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Growth and Yield in Managed Natural Stands of Loblolly and Shortleaf Pine in the West Gulf Coastal Plain

J. D. Burton

Southern Forest Experiment Station

SUMMARY

Second-growth even-aged loblolly-shortleaf pine stands on good and medium sites were thinned from above or below to a basal area of 70 ft^2, 85 ft^2, and 100 ft^2/acre, to an increasing basal area, or according to the judgment of a committee. Treatments began at age 20 for original plots and at age 25 for supplementary plots (on good sites only), which were thinned to a basal area of 55 ft^2, 115 ft^2, or 130 ft^2/acre. Stands were thinned every 5 years.

At age 45, most trees in good-site original plots and supplementary plots thinned from below were in the 10-inch d.b.h. class and larger. In the 70-ft^2, 85-ft^2, and "increasing" treatments, most stems were in the 15-inch class and larger.

On good-site original plots thinned from below, at 45 years standing sawtimber volume for trees $\geq$ 9.6 inches d.b.h. containing $\geq$ one 16-ft log to an 8-inch top was greatest in "increasing" treatment plots and least in 85-ft^2 and 100-ft^2/acre plots. In supplementary plots, standing board-foot volume was greatest in 130-ft^2 and least in 55-ft^2/acre plots. On medium sites, standing volume was greatest in "judgment" and 100-ft^2 and least in 70 ft^2/acre plots.

Sawtimber m.a.i. was still increasing rapidly at age 45 in all treatments. Cubic-foot m.a.i. was increasing slowly on medium sites but declining in supplementary plots and in all good-site original plots except the 70-ft^2 and "increasing" treatments. On good sites, p.a.g. in board feet culminated between ages 30 and 35 in the 70-ft^2 and 85-ft^2 treatments and between ages 40 and 45 in "increasing" plots. On medium sites, p.a.g. apparently was still increasing at 45 years. On both sites, sawtimber ingrowth was much less complete at age 45 in thin-from-above stands than in those thinned from below.

On good sites, sawtimber yield to age 45 in plots thinned from below was greatest in "increasing" treatment plots and least in 100-ft^2/acre stands. In supplementary plots, sawtimber yield was greatest in 55-ft^2 and least in 115-ft^2 /acre treatments. On medium sites, sawtimber yield was greatest in "judgment" and 100-ft^2 and least in 70-ft^2 /acre stands.

On good sites, cubic-foot yield to age 45, in peeled stemwood to a 3-inch d.i.b., trees $\geq$ 3.6 inches d.b.h., in plots thinned from below, was greatest for "increasing" treatment plots and least for 70-ft^2 stands. In supplementary plots, cubic-foot yield was greatest for 130-ft^2 and least for 55-ft^2 /acre plots. On medium sites, cubic-foot yield was greatest for 100-ft^2 and least for 70-ft^2 /acre stands.

This study is a cooperative effort with the Crossett Division, Georgia-Pacific Corp. Plots are on company land, and company personnel participated in periodic remeasurements and thinnings.

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INTRODUCTION

A thinning study in even-aged second-growth loblolly-shortleaf pine (*Pinus taeda* L. and *P. echinatu* Mill.) stands is being conducted near Crossett, Arkansas. This study has told us how thinning method and stand density affect tree size, standing volumes at different ages, growth rates, and total yields on good and medium pine sites in the West Gulf Coastal Plain. Results will enable forest landowners to prescribe more precisely thinning regimes consistent with management objectives. This paper summarizes results from age 20, when thinning was initiated, through age 45. Growth and yields are reported in cubic feet, board feet International ¼-inch rule, and board feet Doyle rule.

METHODS AND MATERIALS

Two experimental areas were selected: an area of good sites in Ashley County, Arkansas and an area of medium sites in Morehouse Parish, Louisiana. In winter 1949-50, twenty-seven 0.1-acre circular plots, each surrounded by a 33-foot-wide isolation zone, were established in each of the two areas.

Site Quality

The good-site plots are on nearly level uplands. Soils are mainly Grenada and Calloway silt loams. Loblolly pine site index, determined before the first thinning at age 20 and based on curves in U.S. Department of Agriculture, Forest Service (1976), averaged 90 ft at 50 years (table 1); individual plot means ranged from 85 ft to 100 ft.

Medium-site plots are on broad, low, island-like ridges in the Ouachita River floodplain. These ridges are flooded every 4 or 5 years. Soils are silt loams in the Wrightsville-Leaf association with some patches of Frizzell. Site index immediately before initial thinning, based on curves in U.S. Department of Agriculture, Forest Service (1976), averaged 73 ft at 50 years; plot means ranged from 69 ft to 79 ft.

Timber Type

Good-site plots were established in volunteer shortleaf pine-loblolly pine-hardwood stands. These stands originated after the virgin timber was cut to a 12-inch d.b.h. limit during 1927 through 1930. This cut left two seed trees per acre. Many hardwoods, some quite large but unmerchantable at that time, also were left standing.

About 1918, virgin timber on medium sites was cut to a 14-inch d.b.h. limit. During the next 10 years, very hot wildfires burned the entire area three times and killed many large residual trees. The present stand grew from the 1929 seed crop, and no charring was evident 20 years later when the study began. No more cutting was done in either area before 1949 when most residual pines and hardwoods were still standing and had grown very large. When study plots were laid out, these old trees were avoided, so growth in the plots was not suppressed by the overstory.

Because inventory procedures did not identify species, relative proportions of shortleaf and loblolly pine are unknown.

Stocking Before Initial Thinning

All these young stands were well stocked. Before being thinned at age 20, good-site plots had 892 pines/acre ≥ 3.6 inches d.b.h. (range 773 to 1,009 by plots), basal area of 140 ft^2 /acre, and mean d.b.h. (d.b.h. of tree of mean basal area) of

J. D. Burton is Soil Scientist, Alexandria Forestry Center, Southern Forest Experiment Station, Forest Service-USDA, Pineville, Louisiana.

Table 1.—*Site index as determined before initial thinning and as determined at age 45 for plots thinned from below*

Thinning level	Thinning method	Site index at 50 years			
		Good sites		Medium sites	
		Initial[a]	Age 45[b]	Initial[a]	Age 45[c]
ft²/acre		———	*trees per acre*		
70	Above	92		71	
	Below	94	93	71	75
85	Above	88		73	.
	Below	88	93	78	81
loo	Above	90	....	75	....
	Below	88	91	73	80
"Incr."	Above	89		73	
	Below	89	93	73	81
"Judg."	Both	96	95	73	80
55	Below	95	96		
115	Below	93	95		
130	Below	91	95		

[a] At age 20 in all original plots, at age 25 in 55 ft², 115 ft², and 130 ft²/acre plots using curve in U.S. Department of Agriculture, Forest Service (1976).
[b] Zahner's (1962) curves for loessial soils were used.
[c] Zahner's (1962) curves for poorly aerated soils were used.

5.4 inches. Sixty-two percent of the cubic-foot volume of stemwood inside bark to a 3-inch top diameter inside bark (d.i.b.) was in the 6-inch d.b.h. class and larger, 15 percent (22 trees/acre) was in the 8-inch class and larger, and 1.2 percent (4 trees/acre) was in the lo-inch class and larger. And 1,162 pines/acre were 21.6 inches d.b.h., had a basal area of 152 ft²/acre, and had a mean d.b.h. of 4.9 inches.

Before the first thinning at age 20 on medium sites, 880 pines/acre were ≥ 3.6 inches d.b.h. (range 823 to 950 by plots), had a basal area of 117 ft²/acre, and had a mean d.b.h. of 4.9 inches. Forty percent of the cubic-foot volume to a 3-inch top was in the 6-inch d.b.h. class and larger; 4 percent of the volume (14 trees/acre) was in the 8-inch class and larger. And 1,054 pines /acre were ≥ 1.6 inches d.b.h., had a basal area of 144 ft², and had a mean d.b.h. of 4.2 inches.

Mean total height of the dominant and codominant 20-year-old pines was 46 ft on good sites and 37 ft on medium sites.

Supplementary Plots

In winter 1954-55, nine more plots were laid out on good sites next to the good-site plots already established. Loblolly pine site index, determined before thinning at age 25, based on curves in U.S. Department of Agriculture, Forest Service (1976), averaged 93 ft (table 1); plot means ranged from 87 ft to 95 ft. These supplementary plots increased the range of stand densities. Supplementary plots, still unthinned at age 25, had 632 pines/acre, with basal area averaging 171 ft²/acre in trees 23.6 inches d.b.h. (range 490 to 780 by plots) and with a mean d.b.h. of 7.0 inches. Ninety-four percent of the cubic-foot volume inside bark to a S-inch d.i.b. was in the 6-inch class and larger; 67 percent of the volume (81 trees/acre) was in the 8-inch class and larger; and 24 percent (54 trees/acre) was in the lo-inch class and larger. And 663 pines/acre were 21.6 inches d.b.h. (range 490 to 830 by plots), had a basal area of 172 ft²/acre, and had a mean d.b.h. of 6.9 inches.

Hardwood Control

In every plot, hardwoods ≥3.6 inches d.b.h. were cut when plots were first thinned. All remaining hardwoods were killed with a weed-killing chemical. In 1959, all hardwood sprouts ≥ 1.0 inch in diameter at the root collar were killed by an injection of a weedkiller. On good-site plots, original and supplementary, a dense, vigorous understory of hardwood sprouts, shrubs, and vines developed after each thinning. On medium sites, the understory was feeble. In every good-site plot, original and supplementary, all hardwoods $\geq$ 1.0 inch at root collar were cut before every inventory through age 40.

Plot Establishment and Treatments

Nine treatments were randomly replicated three times on both good and medium sites:

Thinning initially from above to a basal area of 70 ft^2, 85 ft^2, or 100 ft^2/acre at ages 20 and 25; thinnings at 30, 35, 40, and 45 years were from below, always to the originally assigned density in each plot.

Thinning initially from above to a basal area of 70 ft^2/acre at age 20, increasing to 75 ft^2/acre at age 25, then thinning from below to 80 ft^2 at age 30, to 85 ft^2 at age 35, to 90 ft^2 at age 40, and to 95 ft^2 at age 45.

Thinning from below to a basal area of 70 ft^2, 85 ft^2, or 100 ft^2/acre at age 20 and at 5-year intervals to the same densities.

Thinning from below to a basal area of 70 ft^2/acre at age 20, increasing to 75 ft^2 at age 25, to 80 ft^2 at 30 years, to 85 ft^2 at 35 years, to 90 ft^2 at 40 years, and to 95 ft^2 at 45 years.

