Yield Comparisons from Even-Aged and Uneven-Aged Loblolly-Shortleaf Pine Stands

James M. Guldin, *Department of Forest Resources, Arkansas Agricultural Experiment Station, University of Arkansas, Monticello, Arkansas, and* **James B. Baker,** *Forestry Science Laboratory, Southern Forest Experiment Station, USDA Forest Service, Monticello, Arkansas.*[1]

*ABSTRACT. Empirical yields for a 36-year management period are presented for seven long-term studies on similar sites in loblolly-shortleaf pine (*Pinus taeda *L.-P.* echinata *Mill.) stands on the upper southern coastal plain of southern Arkansas and northern Louisiana. Total merchantable cubic-foot yields are highest for conventionally managed even-aged plantations; sawtimber cubic-foot yields are highest for intensively managed even-aged plantations and intensively managed uneven-aged stands. However, uneven-aged stands have higher board-foot sawtimber yields than the most productive even-aged stands, particularly in comparisons using the Doyle log rule. It is hypothesized that the even-aged plantations have higher cubic-foot yields because they are more fully stocked with trees of merchantable size. Conversely, the uneven-aged stands have higher board-foot yields because of the greater proportion and continuous supply of sawtimber basal area, especially in stems of large size, which can be developed using the uneven-aged selection method.*

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The debate over the relative merits of different silvicultural systems is as old as the forestry profession itself and will no doubt continue in response to new technical innovations, changing market and economic conditions, and adjustments in landowner attitudes. For example, in the pine forests of the southern United States, foresters have discussed the choice between natural and artificial regeneration from the standpoint of economics (Derr and Mann 1971, Campbell and Mann 1973, Barnett 1982, Dutrow 1984, Dutrow and Kaiser 1984, Baker 1985) and silviculture (Porterfield and Moak 1977, Williston 1978, Langdon 1981, Baker 1982, Toliver 1982, Dennington and Larson 1984). In a similar way, the role of even-aged and uneven-aged silvicultural systems continues to be studied (Smith 1972, 1973, Sunda and Lowry 1975, Gibbs 1978, Chang 1981, Baker 1986, Haight 1987).

The general consensus arising from this debate is that industrial timber production is optimized by the capital-intensive methods of clearcutting followed by site preparation and artificial regeneration. Alternative silvicultural systems are thought to apply only in situations such as nonindustrial private forestlands, where market limitations, esthetic or ecological concerns, poor site quality, or an unwillingness to make heavy capital investments outweigh the desire to optimize timber production.

Yet, this consensus is not borne out by the situation in the loblolly-shortleaf (*Pinus taeda* L.-*P. echinata* Mill.) pine type in the West Gulf region. Here, large-product forest industries routinely practice natural regeneration methods such as the even-aged shelterwood and seed-tree methods and the uneven-aged selection method. In addition, forest industries that practice clearcutting and planting often find their pine plantations overwhelmed with unintended natural regeneration. These experiences suggest that silviculturally intensive natural regeneration methods might be an acceptable timber management alternative in appropriate situations.

To consider such alternatives, foresters and landowners should be aware of the yields of wood products that might reasonably be expected. Unfortunately, long-term yields from similar stands, occupying similar sites under similar ecological conditions but managed under different silvicultural systems, have rarely been compared. The opportunity to conduct such a comparison, however, is possible because of the carefully documented long-term forest research in southern Arkansas and northern Louisiana. This paper presents empirical yield results at age 36 for even-aged loblolly pine plantations, and even-aged and uneven-aged natural stands of loblolly pine mixed with minor and varying proportions of shortleaf pine, found on similar sites and soils of the upper southern coastal plain of southern Arkansas and northern Louisiana.

STUDY AREAS AND METHODOLOGY

General attributes

Seven long-term research studies, ranging in duration from 29 to 41 years, comprise the database for this analysis. In each study, stands under treatment have had complete documentation of the yields from all intermediate cuttings or harvests, or from both, made from the inception of management through their most recent inventory. The stands occupy sites that are roughly comparable, having site indices for loblolly pine of from 85 to 100 ft at 50 years, and soils that vary from silt loams to fine sandy loams (Table 1).

