (base age 50 years) and would remove the slow-growing and poorly formed trees. The third thinning, about 7 years after the second one, would remove the remaining pulpwood trees and some small sawlogs, A fourth thinning and the final harvest cut made at intervals of 8 to 10 years as diameter growth slows, would be composed entirely of sawlogs and poles. Landowners should avoid any temptation to clearcut for pulpwood and should manage their shortleaf stands for sawtimber because shortleaf does so well after age 20."

The acreage of shortleaf pine plantations established on old-fields is declining. Little agricultural land is being abandoned, and practically none is being planted to shortleaf. Owners are replanting harvested acres with the faster growing loblolly pine. Consequently, the available mensurational data seems adequate to manage this diminishing resource. However, the Conservation Reserve Program proposed in recently enacted farm legislation may spur the largest tree planting effort ever in the United States. If sizable acreages of shortleaf pine are established on former cropland under this program, there will be a need for more regional growth and yield information for unthinned and thinned plantations comparable to that available now for unthinnned plantations established on old-fields in the Interior Uplands (Smalley and Bailey 1974).

Currently, thousands of acres of shortleaf pine are being planted annually on eastern National Forests (particularly the Ouachita and Ozark) on recently harvested forest land. Planting follows a variety of site preparation methods ranging from all mechanical to all hand-applied chemicals. Although these non-old-field plantations will not be merchantable for 15 to 20 years, studies need to be initiated now so that the information necessary for prudent management will be available when needed.

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