Thinning according to the consensus of participating personnel, with no restrictions on method or intensity; this was called the "judgment" treatment. The basal area left after each thinning varied considerably between thinnings and between plots within thinnings. Basal area ranged by plot from 67 ft^2 to 81 ft^2/acre and averaged about 75 ft^2/acre on both sites. "Judgment" thinning was partly from above but mostly from below.

No unthinned control treatment was established.

For all thinning treatments, if trees were of equal quality, field workers cut shortleaf and kept loblolly pines. Reasonably uniform spacing between trees was maintained.

Thinning from above favored well-formed, relatively smooth codominant and intermediate trees by removing most dominants. Those suppressed merchantable trees apt to die within 5 years were cut, as were defective and poorly formed trees, regardless of crown class.

In thinning from below, dominants were favored, and competing trees in other crown classes were removed. Where removing coarse-limbed or misshapen dominants was desirable, codominants were left.

Supplementary plots were thinned from below to a basal area of 55 ft^2, 115 ft^2, or 130 ft^2/acre and at 5-year intervals to the same residual densities.

Since thinning from above at ages 20 and 25 removed the most vigorous trees, average total height of the 50 tallest trees/acre, from age 35 onward, was noticeably less in thin-from-above plots than in thin-from-below plots: this difference averaged 3 feet on both sites, although it varied among inventories, and it usually was greater on good sites than on medium. Researchers determined 50-year site index at age 45 only for plots thinned from below, using Zahner's (1962) curves for loessial soil in good-site original and supplementary plots and his curves for poorly aerated soils for medium-site plots. The age-45 site index determinations (all treatments averaged) exceeded the age-20 and age-25 values by 3 ft on good-site original plots, 6 ft on medium sites, and 4 ft on supplementary plots.

Changing attitudes on how to treat basal area in submerchantable trees (trees 1.6 -3.5 inches d.b.h.) resulted in varying thinning procedures till age 30. When the original plots were first thinned, researchers included only merchantable pine trees in computing basal area and in selecting trees to cut. Most plots contained many submerchantable trees; their numbers varied widely between plots within treatments; so, plots treated alike were not alike in density, stand structure, and competition intensity. Thinning at age 25 again removed only merchantable stems, but the designated residual basal area included submerchantable trees. So, residual basal area in 3.6-inch and larger trees averaged 7 ft^2/acre less than prescribed stand densities, but the deficit was as much as 21 ft^2/acre on individual plots. All submerchantable stems were cut at age 30. After age 30, residual stands consisted entirely of trees 3.6 inches d.b.h. and larger.

Violent winds destroyed or damaged many trees on good sites during the 41st growing season. Distribution and severity of damage were related to the storm track and were not caused by thinning. During the next 4 years, many trees on good sites and a few on medium sites were killed by the southern pine beetle ***(Dendroctonus frontalis*** Zimm.). Beetle-caused mortality was not related to site quality, but was more severe on lightly thinned than on heavily thinned plots.

Measurements and Analysis

The 54 original and 9 supplementary plots, from 1954 onward, were inventoried and thinned as one study. Merchantable height to an estimated 3-inch top d.i.b. was measured with a handheld altimeter. And d.b.h. was measured with a diameter tape on every tree. Total height was measured on sample trees. Using ladders, diameter tapes, and Swedish bark gages, field workers collected data for Girard form class.

Board-foot volumes (Doyle and Int. ¼) were obtained from the form-class volume tables of Mesavage and Girard (1946). Board-foot volumes were determined for trees $\geq$ 9.6 inches d.b.h. containing at least one 16-ft log to a top diameter outside bark (d.o.b.) of about 8 inches. Cubic-foot volume of pulpwood inside bark to a 3-inch top d.i.b. in trees 23.6 inches d.b.h. was reckoned from Mesavage's (1947) tables.

In this paper, standing volume means cubic-foot or board-foot volume of stemwood per acre in living pine trees before thinning at any specified age. Total yield to any age consists of standing volume plus volume in all previous merchantable thinnings plus volume in natural mortality occurring in merchantable trees after age 30. Net yield at any age includes standing volume plus volume in merchantable thinnings. The difference between total yield and net yield is natural mortality. No record was made of mortality before age 30, but it probably was confined almost entirely to submerchantable trees.

Because of a large spread in standing volume amounts before initial thinning, I had to calculate an adjusted initial cut before computing later cubic-foot yields. In good-site original plots, standing volume at age 20 ranged from 1,269 ft^3 to 2,000 ft^3 and averaged 1,471 ft^3/acre; on medium sites, standing volume ranged from 810 ft^3 to 1,572 ft^3 and averaged 1,261 ft^3/acre; in supplementary plots at age 25, standing volume ranged from 2,580 ft^3 to 3,967 ft^3 and averaged 3,246 ft^3/acre. Average merchantable yield before initial thinning was calculated for each of the three groups of plots: good-site original, medium-site, and supplementary. Adjusted initial cut for each plot was: the group pre-thinning average minus the individual plot residual cubic-foot volume.

No adjustment was needed for board-foot yield.

Using analysis of variance, I evaluated treatment-associated differences in:

1. Adjusted cubic-foot yield to ages 25 through 45,
2. Unadjusted standing cubic-foot volume at ages 25 through 45,
3. Unadjusted board-foot yield at ages 30 through 45,
4. Unadjusted standing board-foot volume at ages 30 through 45,
5. Adjusted periodic annual cubic-foot volume growth by 5-year periods from age 20 through age 45, and
6. Adjusted mean annual cubic-foot volume growth to ages 25, 30, 35, 40, and 45.

Separate analyses were made of data from good-site original plots, medium-site plots, and supplementary plots. Level of significance was 0.05. Singledf comparisons were orthogonal.

RESULTS

Thinning method caused few differences in relationships among treatments. And, because most commercial, non-mechanical thinning of natural stands of southern pines is done mainly from below, I will refer to thin-from-above treatments only when their results are significantly different.

Diameter Growth and Diameter Distribution

Bole diameter growth in good-site original plots from age 20 to age 45 was most rapid in the 70-ft^2/acre plots, slowest in the 100-ft^2 (fig. 1). Mean d.b.h. in the "increasing" treatment was almost the same as mean d.b.h. in the 70-ft^2 treatment till age 30. Then, "increasing" residual basal area was 80 ft^2/acre; thereafter the "increasing" matched the 85-ft^2 plots' mean d.b.h. At age 40 in "increasing" plots, residual basal area was 90 ft^2/acre, so the 85-ft^2 curve soon rose above the curve for the "increasing" treatment. And although standing basal area at age 45 was about the same for the 100 ft^2 treatment and the "increasing" treatment, mean d.b.h. was much larger for the "increasing" treatment (14.6 inches) than for the 100-ft^2 treatment (12.5 inches).

Mean d.b.h. in good-site supplemental plots was greatest in heavily thinned plots, least in lightly thinned plots from age 35 onward. At age 40, before thinning, mean d.b.h. was 15.4 inches in the 55-ft^2, 12.4 in the 115-ft^2, and 11.9 inches in the 130-ft^2 treatment (fig. 2).

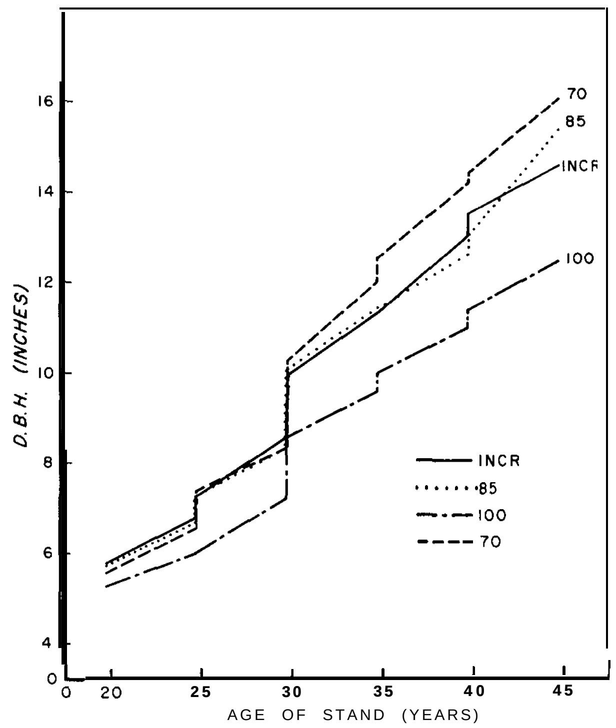

Figure 1.-Mean d.b.h. by treatment in stands thinned from below on good sites, based on all surviving pine trees ≥ 3.6 inches d.b.h. at each inventory.

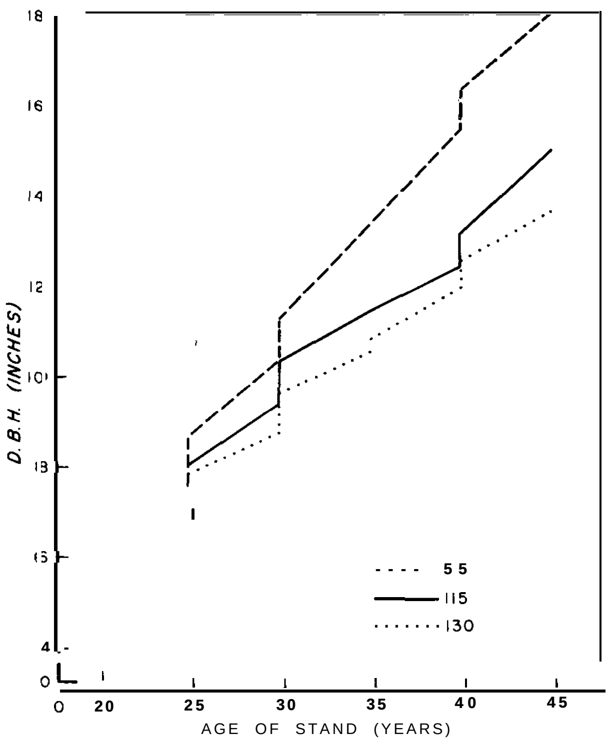

Figure 2.-Mean d.b.h. in supplementary plots, based on all surviving pine trees ≥ 3.6 inches d.b.h. at each inventory.