The stands in these studies were sorted into three major categories. even-aged plantations, even-aged natural stands, and uneven-aged natural stands. Each category was subdivided into two intensities of application: conventional silviculture and intensive silviculture. The difference between the two intensities is the degree or frequency, or both, of intermediate treatments. A third subdivision was employed in the intensive category of the uneven-aged stands to reflect whether stand structure was poorly regulated (volumes based on both the initial 15-year rehabilitation period and the 26-year well-stocked period) or well-regulated (volumes based on only the 26-year well-stocked period).

In these comparisons, mean annual increment (MAI) refers to even-aged stands and is based on the final standing volume at the specified age plus all preceding intermediate harvests. Average annual yield (AAY) is analogous to MAI but applies to uneven-aged stands. The AAY is based on the standing volume at the end of the management period plus all intermediate harvests minus the initial standing volume at the beginning of the management period.

The ages during which stand inventories were conducted are shown in Table 1. Yields at age 36

Table 1. Site characteristics of research studies included in these yield comparisons.

Study	Location	Inventory Years	Soils	Loblolly Pine Site Index Base 50
1. Cattle Farm Plantation, Georgia-Pacific Corp.	Ashley Co., AR	35,39	Glossic and Glossaquic Fragiudalfs	80–85[1]
2. Sudden Sawlog Study, USFS/Georgia-Pacific Corp.	Ashley Co., AR	36	Typic Fragiudalf	85[1]
3. Hill Farm Thinning Study, LSU	Claiborne Parish LA	29, 34	Typic and Plinthic Paleudults	100[2]
4. Methods of Thinning Study, USFS	Ashley Co., AR	35, 40	Glossic and Glossaquic Fragiudalfs	80–85[1]
5. Methods of Cutting Study, USFS	Ashley Co., AR	36	Typic and Glossic Fragiudalfs	85–90[1]
6. Poor Farm Forty Study, USFS	Ashley Co., AR	15, 41	Typic and Glossaquic Fragiudalfs	84–90[1]
7. Good Farm Forty Study, USFS	Ashley Co., AR	15, 41	Typic and Glossaquic Fragiudalfs	84–90[1]

[1] USDA 1979.
[2] Evans et al. 1983.

in studies 1 and 4 were calculated as the total yield at age 35 plus one year of periodic annual increment between year 35 and the subsequent stand inventory. Study 3 was given a second intensive treatment after the inventory at age 29; its 36-year yields are based on linear projections of MAI at ages 29 and 34 to year 36. Yields after 36 growing seasons for studies 6 and 7 were derived by determining the AAY over 41 years (poorly regulated production) and the AAY between years 15 and 41 (well-regulated production) and then multiplying the appropriate AAY by 36.

Specifications for total merchantable cubic volume are not greatly different among the studies in this comparison (Table 2). Sawtimber standards were slightly different, mostly regarding the larger minimum dbh for sawlogs in studies 5, 6, and 7. Comparisons among studies must be made with an awareness of these differences in merchantability specifications.

Even-aged Plantations

The first study is located on the 69-ac Cattle Farm demonstration plantation managed by the Mid-Continent Division of Georgia-Pacific, and located east of Crossett, Arkansas. This stand, the oldest pine plantation in the state, was established on an old field in 1927 by the Crossett Lumber Company. Seedlings were planted at a spacing of 3 to 5 ft in rows 6 ft apart. The first cutting was an ice storm salvage cut in 1940 for pine pulpwood; the timber has been thinned regularly since then on a 3- to 5-year schedule. This treatment illustrates conventional thinning by forest industry and its yields typify the conventional application of the clearcutting system.

The second study is the Sudden Sawlog Cooperative Study of the USDA Forest Service and Georgia-Pacific (Burton 1982). These old-field plantations were established in 1945 with an intensive thinning prescription implemented in 1953 (Burton 1982). The control treatments approximate existing industrial thinning practices and represent the conventional clearcutting system. The three intensive thinning treatments in this study produced similar yields and were combined in this comparison to represent an intensive clearcutting regime.