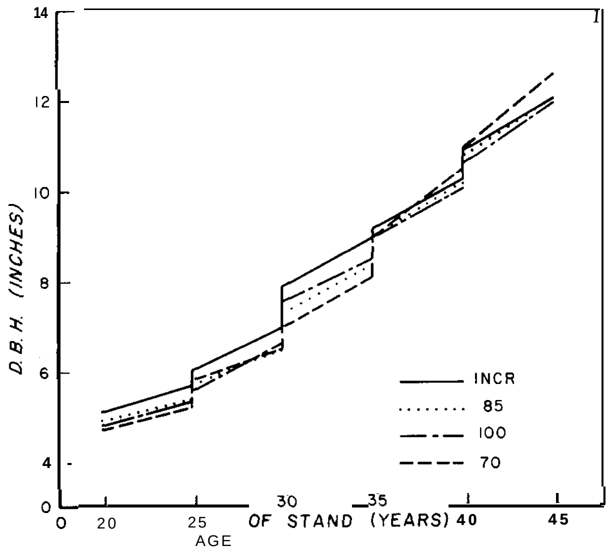

Figure 3.-Mean d.b.h. by treatment in stands thinned from below on medium sites, based on all surviving pine trees ≥ 3.6 inches d.b.h. at each inventory.

Mean d.b.h. on the medium sites responded only weakly and very slowly to thinning levels (fig. 3).

Table 2 shows diameter distribution on good sites after thinning at age 20. Tables 3-7 show diameter distribution on good sites (original plots and supplementary plots) before thinning at ages 25, 30, 35, 40, and 45.

Just after initial thinning at age 20, 76 to 97 percent of the merchantable trees were in three d.b.h. classes. At age 25 before thinning, the majority (85 to 98 percent) had spread through five (4- through 8-inch) classes. At age 30, merchantable trees were distributed through a wide range of d.b.h. classes. Light thinning widened the range of classes more than did heavy thinning. Thinning from above widened the range more than thinning from below. At age 35, all trees in the 70 ft and 89 percent in the "increasing" thin-from-below plots were in the lo-inch class and larger.

Table 8 shows diameter distribution on medium sites after thinning at age 20. Tables 9-13 show diameter distribution on medium sites before thinning at ages 25, 30, 35, 40, and 45.

After the first thinning at age 20, most (70 to 87 percent) of the merchantable trees on medium sites were in two d.b.h. classes. The range of classes began to expand immediately and continued to increase through age 45.

Cubic-foot Growth and Yield

Standing Volumes. -Standing volumes before each thinning represent the resource available for immediate liquidation if the rotation were to be ended at that age. Except where catastrophic losses occurred, standing cubic-foot volumes in this study increased with age and were greater in lightly thinned than on heavily thinned plots. The result from thinning from above was usually not much different from the result from thinning from below. Differences among the 70-ft^2, 85-ft^2, and 100-ft^2 thinning levels were significant at every inventory from age 25 onward on medium sites and from age 30 onward on good sites. Differences between the 55-ft^2 and the 115-ft^2 and 130-ft^2 combined were significant at every inventory from age 30 onward. There were no significant differences between the 115-ft^2 and the 130-ft^2 treatments.

Tables 14-18 show distribution of standing cubic-foot volume on good-site original plots and supplementary plots. On original plots at age 25, 4 to 18 percent (average 11 percent) of standing cubic-foot volume was in lo-inch and larger trees; in supplementary plots, which were still unthinned at age 25, 19 to 29 percent (average 24 percent) of standing cubic-foot volume was in sawtimber-sized trees (table 14).

Tables 19-23 show distribution of standing cubic-foot volume on medium-site plots. At every inventory, from age 25 through age 45, standing cubic-foot volume increased as stand density increased; among the 70-ft^2, 85-ft^2, and 100-ft^2 levels this effect was significant. Only at age 30 was any difference associated with thinning from above or below-thin-from-below plots contained significantly more volume than did thin-from-above plots.

Total Yields. -Yield in cubic feet of stemwood inside bark to a 3-inch top d.i.b. was greatest under the lightest thinnings, least under the heaviest thinnings. These effects were significant at ages 35 and 40 on good-site original plots and at ages 25 through 45 on medium sites; on supplementary plots, these differences were not significant.

Total yield to age 30 averaged 3,593 ft^3/acre on good-site original plots, 2,536 ft^3/acre on medium sites, and 3,992 ft^3/acre on supplementary plots. Yield to age 40 averaged 5,935 ft^3/acre on good-site original, 4,736 ft^3/acre on medium-site, and 6,411 ft^3/acre on supplementary plots.

Net yield was equal to total yield through age 45 in the good-site 70-ft^2 plots; no trees died after age 30 (fig. 4). Nor did any mortality occur after age 30 in 55-ft^2 plots; in all other thin-from-below treatments on good-site original and supplementary plots, some trees died. On medium sites, mortality was light and showed little effect of treatment.

The greatest total adjusted 45-year yields in good-site original plots thinned from below were in "increasing" plots (6,949 ft^3/acre) and 100 ft^2 plots (6,666 ft^3/acre). Net yield was 6,186 ft^3/acre in 100 ft^2 plots and 6,416 ft^3/acre in 70 ft^2 plots. Greatest total yields in supplementary plots occurred in 130-ft^2 (7,442 ft^3/acre) and 115-ft^2 (7,156 ft^3/acre) treatments at 45 years. Greatest net cubic-foot yields were in 55-ft^2 (6,608 ft^3/acre) and 130 ft^2 (6,468 ft^3/acre) plots.

Greatest total yield (6,089 ft^3/acre) and net yield (6,049 ft /acre) at age 45 on medium sites resulted from thinning from below to a basal area of 100 ft^2 (fig. 5). Net yields from 85 ft^2 and "increasing" stand densities were slightly less,

Table 2.—*Diameter* distribution *of trees per acre on good sites after* thinning *at age* 20

Thinning level	Thinning method	D.b.h. (inches)								Total	
		2&3	4	5	6	7	8	9	10	1 4	2 2
ft²/acre		*trees per acre*									
70	Above	127	120	130	83	43	27	10	0	413	540
	Below	340	117	123	117	43	23	3	0	426	766
85	Above	270	223	187	103	50	17	0	0	580	850
	Below	200	113	150	107	80	27	7	3	487	687
100	Above	103	147	200	147	80	20	3	0	597	700
	Below	280	227	210	133	63	17	0	3	653	933
"Incr."	Above	480	267	213	70	17	0	0	0	567	1047
	Below	300	100	90	113	60	23	0	7	393	693
"Judg."	Both	327	163	147	97	57	27	0	0	490	817

Table 3.-Diameter distribution *of trees per acre on good sites* before thinning *at age* 25

Thinning level	Thinning method	D.b.h. (inches)											Total	
		2&3	4	5	6	7	8	9	10	11	12	13	2 4	2 2
ft²/acre		*trees per acre*												
70	Above	20	60	70	100	70	40	27	13	13	0	0	393	413
	Below	147	73	80	113	80	60	27	10	3	0	0	446	593
85	Above	142	117	167	120	97	50	30	7	0	0	0	588	730
	Below	104	73	80	114	90	47	53	13	3	3	0	476	580
100	Above	31	83	133	107	103	73	33	10	3	0	0	545	576
	Below	106	167	150	147	107	57	23	3	0	3	0	657	763
"Incr."	Above	204	200	130	173	63	33	10	0	0	0	0	609	813
	Below	67	60	60	93	63	77	30	20	0	3	0	406	473
"Judg."	Both	147	100	80	107	93	60	33	7	0	0	0	480	627
55	Below	47	97	120	153	80	80	67	17	23	3	3	643	690
115	Below	18	70	93	123	90	83	77	40	23	0	3	602	620
130	Below	28	67	123	113	130	80	93	30	3	10	3	652	680

Table *I.-Diameter distribution of trees per acre* on *good* sites *before thinning* at age *30*

Thinning level	Thinning method	D.b.h. (inches)														Total	
		2&3	4	5	6	7	8	9	10	11	12	13	14	15	16	2 4	2 2
ft²/acre		*trees per acre*															
70	Above	***9***	***13***	***40***	***37***	***33***	***70***	***37***	***27***	***17***	10	0	***7***	***3***	***0***	***294***	***303***
	Below	***56***	***53***	10	***17***	17	37	60	30	30	10	3	3	0	0	270	326
85	Above	37	83	50	87	70	53	57	30	13	7	3	0	0	0	453	490
	Below	27	37	37	17	33	43	27	53	40	10	3	3	0	0	303	330
100	Above	7	43	70	77	53	80	63	37	13	10	3	0	0	0	449	456
	Below	40	73	70	63	87	63	67	40	7	10	0	0	0	0	480	520
"Incr."	Above	100	100	63	60	83	60	33	17	10	0	0	0	0	0	426	526
	Below	30	40	7	27	30	37	43	53	23	17	0	0	3	0	280	310
"Judg."	Both	66	80	23	27	50	47	43	53	17	7	0	0	0	0	347	413
55	Below	1710		0	7	7	13	23	30	20	17	20	3	0	3	153	170
115	Below	6	7	7	37	33	30	50	63	30	27	13	0	3	0	300	306
130	Below	13	3	17	53	67	47	57	77	20	10	13	3	0	0	367	380

Table S.-*Diameter distribution of trees per acre on good sites before thinning at age35*

Thinning level	Thinning method	D.b.h. (inches) 5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total 5-18
ft ^{2}/acre		*trees per acre*														
70	Above	0	0	0	7	40	17	33	7	10	13	0	3	3	3	136
	Below	0	0	0	0	0	10	37	20	23	13	7	3	0	0	113
85	Above	0	3	7	43	30	40	23	20	13	3	7	0	0	0	189
	Below	0	0	3	3	27	10	43	47	13	3	7	0	0	0	156
100	Above	0	0	13	40	47	57	33	20	13	3	0	0	0	0	226
	Below	3	7	43	30	60	40	40	10	13	0	0	0	0	0	246
"Incr."	Above	7	20	43	40	73	33	17	7	10	0	0	0	0	0	250
	Below	0	0	3	0	13	40	33	30	20	10	0	0	0	0	149
"Judg."	Both	0	0	3	7	20	27	30	33	10	7	3	0	0	0	140
55	Below	0	0	0	0	0	3	13	20	10	20	10	7	0	0	83
115	Below	0	0	10	6	17	37	50	20	37	10	7	3	0	0	197
130	Below	0	3	23	33	47	30	63	17	13	10	0	7	3	0	249

Table 6.—*Diameter distribution of trees per acre on good sites before thinning at age 40*