The third study in this analysis is the Plantation Spacing Study from the North Louisiana Hill Farm Experiment Station near Homer, LA (Foil et al. 1964, Sprinz et al. 1979, Clason and Cao 1985). These old-field plantations were established in 1950, and intensive thinnings were conducted after the 11th and 29th growing seasons. Yields from these stands represent two intensive even-aged plantation systems—one with a single heavy thinning prescription at age 11, and the second with two heavy thinnings.

Even-Aged Natural Stands

Study 4, the Methods of Thinning Study, is a USDA Forest Service study designed to evaluate the effects of eight different thinning intensities on the development of even-aged natural pine stands in southern Arkansas and northern Louisiana (Burton 1972, 1978, 1980). The stands originated following clearcutting in 1930. Five-year thinning cycles were initiated at ages 20 or 25 through age 45. Burton studied both good and poor sites, as well as thinning from above and below; for these comparisons, only the good-site, thinned-from-below plots are

Table 2. Merchantability specifications for the studies in these yield comparisons.

Study	Stump height (ft)	Total Merchantable volume: measured units	minimum dbh	minimum top diameter	Sawtimber volume: measured units	minimum dbh	minimum top diameter
1. Georgia-Pacific Plantation	unknown	cords[1]	unknown	unknown	bd ft Doyle[2] bd ft Int. ¼	unknown	unknown
2. Sudden Sawlog Plantation	varying	ft³	3.6 in.	3.0 in. dib	bd ft Doyle[2] bd ft Int. ¼	9.5 in.	.8 in. dib[3]
3. Hill Farm Plantation	1 ft	ft³ [4]	4.0 in.	4.0 in. dob	ft³ [4] bd ft Doyle[5] bd ft Int. ¼[5]	9.6 in.	7 in. dob
4. Methods of Thinning Study	varying	ft³	3.6 in.	3.0 in. dib	bd ft Doyle[2] bd ft Int. ¼	9.6 in.	8 in. dob or[3] merchantable
5. Method of Cutting Study	varying	ft³ (ib)	3.6 in.	3.5 in. dib	bd ft³ ib bd ft Doyle bd ft Int. ¼	11.0 in.	7.5 in. dib or merchantable
6. Poor Forty uneven-aged stand	varying	ft³ (ib)	3.6 in.	3.5 in. dib	bd ft³ ib bd ft Doyle bd ft Int. ¼	11.0 in.	7.5 in. dib or merchantable
7. Good Forty uneven-aged stand	varying	ft³ (ib)	3.6 in.	3.5 in. dib	ft³ ib bd ft Doyle bd ft Int. ¼	11.0 in.	7.5 in. dib or merchantable

[1] Cubic feet obtained by conversion, using 80 ft³/cord
[2] Cubic feet (sawtimber) obtained as total merchantable volume less pulpwood/tops volume
[3] Bole containing one or more 16 ft logs
[4] Determined by applying plantation loblolly pine taper functions and volume tables (Feduccia et al. 1979) to data published as mean dbh, mean total height, and no. of stems/ac.
[5] Determined by applying taper-function merchantable heights to board-foot volume equations (Murphy 1983).

used. Three of Burton's eight thinning intensities, having residual basal areas (RBA) of 100, 115, and 130 ft²/ac, were grouped as an intensive light-thinning prescription for these comparisons. The remainder (RBA 55, 70, 85, increasing RBA, and judgment RBA) were grouped as an intensive heavy-thinning prescription.

Study 5 is the Methods of Cutting Study, located on the Crossett Experimental Forest of the USDA Forest Service. Thirty-six-year yields from these stands were recently reported (Baker and Murphy 1982). The plots upon which the clearcutting system was used were harvested in 1943, and natural pine regeneration was released in 1946. No subsequent intermediate thinnings were made. The heavy seed-tree method consisted of a seed cut in 1943, a pine-release treatment in 1946, and seed-tree removal in 1958, with no other intermediate treatments. Yields for the seed-tree method were derived in two ways, either by including or excluding the production of the seed trees during the regeneration period. The absence of thinning classified these prescriptions as conventional applications of even-aged natural regeneration silviculture.