Thinning level	Thinning method	D.b.h. (inches) 7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total 7-20
ft ^{2}/acre		*trees per acre*														
70	Above	0	3	0	3	20	17	20	7	7	7	0	7	0	3	94
	Below	0	0	0	0	3	13	13	23	17	7	7	0	0	0	83
85	Above	0	13	13	23	20	20	23	20	3	0	7	0	0	0	132
	Below	0	0	7	10	17	20	27	30	7	3	0	0	0	0	121
100	Above	0	17	7	23	47	27	10	23	3	7	0	0	0	0	164
	Below	13	13	17	53	27	27	17	3	13	0	0	0	0	0	183
"Incr."	Above	13	7	27	47	43	20	3	10	7	0	0	0	0	0	177
	Below	0	0	0	7	33	10	27	13	27	0	0	0	0	0	117
"Judg."	Both	0	3	0	17	3	27	23	13	10	7	3	0	0	0	106
55	Below	0	0	0	0	0	3	13	10	7	7	3	13	0	0	56
115	Below	7	7	7	20	17	30	23	30	10	3	7	0	0	0	161
130	Below	10	7	30	27	20	40	27	13	7	3	7	0	3	0	194

Table 'I.-*Diameter distribution of trees per acre on good sites before thinning at age 45*

Thinning level	Thinning method	D.b.h. (inches) 9	10	11	12	13	14	15	16	17	18	19	20	22	Total 9-22
ft ^{2}/acre		*trees per acre*													
70	Above	0	0	0	3	3	27	3	10	0	0	7	7	3	63
	Below	0	0	0	0	3	13	7	20	10	7	3	0	0	63
85	Above	0	0	13	13	20	13	17	10	0	3	3	0	0	92
	Below	0	0	0	0	3	7	13	23	0	3	0	0	0	49
100	Above	0	7	3	20	26	10	17	7	7	3	0	0	0	100
	Below	7	7	37	27	10	10	13	7	3	0	0	0	0	121
Incr."	Above	0	13	20	33	20	10	3	10	3	0	0	0	0	112
	Below	0	0	0	20	7	17	17	23	7	0	0	0	0	91
"Judg."	Both	0	3	3	0	17	17	13	10	10	3	7	0	0	83
55	Below	0	0	0	0	0	0	0	7	7	7	7	10	0	38
115	Below	0	0	0	7	13	10	20	17	3	7	0	0	0	77
130	Below	7	10	7	17	33	17	17	0	7	3	0	3	0	121

Table **8.-Diameter distribution of trees per acre on medium sites after thinning at age 20**

Thinning level	Thinning method	D.b.h. (inches)							Total	
		2&3	4	5	6	7	8	9	2 4	2 2
ft²/acre		*trees per acre*								
70	Above	363	230	183	70	23	13	0	519	882
	Below	733	300	210	67	7	3	0	587	1,320
85	Above	603	360	200	83	20	3	3	669	1,272
	Below	720	280	197	113	23	10	0	623	1,343
100	Above	427	270	203	133	60	10	3	679	1,106
	Below	670	383	247	107	30	7	0	774	1,444
"Incr."	Above	903	410	130	50	20	0	0	610	1,513
	Below	433	180	220	83	23	13	0	519	952
"Judg."	Both	763	283	177	60	13	3	3	539	1.302

Table **Q.-Diameter distribution of trees per acre on medium sites before thinning at age25**

Thinning level	Thinning method	D.b.h. (inches)									Total	
		2&3	4	5	6	7	8	9	10	12	2 4	2 2
ft²/acre		*trees per acre*										
70	Above	157	183	187	137	70	20	13	0	0	610	767
	Below	424	243	207	153	57	13	3	0	0	676	1.100
85	Above	307	250	210	157	87	20	10	3	3	740	1,047
	Below	351	263	173	127	83	17	13	3	0	679	1,030
100	Above	202	217	187	173	77	43	17	7	0	721	923
	Below	330	280	240	187	103	23	7	0	0	840	1,170
"Incr."	Above	517	403	183	100	40	27	3	0	0	756	1,273
	Below	206	173	123	147	87	30	17	0	0	577	783
"Judg."	Both	443	233	187	153	63	17	0	7	0	660	1,103

Table **lO.-Diameter distribution of trees per acre on medium sites before thinning at age 30**

Thinning level	Thinning method	D.b.h. (inches)										Total	
		2&3	4	5	6	7	8	9	10	11	12	≥4	2 2
ft²/acre		*trees per acre*											
70	Above	75	83	87	87	107	47	20	10	0	0	441	516
	Below	227	110	33	60	70	73	33	7	3	0	389	616
85	Above	127	120	93	107	93	47	33	10	0	0	S03	630
	Below	190	97	73	Q0	83	63	17	17	3	'7	450	640
100	Above	73	87	127	93	103	60	43	7	7	0	527	600
	Below	156	87	70	117	97	100	43	10	0	0	524	680
"Incr."	Above	251	130	153	Q0	53	23	17	13	0	0	479	730
	Below	84	67	30	63	73	70	43	13	7	0	366	450
"Judg."	Both	242	127	60	107	Q0	67	30	17	0	3	501	743

Table *II.-Diameter distribution of trees per acre on medium sites before thinning at age 35*

Thinning level	Thinning method	D.b.h. (inches)											Total
		4	5	6	7	8	9	10	11	12	13	15	4-15
ft²/acre		*trees per acre*											
70	Above	0	0	17	60	80	33	43	0	10	0	0	243
	Below	53	10	7	27	53	70	23	17	3	3	0	266
85	Above	0	17	33	77	80	43	37	23	0	0	0	310
	Below	7	20	40	43	57	63	37	7	10	7	3	294
100	Above	3	47	57	83	77	50	40	7	33		0	370
	Below	0	0	30	70	73	80	43	23	0	0	0	319
"Incr."	Above	50	53	103	70	57	17	30	10	3	0	0	393
	Below	0	0	7	47	47	63	47	13	13	0	0	237
"Judg."	Both	0	0	17	57	60	63	43	10	13	3	0	256

Table 12.—*Diameter distribution of trees per acre on medium sites before thinning at age 40*

Thinning level	Thinning method	D.b.h. (inches)												Total
		5	6	7	8	9	10	11	12	13	14	15	16	5-16
ft²/*acre*		*trees per acre*												
70	Above	0	0	7	23	63	30	27	10	10	0	0	0	170
	Below	0	0	3	27	23	53	17	13	13	3	3	0	155
85	Above	0	17	7	47	50	33	23	27	13	0	0	0	217
	Below	3	3	10	20	47	50	27	7	13	3	3	3	189
100	Above	3	27	30	50	40	53	27	17	7	3	0	0	257
	Below	0	0	10	37	43	63	27	37	10	0	0	0	227
"Incr."	Above	10	13	50	63	50	23	13	27	0	3	0	0	252
	Below	0	0	10	30	27	43	37	17	17	3	0	0	184
"Judg."	Both	0	0	0	13	23	30	48	20	13	3	3	0	153

Table 13.—*Diameter distribution of trees per acre on medium sites before thinning at age 45*

Thhming level	Thinning method	D.b.h. (inches)													Total
		6	7	8	9	10	11	12	13	14	15	16	17	18	6-18
ft²/acre		*trees per acre*													
70	Above	0	0	0	7	37	23	23	17	10	3	3	0	0	123
	Below	0	0	0	7	3	27	23	13	13	10	7	0	0	103
85	Above	0	0	13	30	20	13	20	17	27	7	0	0	0	147
	Below	0	0	7	7	23	27	37	10	10	3	3	3	3	133
100	Above	0	3	27	27	30	37	30	20	10	0	3	0	0	187
	Below	0	0	0	3	20	57	30	27	17	7	0	0	0	161
"Incr."	Above	3	7	27	33	54	20	7	20	13	0	0	0	0	184
	Below	0	0	3	7	13	37	27	33	10	10	0	0	0	140
"Judg."	Both	0	0	0	3	0	17	30	33	10	10	7	0	0	110

Table 14.—*Distribution of standing cubic-foot volume at age 25 among d. b. h. classes on good-site original plots thinned from below and on supplementary plots*

Thinning treatment	Proportion of standing volume in trees having d.b.h. in inches ≥:					Total volume
	4	6	8	10	12	
ft ²/acre	------------------		*percent*	------------------		*ft s/acre*
70	100	90	50	10	0	1,905
85	100	92	54	12	3	2,173
100	100	82	34	5	3	2,129
"Incr."	100	93	59	15	3	1,918
"Judg."	100	89	44	4	0	1,918
55	100	93	65	23	4	3,037
115	100	95	71	29	2	3,262
130	100	94	65	19	7	3,438

Table 15.—*Distribution of standing cubic-foot volume at age 30 among d. b. h. classes on good-site original plots thinned from below and on supplementary plots*

Thinning treatment	Proportion of standing volume in trees having d.b.h. m-inches ≥:							Total volume
	4	6	8	10	12	14	16	
ft ²/acre				*percent*	------------------			*ft ³/acre*
70	100	98	92	53	18	5	0	2,167
85	100	97	89	65	15	4	0	2,466
100	100	95	72	29	8	0	0	2,544
"Incr."	100	99	90	62	20	5	0	2,338
"Judg."	100	96	82	47	6	0	0	2,206
55	100	100	98	84	51	11	7	2,146
115	100	100	92	70	31	4	0	3,083
130	100	99	85	59	21	3	0	3,325

Table 16.—*Distribution of standing cubic-foot volume at age 35 among d. b. h. classes on good-site originalplots thinned from below and on supplementary plots*

Thinning treatment	Proportion of standing volume in trees having d.b.h. in inches 2:							Total volume
	4	6	8	10	12	14	16	
ft ²/acre	------------------			.-percent-----.			------	*ft ³/acre*
70	100	100	100	100	62	19	5	2,637
85	100	100	99	87	57	11	0	3,178
100	100	100	90	58	18	0	0	3,350
"Incr."	100	100	99	93	52	10	0	3,039
"Judg."	100	100	99	86	49	12	0	2,681
55	100	100	100	100	87	52	12	2,443
115	100	100	99	92	56	21	4	3,763
130	100	100	96	75	37	19	11	3,996

Table *17.-Distribution of standing cubic-foot volume at age 40 among d.b.h. classes on good-site original plots thinned from below and on supplementary plots*