Uneven-Aged Natural Stands

The Methods of Cutting Study (Baker and Murphy 1982) also included two types of conventional uneven-aged systems—the classic selection method and the strict application of the diameter-limit method. Both stands were cut to their guiding diameter limits in 1943 and given a pine release treatment in 1946. In the diameter-limit stands, trees greater than 11.5 in. dbh were harvested in 1953, 1958, and 1968, with subsawtimber thinning in 1968. The selection stands were regulated using the volume-control, guiding-diameter-limit method of Reynolds (Farrar 1981, 1984) on a five-year cutting cycle; the last such cutting was in 1968. Yields from the application of these two uneven-aged systems typify conventional uneven-aged silvicultural systems.

Studies 6 and 7 are the Farm Forestry Good Forty and Poor Forty demonstration areas of the Crossett Experimental Forest (Reynolds et al. 1984, Baker 1986). Annual harvests were made during 30 of the first 31 years of management in these stands, and in the 36th year. Two sets of yield estimates were derived for each study. The first set is 36-year yields based on the AAY from year 0 to year 41 (the poorly regulated yields). The second set is 36-year yields derived from the AAY during the interval when the stands were well regulated (between 15 and 41 years). The frequent harvests in these stands are assumed to illustrate the intensive application of the selection system of uneven-aged silviculture.

RESULTS

Total Merchantable Yields After 36 Years of Management

The yield of total merchantable cubic volume at age 36 ranges from 3,000 to 6,000 ft³/ac (Table 3). The conventional even-aged plantations have the highest total merchantable yields (Figure 1), followed by the intensive even-aged natural stands and the intensive even-aged plantations. The stands with the lowest yields are the conventional even-aged and conventional uneven-aged natural stands.

These observations are consistent with prevailing silvicultural wisdom. Plantations are thought to be advantageous because of enhanced control of density and stocking. This effect is clearly reflected in the yields of the conventional plantations.

In addition, stand-level production is thought to be independent of stocking, at least within reasonable limits of overstocking and understocking, and as conditioned by not only merchantability standards but also intensity and frequency of thinning (Mar:Moller et al. 1954, Smith 1986). The judicious thinnings of the conventional plantations and the intensive even-aged natural stands allow redistribution of scarce resources to the best trees, concurrently salvaging incipient mortality. Conversely, stands such as the intensive plantations and the uneven-aged stands are deliberately understocked. In the Sudden Sawlog stand, understocking enhances the rapid growth of individual stems. In the uneven-aged stands, the goal is to allocate proportion of the growing space to submerchantable stock for long-term structural regulation. In both instances, the result is a reduction in total merchantable yield.

Sawtimber Yields After 36 Years of Management

Sawtimber cubic-volume yields range from 1,600 to 3,800 ft³/ac (Table 3). The highest yields are from the intensive plantations and the intensive, well-regulated, uneven-aged stands (Figure 1). The deliberate understocking in these stands resulted in enhanced volume growth on individual trees, which results in high per-acre yields of sawtimber. The uneven-aged stands have lower sawtimber basal areas than the intensive plantations. However, their broader range of diameters, extending into large sawtimber (>20 in. dbh), gives these stands their high yields.

International ¼" bd ft volume yields vary from 14,300 to 22,900 fbm/ac after 36 years (Table 3). As with cubic-volume sawtimber yields, the highest yields are from the intensive plantations and the intensive uneven-aged stands (Figure 2). Yields from the conventional plantations and the conventional uneven-aged stands are only slightly lower. The lowest yields are from the conventional even-aged stands.

Yields of board-foot volume using the Doyle scale range from 7,000 to 16,900 fbm/ac for the 36-year management interval (Table 3). The stands with the highest yields are the intensive uneven-aged stands (Figure 2); the

Table 3. Actual or projected yields/ac after 36 growing seasons for stands in this analysis. In even-aged stands, yields are based on MAI data for indicated age; in uneven-aged stands, yields are based on AAY data for indicated management interval (MI).