Thinning treatment	Proportion of standing volume in trees having d.b.h. in inches ≥: 4	6	8	10	12	14	16	18	Total volume
ft²/acre				*percent*					*ft³/acre*
70	100	100	100	100	97	72	22	0	3,176
85	100	100	100	97	79	44	5	0	3,561
100	100	100	97	87	48	17	0	0	3,848
"Incr."	100	100	100	100	78	46	0	0	3,656
"Judg."	100	100	100	99	88	40	17	0	3,370
55	100	100	100	100	100	86	53	33	2,632
115	100	100	99	95	78	44	12	0	4,511
130	100	100	98	88	69	31	16	5	4,986

Table 18.—*Distribution of standing cubic-foot volume at age 45 among d. b. h. classes on good-site original plots thinned from below and on supplementary plots*

Thinning treatment	Proportion of standing volume in trees having d.b.h. in inches ≥: 8	10	12	14	16	18	20	Total volume
ft²/acre				*percent*				*ft³/acre*
70	100	100	100	97	71	21	0	3,271
85	100	100	100	96	59	9	0	2,310
100	100	98	66	37	14	0	0	3,408
"Incr."	100	100	100	80	42	0	0	3,921
"Judg."	100	100	96	81	47	18	0	3,787
55	100	100	100	100	100	71	33	2,493
115	100	100	100	81	44	7	0	3,349
130	100	98	90	53	21	12	7	4,443

Table *lg.-Distribution of standing cubic-foot volume at age 25 among d. b.h. classes on medium-site plots thinned from below*

Thinning treatment	Proportion of standing volume in trees having d.b.h. in inches ≥: 4	6	8	10	Total volume
ft²/acre		*percent*			*ft³/acre*
70	100	62	8	0	1,301
85	100	69	18	2	1,487
100	100	68	11	0	1,861
"Incr."	100	79	23	0	1,456
"Judg."	100	69	14	6	1,346

Table 20.—*Distribution of standing cubic-foot volume at age 30 among d. b.h. classes on medium-site plots thinned from below*

Thinning treatment	Proportion of etanding volume in trees having d.b.h. in inches ≥:					Total volume
	4	6	8	10	12	
ft²/acre	*percent*					*ft³/acre*
70	100	92	58	8	0	1,291
85	100	89	51	20	7	1,667
100	100	92	66	6	0	2,013
"Incr."	100	96	66	16	0	1,650
"Judg."	100	90	50	13	4	1,612

Table 21.-*Distribution of standing cubic-foot volume at age 35 among d. b.h. classes on medium-site plots thinned from below*

Thinning treatment	Proportion of standing volume in trees having d.b.h. in inches ≥:						Total volume
	4	6	8	10	12	14	
ft²/acre	*percent*						*ft³/acre*
70	100	97	88	33	6	0	2,024
85	100	99	84	40	17	4	2,560
100	100	83	32	0	0	0	2,834
"Incr."	100	100	87	45	10	0	2,402
"Judg."	100	100	83	41	13	0	2,430

Table 22.-Distribution *of standing cubic-foot volume at age 40 among d. b.h. classes on medium-site plots thinned from below*

Thinning treatment	Proportion of standing volume in trees having d.b.h. in inches ≥:							Total volume
	4	6	8	10	12	14	16	
ft²/acre	*percent*							*ft³/acre*
70	100	100	99	79	35	8	0	2,549
85	100	100	98	74	31	14	6	3,148
100	100	100	98	73	33	0	0	3,549
"Incr."	100	100	98	78	31	3	0	3,111
"Judg."	100	100	100	85	33	4	0	2,857

Table 23.-*Distribution of standing cubic-foot volume at age 45 among d. b.h. classes on medium-site plots thinned from below*

Thinning treatment	Proportion of standing volume in trees having d.b.h. in inches ≥: 4	6	8	10	12	14	16	18	Total volume
ft²/acre				*percent*					*ft³/acre*
70	100	100	100	97	76	42	10	0	2,612
85	100	100	100	95	69	33	17	7	3,238
100	100	100	100	99	61	21	0	0	3,742
"Incr."	100	100	100	96	69	23	0	0	3,328
"Judg."	100	100	100	99	90	34	6	0	3,005

and yield from 70 ft² was noticeably less; all these differences were significant.

Andrulot et al. (1972) reported yields through age 50 of plots established by H. H. Chapman near Urania, Louisiana. Many differences exist between the two studies, but comparisons can be useful. In the tabulation below, the Urania study's net yields (including thinnings, excluding mortality) in total stands (including hardwood) and in pine only are arrayed with yields of the 70-ft², 100-ft², and "increasing" treatments in the Crossett study.

Age of stand	Urania study: Total stand	Urania study: Pine only	Crossett study, thinned from below to: 70 ft²	100 ft²	"Incr."
			ft³/acre		
25	2,652	2,482	2,664	2,654	2,709
30	3,439	3,251	3,492	3,581	3,641
35	4.208	4,009	4,615	4,901	4,909
40	4,901	4,696	5,657	6,000	6,081
46	5,460	5,251	6,416	6,666	6,949

So, total yields to a 3-inch top in the Crossett study were very similar to net yields of total stemwood in the Urania study. Crossett yields were a little larger than Urania yields, in part because Crossett plots were kept free of hardwood, in part because site index at Crossett was higher than the 88-foot average site index at Urania, and in part because early thinnings at Urania were more drastic than those at Crossett.

Periodic Annual Increment. -Periodic annual growth (p.a.g.) in cubic feet to a 3-inch top culminated between ages 30 and 35 in the good-site original plots and between ages 35 and 40 on medium sites. In supplementary plots, p.a.g. culminated between 'ages 30 and 35 in 55-ft² plots and between ages 35 and 40 in 115-ft² plots and 130-ft² plots (table 24).

Periodic annual growth, age 20 to 45, on good-site original plots thinned from below averaged 195 ft³/acre (range 187 ft³ to 208 ft³/acre by treatments); on medium sites p.a.g. averaged 168 ft³/acre (range 148 ft³ to 193 ft³/acre), though it declined suddenly for no apparent reason in the 100-ft² plots between 40 and 45 years. Periodic annual growth, age 25 to 45 in supplementary plots averaged 191 ft³/acre for all treatments combined (range 168 ft³ to 210 ft³/acre).

The p.a.g. values in table 24 appear similar to those reported by Nelson et al. (1961) for a study in Georgia, South Carolina, and Virginia. But results of the two studies are not comparable for several reasons:

1. Cubic-foot volumes in the southeastern study were outside bark to a 4-inch top in trees 24.6 inches d.b.h.
2. Management and analysis procedures in the two studies differed greatly.
3. Stand basal area in the southeastern study included trees considered submerchantable in the Crossett study.
4. The southeastern plots, before their first thinning, had a range of density from 40 to 130 percent of full stocking. Crown lengths in the overstocked plots, especially in stands over 40 years old, must have been much shorter than crown lengths in trees of the same age in the Crossett study.
5. The Crossett study considers total growth, but the southeastern study dealt with net growth.
6. Different site index curves were used in the two studies.

Mean Annual Increment. -Mean annual increment (m.a.i.) in cubic feet was still increasing slowly on medium sites at age 45 (table 25). In supplementary plots and in two of the five good-site original thin-from-below treatments, cubic-

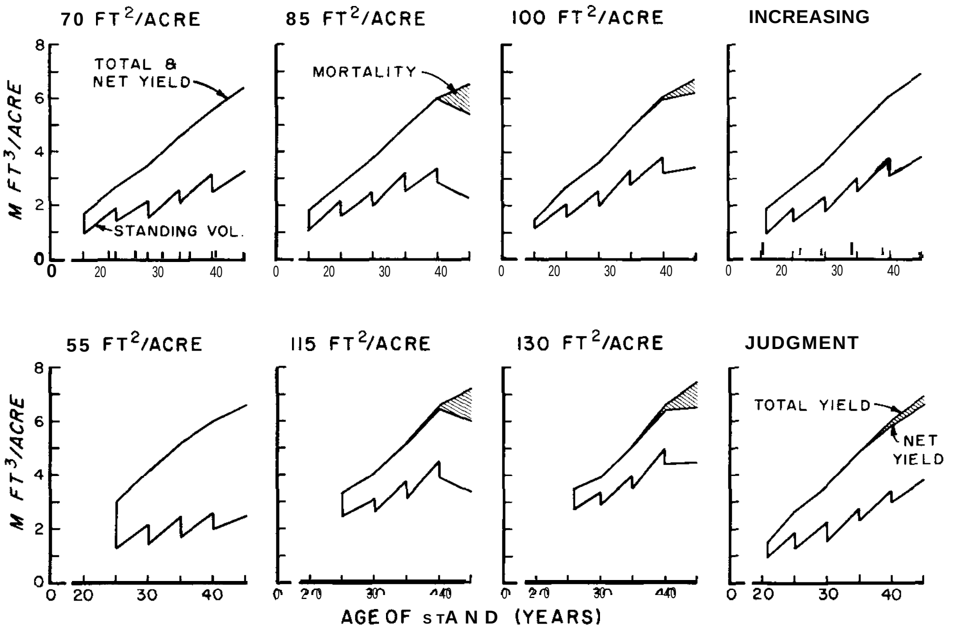

Figure I.-Total and net cubic-foot yield, cumulative natural mortality, standing volume, anu volume harvested in good-site original plots thinned from below and in supplementary plots: 70-ft^2, 85-ft^2, 100-ft^2, "increasing", "judgment", 55-ft^2, 115-ft^2, and 130-ft^2/acre treatments.