Stand	Age or MI (yr)	Yields at age 36: Total Merchantable ft³	Sawtimber ft³	Sawtimber bd.ft (Doyle)	bd.ft (Intl)
I. Even-aged plantations					
A. Conventional silviculture					
1. Georgia-Pacific Demonstration Plt.	36	6123	2694	10222	17328
2. Sudden Sawlog Study, control plots, USFS	36	5829	2708	10676	18009
B. Intensive silviculture					
1. Sudden Sawlog Study, thinned plots, USFS	36	4152	3187	15450	21026
2. Hill Farm Plantations					
a. one thinning (11)	36[1]	5625	3808	7380	16348
b. two thinnings (11, 29)	36[2]	5102	3469	10793	22463
II. Even-aged natural stands					
A. Conventional silviculture					
1. Clearcutting system MOC Study, USFS	36	3348	2115	9360	14328
2. Seed tree system, (excl. residual volume) MOC Study, USFS	36	3166	2113	9763	15035
3. Seed-tree system (incl. residual volume) MOC Study, USFS	36	4212	2636	13032	18018
B. Intensive silviculture					
1. Clearcutting system, light thinning MOT Study, USFS	36	5272	2155	7042	14644
2. Clearcutting system, heavy thinning MOT Study, USFS	36	5301	2235	8106	16095
III. Uneven-aged natural stands					
A. Conventional silviculture					
1. Diameter-limit system MOC study, USFS	0–36	3852	2861	11880	19368
2. Selection System, MOC Study, USFS	0–36	3024	2532	13572	17676
B. Intensive silviculture					
1. Poor Farm Forty, USFS					
a. poorly regulated	0–36[3]	4190	2851	14304	19800
b. well-regulated	15–36[4]	5054	3545	16916	22940
2. Good Farm Forty, USFS					
a. poorly regulated	0–36[3]	3404	2762	14850	19341
b. well-regulated	0–36[4]	3882	3009	15812	19583

[1] Based on extrapolation of MAI at year 29 to 36 years
[2] Based on MAI at year 34, plus extrapolation of PAI between years 29 and 34 to year 36
[3] Based on 36 years of AAY as determined between years 0 and 41 (poorly regulated structure).
[4] Based on 36 years of AAY as determined between year 15 and 41 (well regulated structure).

highest Doyle yield among the even-aged systems is from the intensively thinned plantation from the Sudden Sawlog Study. The two stands with the greatest yields are the well regulated Good Forty and the well regulated Poor Forty, respectively. Interestingly, the Doyle AAY of the Good Forty during its 15-year management initiation period (366 fbm Doyle/ac/yr) was higher than the 36-year MAI of all of the even-aged stands except the intensive Sudden Sawlog plantation. The stands with the lowest Doyle volume yields are the even-aged natural stands.

DISCUSSION

Higher total merchantable volume yields for the even-aged plantations and intensively managed even-aged natural stands in this study are not surprising and support traditional ideas about even-aged silvicultural systems. The clearcutting system using artificial regeneration has long been the method of choice for maximizing the yield of total merchantable volume. This is partly the result of administration and operational advantages and partly because of the biological characteristics of the stem exclusion or aggradation stages of stand development (Oliver 1981, Bormann