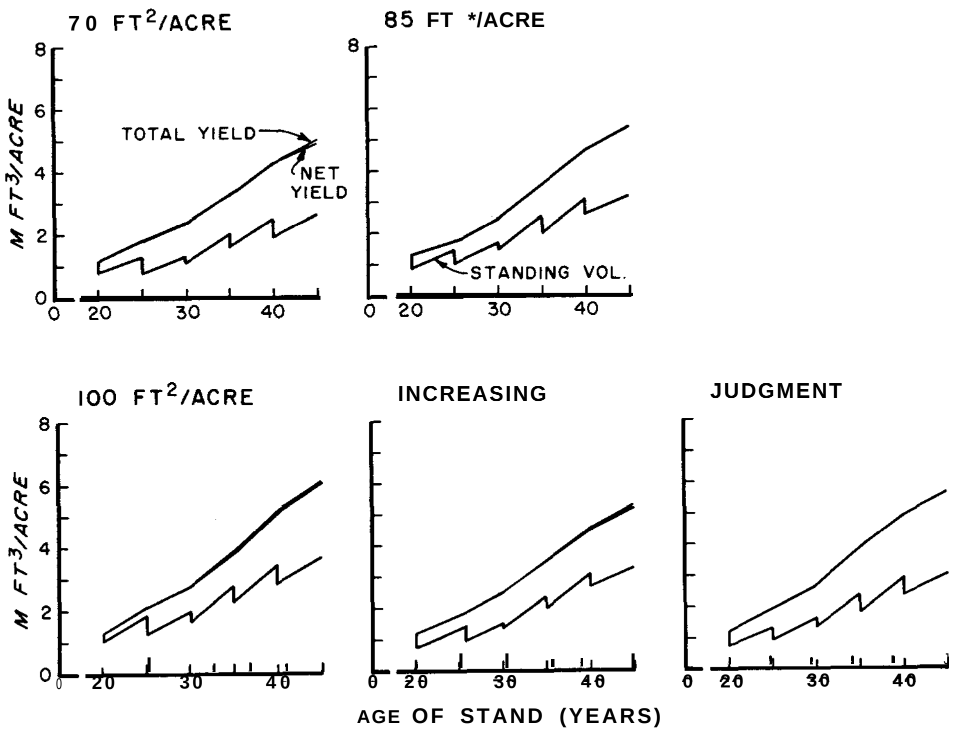

Figure 5.-Total and net cubic-foot yield, cumulative natural mortality, standing volume, and volume harvested in stands thinned from below on medium sites: 70-ft^2, 85-ft^2, 100-ft^2/acre, "increasing", and "judgment" treatments.

Table 24.-Periodic annual *growth* in cubic-foot *volume*[a]

Thinning treatment	Good sites, ages						Medium sites, ages					
	20-25	25-30	3035	35-40	40-45	20-45	20-25	2530	3035	35-40	40-45	20-45
ft²/acre						ft³/acre[b]						
70	189	162	225	208	152	187	112	107	193	192	136	148
85	217	166	244	219	105	190	114	127	221	232	129	165
100	183	185	264	220	133	197	165	148	223	250	180	193
"Increasing"	194	186	254	234	174	208	125	110	207	228	129	160
"Judgment"	181	190	230	244	179	205	125	143	233	222	144	173
						--25-45--						
55	.	180	204	181	107	168	. .	....	....	...	...	.
115	...	142	229	295	116	195	. .	....	...	...	...	....
130	...	125	236	306	172	210	...	...	...	. .	....	....

[a]Plots thinned from above were omitted from these calculations.
[b]Inside bark in trees ≥ 3.6 inches d.b.h. containing ≥ two 63-inch bolts to a 3-inch top d.i.b.

Table 25.-Adjusted *cubic-foot mean annual increment*[a]

Thinning treatment	Good sites to age					Medium sites to age				
	25	30	35	40	45	25	30	35	40	45
ft²/acre					*ft³/acre*[b]					
70	107	116	132	141	143	73	78	95	107	110
85	113	122	139	149	144	73	82	102	118	119
100	106	119	140	150	148	83	94	113	130	135
"Increasing"	108	121	140	152	154	75	81	99	115	117
"Judgment"	106	120	136	149	153	76	87	108	122	124
55	.	138	148	152	147	. .	. .	. .	.	.
115	. .	132	146	164	159	. .	.	.	. .	.
130	.	129	144	165	165		. .	.	. .	. .

[a]Plots thinned from above were omitted from these calculations.
[b]Inside bark, in trees ≥3.6 inches d.b.h. containing ≥two 63-inch bolts to a 3-inch top d.i.b.

Table *26.-Periodic annual growth of sawtimber (Doyle)*

Thinning treatment	Good sites, ages				Medium sites, ages			
	30-35	*35-40*	*40-45*	*30-45*	*3035*	*35-40*	*40-45*	*30-45*
ft²/acre				*fbm/acre*[a]				
70	954	916	857	909	217	577	479	424
85	833	827	529	730	268	633	715	539
100	571	686	621	626	277	633	828	580
"Increasing"	907	923	945	925	307	601	689	532
"Judgment"[b]	840	937	1,029	935	271	688	743	567
55	939	893	659	830	...	. .	. .	. .
115	684	927	653	755	...	...	. .	.
130	717	910	711	779	. .	. .	. .	. .

[a]Trees ≥9.6 inches d.b.h. containing ≥ one 16-foot log to an 8-inch top d.o.b.
[b]"Judgment" treatment included thinning from above and below. In all other treatments in this table, thinning was always from below.

foot m.a.i. was declining. Apparently then, cubic-foot m.a.i. in periodically thinned stands culminates at about 45 years, slightly earlier on better sites, slightly later on medium sites; however, at least one more regular inventory will be needed to confirm this trend. On good-site original thin-from-below plots, m.a.i. at 45 years was about 148 ft^3 /acre; on supplementary plots, m.a.i. was 157 ft^3 /acre; and on medium-site thin-from-below plots, m.a.i. was 121 ft^3 /acre.

Yield tables such as those inU.S. Department of Agriculture, Forest Service (1976) and Meyer (1942) clearly show that m.a.i. in fully stocked stands culminates at about age 35. This early culmination occurs because at age 35 natural mortality caused by crowding exceeds the rate of stand total growth. Thinning from below mostly prevents crowding-induced mortality. So, we must expect culmination of m.a.i. to occur later in managed stands than it does in unmanaged. Culmination occurs as a plateau, not a sharp peak.

Board-Foot Growth and Yield

Standing Volumes. -Standing sawtimber volume in board feet (Doyle), all treatments combined, averaged:

	Medium sites	Good sites	Supplementary
30 years	224	1,882	3,978
35 years	1,386	5,396	7,417
40 years	4,095	8,911	10,974
45 years	7,108	11,450	12,083

Standing sawtimber volume on good-site original plots (fig. 6) was significantly greater when reckoned in Doyle rule from age 35 onward in the 70-ft^2 than in the 100-ft^2 treatment and from age 40 onward in the 70-ft^2 than in the 85-ft^2 treatment, because: (1) stem diameter growth is usually more rapid in heavily thinned stands than in those lightly thinned; (2) some trees in lightly thinned stands had not yet attained sawtimber size, even by age 45; and (3) the Doyle rule assigns disproportionately smaller volumes to small-diameter logs than to large-diameter logs.

Good-site original plots thinned from below to "increasing" basal area contained as much standing volume in board feet (Doyle) as the 70-ft^2 plots had at 30, 35, and 40 years; at 45 years "increasing" plots contained the greatest standing volume of any treatment (14.2 M bm), original or supplementary. The "judgment" treatment surpassed the 100 ft^2 treatment at age 35, equaled the 85-ft^2 treatment at age 40, and rivaled the "increasing" treatment at age 45.

In supplementary plots, standing board-foot volume (Doyle) differed little between treatments (fig. 7). When volumes were reckoned by the International ¼-inch rule, however, the 115-ft^2 and 130-ft^2 stands contained 3 to 5 M bm more volume than did the 55-ft^2 stands at 40 and 45 years. In contrast, for good-site plots, use of International ¼-inch rule instead of Doyle usually lessened the differences in standing volume between treatments.

No significant differences between treatments occurred in standing sawtimber volume (Doyle or Int. ¼) at any age on medium sites (fig. 8).

Thinning from below to an increasing basal area usually produced noticeably greater standing volumes (Doyle) than did thinning from above. These differences, significant on good sites but not on medium, diminished as the stands grew older. The differences were due in part to the bias inherent in the Doyle rule and in part to thinning method. For example, good-site stands thinned initially from above to "increasing" basal area had a mean d.b.h. of 10.6 inches at age 40, and 27 percent of the trees were below sawtimber size. Stands thinned always from below to "increasing" basal area on good sites had a mean d.b.h. of 13.0 inches at age 40, and every tree was in the lo-inch class or larger.

Total Yields. -On good-site original plots, sawtimber yield varied significantly with intensity of thinning, being low in the 100-ft^2, intermediate in the 85-ft^2, and high in the 70 ft^2 treatment. The "increasing" thin-from-below treatment produced board-foot yields somewhat greater than yields in the 70-ft^2 plots (Doyle and Int. ¼) (fig. 6). The "judgment" treatment surpassed the 100-ft^2 at age 35 and thereafter closely trailed the 70-ft^2 treatment.

Thinning to 55 ft^2 basal area resulted in greater sawtimber net yields (Doyle and Int. ¼) than did thinning to 115 ft^2 or 130 ft^2 (fig. 7). At 45 years, the 55 ft^2 stands had a net yield of 16,727 fbm/acre (Doyle) or 26,057 fbm/acre (Int. ¼). In short rotations on good sites, heavy thinning produced the largest net board-foot yields.

On medium sites from age 35 onward, the 70-ft^2 treatment yielded much less sawtimber than did any other treatment. Little difference was evident in board-foot yield among the 85-ft^2, 100-ft^2, "increasing," and "judgment" treatments.

As shown below, sawtimber yields of the 70-ft^2, 85-ft^2, and "increasing" treatments on good sites in this study are similar to those reported by Andrulot et al. (1972) for the "normal thinning" plots in the Urania study.

Age of stand	Urania study: Total stand	Urania study: Pine only	Crossett study, thinned from below to: 70 ft^2	85 ft^2	"Incr."
years			*fbm/acre Int. ¼*		
30	7,594	7,441	4,960	6,263	5,980
35	13,185	13,003	14,173	14,520	14,923
40	18,777	18,575	20,587	20,843	21,810
45	23,369	23,155	26,233	24,427	28,243

Thirty-year yields exceeded those at Crossett, perhaps because a 5-inch top was used at Urania and an 8-inch top at Crossett, and because early thinning at Urania was more drastic than that at Crossett. From age 35 onward, Crossett yields exceeded Urania yields, in part because Crossett plots were kept free of hardwoods and in part because site index was about 5 feet higher at Crossett.

Periodic and Mean Annual Increment.— Periodic annual growth in sawtimber culminated between ages 35 and 40 at 858 fbm/acre in good-site original plots thinned from below (all treatments combined) and at 910 fbm/acre in supplementary plots. Periodic annual growth culminated at 954 fbm/acre in the 70-ft^2 and 833 in the 85-ft^2 between ages 30 and 35, and at 945 fbm between ages 40 and 45 in the "increasing" plots (table 26).

On good sites, culmination usually occurred earlier in the rotation and at a higher value in heavy thinning treatments and occurred later at a lower value in light thinning treatments. On medium sites, p.a.g. was 678 fbm/acre between ages 40 and 45 in plots thinned from below (all treatments combined); whether this rate was a maximum cannot be known before the next inventory. Culmination usually occurred later on medium sites than on good sites. Thinning intensity also affected results on medium sites, in a reverse of its effect on good sites. On medium sites, p.a.g. culminated at 828 fbm in the 100-ft^2, at 715 fbm in the 85-ft^2, at 689 fbm in the "increasing", and at 577 fbm in the 70-ft^2 treatment.

When these p.a.g. calculations were made with board feet Int. ¼, culmination occurred between ages 30 and 35 on good sites, in all thin-from-below treatments, original and supplementary. On medium sites, p.a.g. culminated between ages 40 and 45 in all thin-from-below plots except the 70

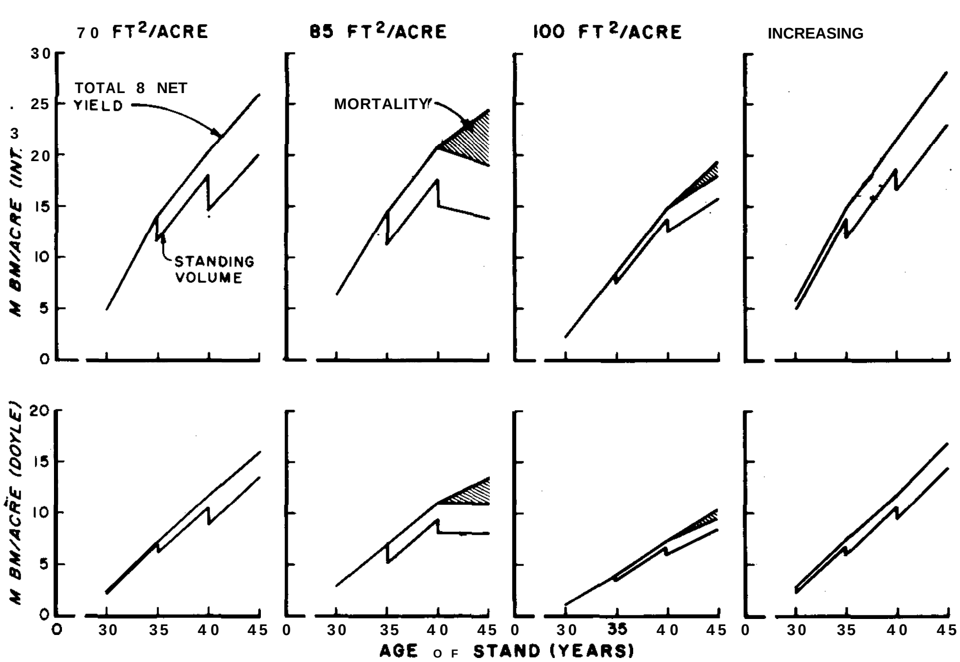

Figure 6.-Total sawtimber yield, net yield, cumulative natural mortality, standing volume, and volume harvested in thinning from below: 70-ft^2, 85-ft^2, 100-ft^2/acre, and "increasing" basal area on good sites.

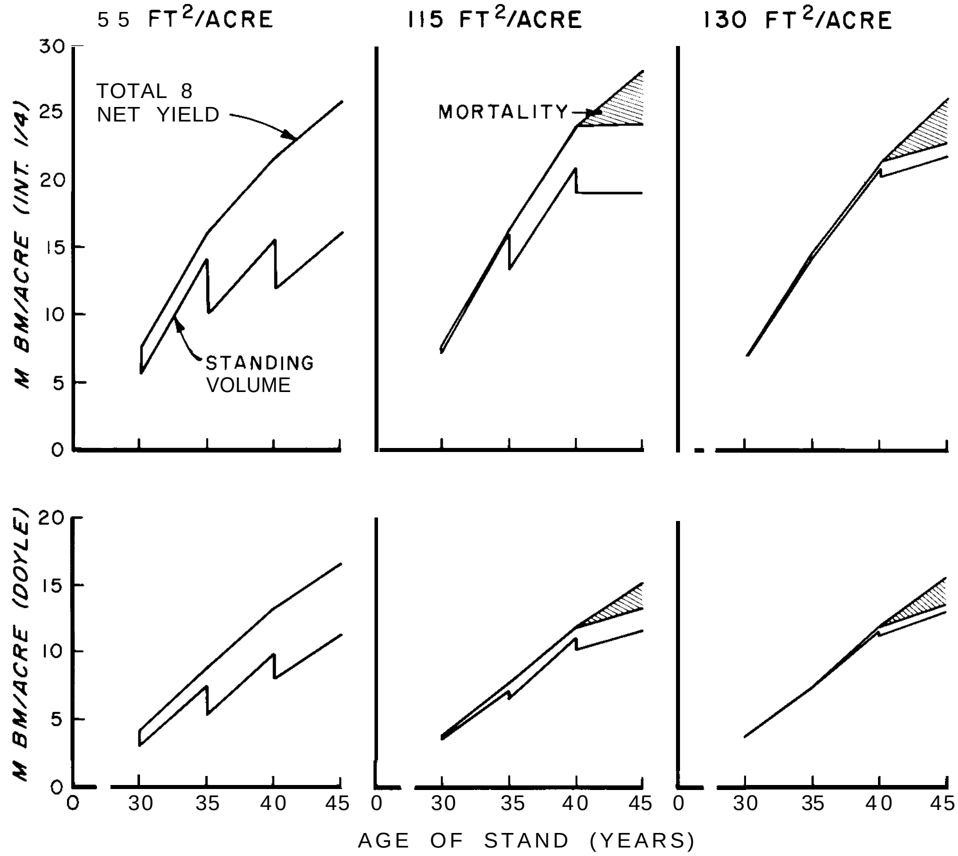

Figure 7.-Total sawtimber yield, net yield, cumulative natural mortality, standing volume, and volume harvested in thinning from below: 55-ft², 115-ft², and 130-ft²/acre on good sites.

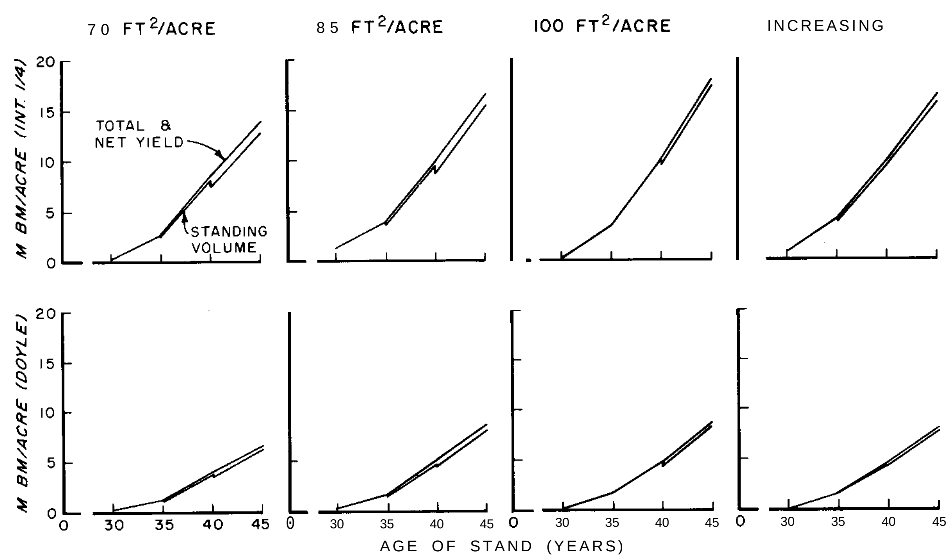

Figure 8.—**Total** and net sawtimber yield, standing volume and volume harvested, in thinning from below: 70-, 85-, 100-ft², and "increasing" basal area on medium sites.

ft^2 where it culminated between ages 35 and 40.

The p.a.g. values in table 26 cannot be compared directly with those found by Nelson et al. (1961) for the southeastern study, because the latter are in board feet Int. ¼. And even when table 26 is converted to Int. ¼, the p.a.g. values are much higher in the Crossett study than in the southeastern study.

Mean annual increment calculated in board feet Doyle (table 27) or Int. ¼ was still increasing rapidly at age 45 in all treatments on both sites.

Table 58 in U.S. Department of Agriculture, Forest Service (1976) shows that culmination in normal stands occurs at 70 years on site index 80, at 65 years on site index 90, and at 60 years on site index 100, for board feet (Doyle). Davis (1954), plotting data from Meyer's (1942) bulletin, indicated 44 years on site index 100, 45 years on site index 90, and 46 years on site index 80 for board feet Int. ¼ in unthinned fully stocked stands. Culmination can be expected to occur later in managed than in unmanaged stands.

This 41-year-old stand was thinned always from below to an increasing basal area. The increasing technique, one of several compared in this study, was the most effective at growing sawtimber in 45 years on good sites.

This 41-year-old stand on a medium site was thinned always *from below to 100* ft^2/acre. This thinning regime was the most effective of several compared for growing sawtimber on medium sites.

Table **27.—*Mean annual increment of sawtimber (Doyle)***

Thinning treatment	*Good* sites to age 30	35	40	45	Medium sites to age 30	35	40	45
ft²/acre				*fbm/acre*[a]				
70	78	203	292	355	5	35	***103***	***145***
85	96	201	280	307	17	53	***126***	191
100	36	112	184	233	5	44	117	196
"Increasing"	93	209	299	370	8	51	120	183
"Judgment"[b]	51	164	261	346	11	48	128	197
55	142	256	336	372	...	. .	....	....
115	130	209	299	338	. .	...	....	....
130	125	210	297	343	...	. .	....	....

[a] **Trees** 29.6 inches d.b.h. containing **≥one 16-foot** log to an d-inch top d.o.b.
[b] **"Judgment"** treatment included thinning from above and below. In **all** other treatments in this table, thinning was always from below.