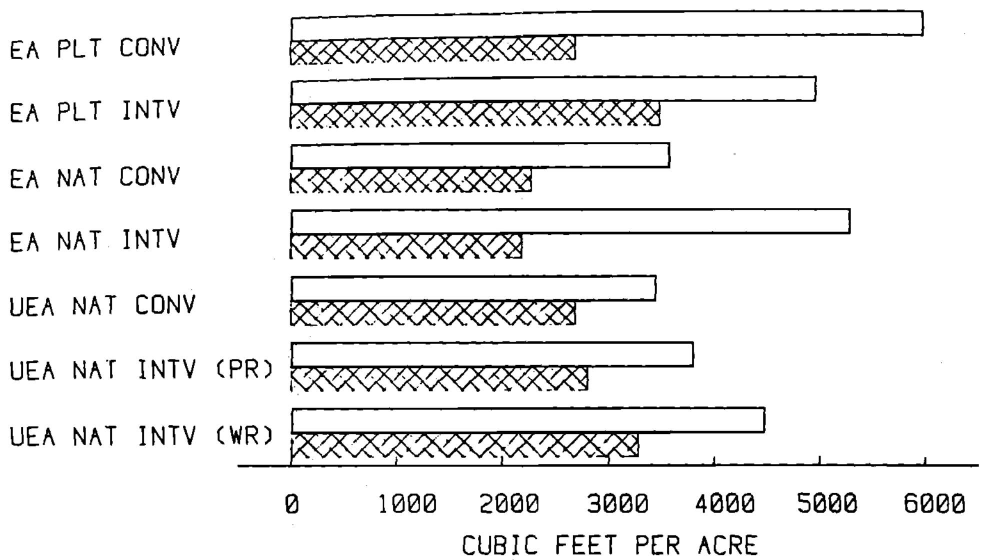

Figure 1. Total merchantable ft³ volume/ac (unshaded bars) and sawtimber ft³ volume/ac (shaded bars) at age 36 for 7 major silvicultural systems in the study. Systems are categorized as even-aged (EA) or uneven-aged (UEA), plantations (PLT) or natural stands (NAT), and managed conventionally (CONV) or intensively (INTV). Intensive uneven-aged systems are further categorized as poorly regulated (PR) or well-regulated (WR).

and Likens 1979), during which even-aged stands achieve the highest rates of production and biomass accumulation that occur during forest succession. Conversely, the selection system has rarely been credited with producing large total merchantable cubic volumes, a characteristic that is borne out by these yield observations.

The yield of sawtimber cubic volume after 36 years is roughly comparable between the even-aged plantations and the intensive uneven-aged stands. This might reflect an age-related transition in yields between the even-aged stands, with many stems in the small sawtimber classes, and the uneven-aged stands, with fewer

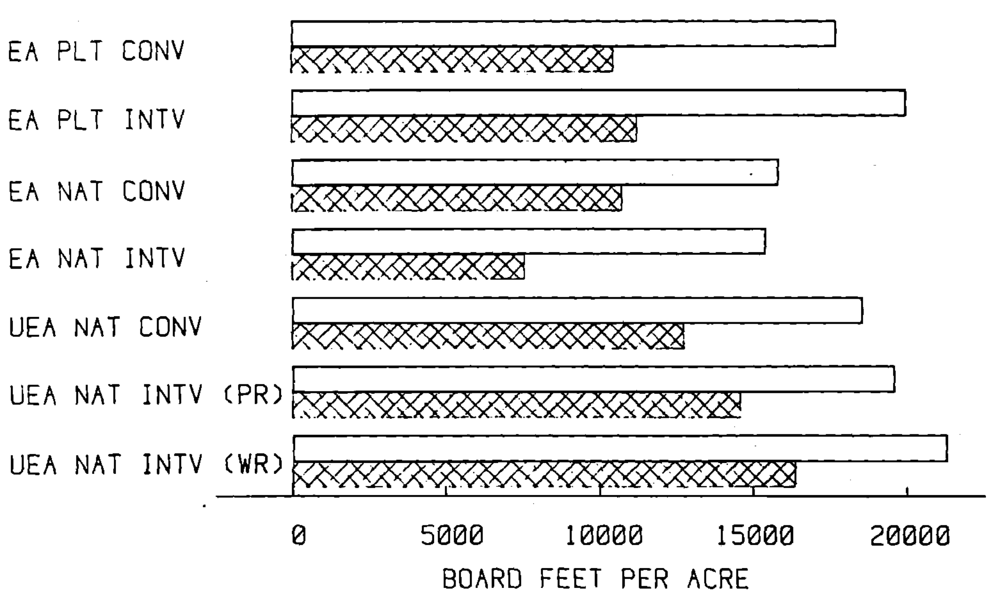

Figure 2. International ¼ in. bd ft volume/ac (unshaded bars) and Doyle bd ft volume/ac (shaded bars) at age 36 for 7 major silvicultural systems in the study. Systems are categorized as even-aged (EA) or uneven-aged (UEA), plantations (PLT) or natural stands (NAT), and managed conventionally (CONV) or intensively (INTV). Intensive uneven-aged systems are further categorized as poorly regulated (PR) or well regulated (WR).

though larger stems. As the even-aged stands continue to develop, their sawtimber cubic volume yields will no doubt exceed that of the uneven-aged stands.