Table *28.-Cubic-foot volumes of **merchantable** wood removed: **unadjusted** initial cut, adjusted initial cut,*[a] *and adjusted total harvests, and natural mortality in merchantable trees*[b]

Thinning level	Thinning method	Good sites: Initial Cut Unadj .	Adj .	**Total** through age 40 Unadj .	Adj .	Mortality **ages 30-45**	Medium sites: Initial cut Unadj .	Adj .	**Total** through age 40 Unadj .	Adj.	Mortality ages 30-45
ft²/acre						*ft³/acre*					
70	Above	1,061	793	***3,630***	***3,362***	***0***	***642***	***522***	***2,302***	2,182	**0**
	Below	767	779	***3,133***	***3,145***	**0**	***392***	***520***	2,196	2,323	**29**
85	Above	737	708	***3,381***	***3,352***	***87***	***405***	***407***	***2,636***	2,638	**0**
	Below	711	652	***3,148***	***3,089***	***1,093***	***430***	***344***	***2,223***	2,137	***0***
100	Above	630	483	***2,987***	***2,840***	***572***	***285***	164	1,889	1,768	***34***
	Below	328	525	2.619	***2,816***	***480***	***209***	***223***	***2,304***	2,318	***40***
"Incr."	Above	738	962	***2,707***	2,931	***335***	***439***	***549***	***1,887***	1,997	144
	Below	940	790	***3,177***	***3,027***	***25***	***444***	***432***	1,943	1,931	9
"Judg."	Both	608	730	***2,747***	2,971	***264***	***455***	***542***	***2,500***	2,587	0
55	Below	1,790	1,999	***3,905***	4.114	***0***	....	....	. .	....	
115	Below	891	875	2,719	2,703	***1,146***	....	....	.....	.....	
130	Below	740	548	***2,354***	2,162	***974***			.....		

'Initial cuts were made at age *25* in the 56 **ft²**, 116 **ft²**, and 130 **ft²/acre** treatments. Initial cuts were made at age 20 in **all** other treatments, on both sites.
[b] **Total** removal **=** total thinnings + **total** mortality.

Cubic-Foot and Board-Foot Volumes in Intermediate Harvests

Table 28 shows total cubic-foot volume of merchantable wood harvested from age 20 through age 40 in original plots and from age 25 through age 40 in supplementary plots. Adjusted and unadjusted volumes in first thinnings are presented side by side, as are adjusted and unadjusted total thinnings through age 40. This arrangement shows the amount of the adjusted initial cut and how it affected total harvest. Total volume in natural mortality of merchantable trees is shown.

Total board-foot volumes (Doyle) harvested, ages 30-40, in good-site original thin-from-below plots ranged from less than 1 M bm in "judgment" plots through 1.4 M bm in 100-ft^2 to 2.9 M bm in 70-ft^2 /acre plots. On medium-site thin-from-below plots, total cut, ages 30-40, averaged only 0.27 M bm; the only apparent effect of thinning level was that "judgment" thinning produced the least volume (< 0.06 M bm). Thinning from above harvested only 58 percent of the harvest of thinning from below on good sites and 82 percent on medium. On supplementary plots, total harvests, ages 30-40, were 5.3 M bm in 55-ft^2, 1.6 M bm in 115-ft^2, and 0.5 M bm in 130-ft^2 /acre plots. Here again, however, the bias inherent in the Doyle rule can lead to erroneous conclusions.

When board-foot volumes harvested were reckoned by Int. ¼ rule, the 70-ft^2 treatment produced the largest total cut (5.9 M bm) on good-site original plots, and the 85-ft^2 treatment produced the largest (1 .1 M bm) on medium sites. On both sites, the smallest total harvests in thin-from-below plots were in the 100-ft^2 treatment: 2.2 M bm on good sites and 0.4 M on medium. On supplementary plots, total cuts ranged from 9.9 M bm on 55-ft^2 to 1.0 M bm on 130-ft^2 /acre plots.

DISCUSSION

Each thinning treatment in this study represents a silvicultural alternative. The "judgment" treatment, however, is a special case. On both good and medium sites, yields in "judgment" plots compared favorably with yields of most other treatments (fig. 9). But this finding

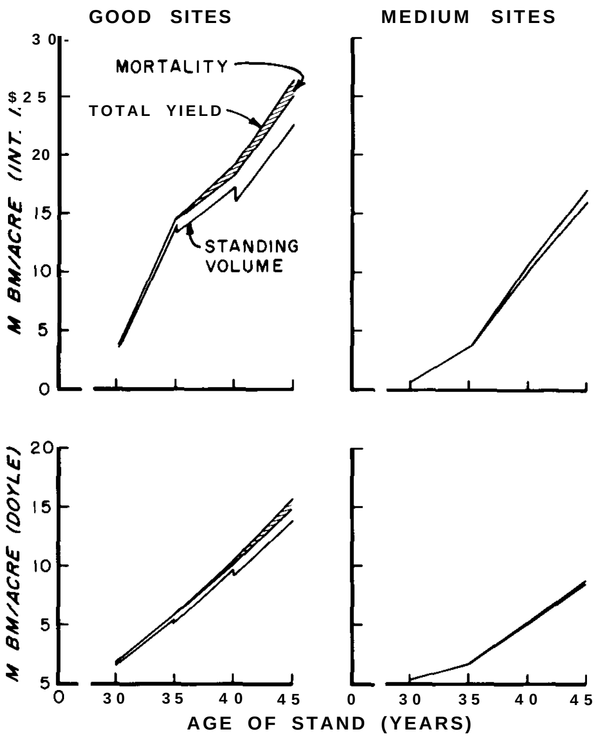

Figure O.-Total and net sawtimber yield, and volume harvested in the "judgment" treatment on good and medium sites.

may be of little value to the average forest landowner. A team of four to six experienced workers acting together and without restrictions can thin as well as, and frequently better than, a single employee faithfully following one of the other eight thinning regimes. In reality, however, most timber marking is done not by a committee of experienced people, but by an individual often with limited experience and limited time to get the job done.

So, the treatment a landowner selects must depend on his objectives and circumstances; the site quality of the land; and the age, condition, and stand structure of his loblolly-shortleaf pine forest.

Management's primary aim may be growing sawtimber trees 9.6 inches d.b.h. and larger, in even-aged stands. Results of this study make a good case for initial heavy thinning from below, on good sites, to a basal area of 70 ft^2 /acre at age 20 and then increasing the residual stand density by 5-ft^2 steps. The "increasing" treatment produced the best yield, and the 70-ft^2 the second best. If the landowner is trying to decide between the two, he may elect to be guided by the expected mean d.b.h. (fig. 1), the number of trees per acre (tables 3-7), and any restraints on rotation length peculiar to his ownership. These two treatments began alike. So, if the landowner selected either treatment, he could change to the other later. The 55-ft^2 treatment also produced large board-foot yields.

These three treatments share some advantages and liabilities: they involve a small investment in growing stock; they encourage rapid growth of trees to large sizes in short rotations; they involve heavy early thinnings and, therefore, relatively large early returns; and they encourage aggressive understory development and, so, require much weeding. The better the site and the more severe the thinning, the more urgent will be the need for understory control.

If the landowner's primary objective is to grow wood fiber, densities higher than these are, indicated. In this study, the 130-ft^2 and the 115-R-2. treatments produced the greatest total cubic-foot yields in the supplementary plots. The 100-ft^2 treatment produced the greatest total yield in the good-site original plots. Most of the reduction of net yield by the southern pine beetle occurred after age 40. So, if growing pulpwood is the sole objective, the landowner may prefer to do no thinning at all and to clearcut at 35 years, in view of the high costs of thinning and the small cut volumes for the 130-ft^2 and the 115-ft^2 treatments.

If the landowner's objective is to grow sawtimber on medium sites, the "increasing" treatment would be best. Thinning to 85 ft^2 or 100 ft^2 produced slightly greater yields at 40 and 45 years, but the "increasing" treatment involves a smaller investment in growing stock and a heavier early thinning.

If the aim of management is to grow pulpwood on medium sites, light thinning, or perhaps no thinning, is called for. Thinning from below to 100 ft^2 was the best pulpwood regime on medium sites in this study.

LITERATURE CITED

Andrulot, E. R., L. P. Blackwell, and P. Y. Burns.
1972. Effects of thinning on yield of loblolly pine in central Louisiana. Div. Res. Coll. Life Sci., Bull. 6,145 p., La. Tech. Univ., Ruston, La.

Davis, K. P.
1954. American forest management. 482 p. McGraw-Hill Book Co., Inc., New York.

Mesavage, C.
1947. Tables for estimating cubic-foot volume of timber. U.S. Dep. Agric. For. Serv. Occas. Pap.111, 71 p. South. For. Exp. Stn., New Orleans, La.

Mesavage, C., and J. W. Girard.
1946. Tables for estimating board-foot volume of timber. U.S. Dep. Agric. For. Serv. [Unnumbered Publ.] 94 p., Washington, D.C.

Meyer, W. H.
1942. Yield of even-aged stands of loblolly pine in northern Louisiana. Yale Univ.: Sch. of For. Bull. 51, 39 p. Yale Univ., New Haven, ct.

Nelson, T. C., T. Lotti, E. V. Brender, and K. B. Trousdell.
1961. Merchantable cubic-foot volume growth in natural loblolly pine stands. U.S. Dep. Agric. For. Serv., Stn. Pap. 127, 12 p. Southeast. For. Exp. Stn., Asheville, N.C.

Nelson, T. C., K. B. Trousdell, E. V. Brender, and T. Lotti.
1963. Board-foot growth of loblolly pine as related to age, site, and stand density. J. For. 61: 120-123.

U.S. Department of Agriculture, Forest Service.
1976. Volume, yield, and stand tables for second-growth southern pines. U.S. Dep. Agric. Misc. Publ. 50 [revision of 1929 edition], 202 p., Washington, D.C.

Zahner, R.
1962. Loblolly pine site curves by soil groups. For. Sci. 8: 104-110.

BURTON, J. D.

1979. Growth and yield in managed natural stands of loblolly and shortleaf pine in the West Gulf Coastal Plain. U.S. Dep. Agric. For. Serv. Res. Pap. SO-159, 23 p. South. For. Exp. Stn. New Orleans, La.

Presents total and net yield, standing volume, volume harvested, and number of trees by d.b.h. class by 5-year periods, ages 20-45, in even-aged stands on two sites, repeatedly thinned to various densities. Cubic-foot volume to a 3-inch top is given for ages 20-45. Board-foot volume, Doyle and Int. ¼-inch, to an 8-inch top, is given for ages 30-45.

Additional keywords: ***Pinus taeda*** L., ***P. echinata*** Mill., stand structure, diameter distribution, stand density.

Conversion to Metric Units

1 inch	= 2.54 centimeters
1 foot	= 0.3048 meter
1 acre	= 0.4047 hectare
1 tree/acre	= 2.47 trees/hectare
1 cubic foot/acre	= 0.06997 cubic meters /hectare
1 square foot/acre	= 0.2296 square meter/hectare
1 board foot	= 0.005663 cubic meter
1 cubic foot	= 0.0283 cubic meter