In a similar way, the yield of International board-foot volume is roughly comparable between the even-aged plantations and the intensive uneven-aged stands. As noted above, the intensive thinning schedules of the even-aged stands promote the development of sawtimber. However, the consistency of sawtimber yields with time of the Good Forty, where an annual yield of 500 fbm/ac (International ¼-in. rule) was produced not only during the entire 41-year observation period but also the first 15 years of observation, is particularly noteworthy. The opportunity to quickly produce and sustain sawtimber yields from cutover stands is perhaps the major advantage of the selection system in this region.

The characteristic underscaling of small sawtimber with the Doyle rule, the legal rule in many southern states, is evident in these comparisons. The apparent superiority of uneven-aged silviculture for board-foot volume yields after 36 years, especially when reckoned with the Doyle rule, may be surprising to some silviculturists. This observation is most logically attributed to differences in relative tree size among the systems. Roughly two-thirds to three-quarters of the merchantable basal area in an uneven-aged stand is in sawtimber, a larger proportion than the average during an even-aged rotation (Farrar et al. 1984, Murphy 1983). Well-regulated uneven-aged stands have the unique ability to continously produce stems of large size (Assmann 1970, Schutz 1981). Though large sawtimber is a considerable investment to risk on the stump, it does allow for lower unit harvesting costs and for better lumber utilization, both in quantity and quality.

The comparatively low Doyle board-foot volume of the even-aged stands indicates that, at age 36, they are composed primarily of small sawtimber. If the even-aged plantations were allowed to develop for longer periods of time, their Doyle board-foot yields would probably exceed those of the uneven-aged stands. Also, a more rigorous thinning regime in stands such as the conventional even-aged natural stands would accelerate the development of larger trees.

It bears reiteration that these are comparative yield data from stands established as demonstration-type case studies rather than designed experiments. Assumptions have been made regarding site uniformity, similarity of merchantability specifications, and other aspects of data and system comparability. The 36-year management interval has been synthesized for some of the studies by interpolation or extrapolation. The results reported here, while based on perhaps the most comparable empirically derived growth and yield data available in the west Gulf region, should be regarded as indicative but not ultimately conclusive.

Nor should economic decisions be based on growth and yield data summarized here. Kellison and Gingrich (1984) suggested that plantation forestry practices generally have higher present net values than naturally regenerated stands for rotations of about 30 years. This comparative data set provides an opportunity to investigate the economic feasibility of longer rotation lengths or the comparative economics of even-aged and uneven-aged stands, but such analyses are beyond the scope of the mensurational comparisons which have been presented.

The plantations in this study were established with woods-run planting stock, before the establishment of the contemporary practice of planting improved seedling stock selected for gains in volume production. Augmenting the standing volumes of these plantations by 20% would widen the discrepancy in yield of total merchantable volume at age 36 between plantations and uneven-aged stands and would probably equalize some of the disparity in sawtimber cubic-foot and board-foot volume. In addition, cultural treatments to maximize plantation survival and growth will undoubtedly render plantation yields three decades hence that are higher than those used in this comparison.

But it is also logical to expect improvements to be made in our understanding of the dynamics of uneven-aged silviculture. Methods to objectively quantify subsawtimber and submerchantable classes and to efficiently regulate uneven-aged stands are currently being developed. There are certain advantages in taking loblolly-shortleaf pine stands that have been subject to past abuses, such as commercial clearcutting to a 5-in. or 10-in. dbh limit with no followup regeneration practices, and structuring them to produce between 270 and 360 fbm (Doyle) /ac/yr within 15 years and even higher yields after that, particularly of large sawtimber. The market flexibility, low out-of-pocket capital investment, and esthetic advantages of the system for the nonindustrial private landowner and for certain forest industries will continue to make such uneven-aged systems a feasible alternative in the repertoire of the silviculturist. □

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