EFFECTS OF PRECOMMERCIAL THINNING ON DIAMETER GROWTH IN YOUNG CENTRAL HARDWOOD STANDS[1/]

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Abstract.--Three young central hardwood stands that developed after clearcutting mature upland oak stands on good sites were each precommercially thinned one time in this study. Stand ages were 13, 17, and 21 years when thinning occurred. Yellow-poplar, red maple, and bigtooth aspen were the predominant species. Oak, black cherry, and white ash were also present. Thinning reduced stocking levels to approximately 70, 50, and 30 percent of normal. Due to varying rates of growth for different species, regression techniques were employed to analyze diameter growth rates 5 years after thinning. Thinning increased diameter growth at all ages and residual stocking levels. The heavier the thinning, the greater the response. The magnitude of the response, however, was progressively greater with increasing stand age, suggesting that precommercial thinnings be delayed until age 20. The resulting regression analysis can be used as a short-term individual-tree diameter growth model for young, mixed species, central hardwood stands growing on good sites.

Although many cultural treatments must be considered for the management of young central hardwood stands, precommercial thinnings should have the most potential for influencing tree and stand growth and yield. Thinnings can be made with crop-tree release techniques or with area-wide thinnings to specified density levels. Both methods have advantages and disadvantages. Crop-tree release is much less expensive to apply in the field because fewer trees must be thinned. However, guidelines are difficult to establish due to the numerous factors affecting release, such as: (1) the number of trees to release per acre, (2) the number of sides of the crown to release, and (3) the distance from crop tree to its nearest competitor. Area-wide thinnings are more expensive because all trees except those composing the specified relative density must be thinned. However, guidelines are developed more readily because tree and stand responses can be associated with only one variable--relative stand density.

Smith and Lamson (1983) and Erdmann (1983) provide excellent reviews of the literature for precommercial thinning in hardwood stands. Regardless of the method of thinning used, tree and stand responses to precommercial thinning have not been consistently positive in hardwood stands. Since some of this inconsistency can be attributed to the different species, ages, and treatments under investigation, it appears that more research results are required before firm conclusions can be reached regarding precommercial thinning.

In this paper we examine the effects of area-wide precommercial thinnings on individual-tree diameter growth rates in young central hardwood stands. Bailey (1984) discussed stand growth and yield responses for the same study area. Since thinning treatments were applied to stands with three different ages, we were able to investigate responses to both the timing (age) and intensity (treatment) of precommercial thinnings.

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DATA

The study was established in 1976 in 13-, 17-, and 21-year-old, even-aged central hardwood stands on the Vinton Furnace Experimental Forest in southeastern Ohio. The stands originated after complete clearcuttings of 100-year-old upland oak stands that were primarily black, scarlet, chestnut, and white oaks. All three stands are located on well-drained north-facing slopes. Site index on these slopes is very good for this geographic region, ranging from 70 to 80 according to Schnur's (1937) site index curves for black oak.

Species composition of the three stands is typical for regeneration on good sites in the region. Yellow-poplar[3/], red maple, and bigtooth aspen tend to dominate these better sites. A fair amount of black cherry and white ash can also be expected. Oak continues to maintain a presence on the better sites, though in substantially fewer numbers than were in the mature stands that were harvested. Oaks, maples, and hickories originate primarily from stump sprouts and advanced regeneration. Yellow-poplar, aspen, cherry, and ash originate primarily from seed.

Precommercial thinnings were made on an area-wide basis on plots that were either 0.5 or 0.6 acre in size (Table 1). A 1/2-chain-wide isolation strip surrounded each plot. Thinning treatments reduced plot and isolation strip relative density levels to 30-, 50-, and 60-percent stocking in the 13-year-old stand, 30-, 45-, and 60-percent stocking in the 17-year-old stands, and 30-, 50-, and 70-percent stocking in the 21-year-old stands. Control (100 percent) plots were not thinned. Percent stocking was based on Gingrich's (1967) tree-area-ratio equation:

$$\text{Tree-area (milacres)} = -.0507\ N + .1698\ \Sigma D + .0317\ \Sigma D^2,$$

where N = number of trees and D = diameter at breast height (dbh). Solving this equation for N = 1 and D = any given diameter defines the tree-area requirements for that size tree. A stand with 1,000 milacres of tree-area per acre is 100 percent stocked. All trees larger than 0.5 inches dbh were used in the stocking calculations because the 13-year-old stand contained only a small percentage of trees greater than 3.5 inches dbh.

[3/] See Little (1979) for scientific names of all species referred to in this paper.

Table 1.--Acreages, number of trees per acre, and basal areas per acre after thinning in 1976 (includes all trees greater than 0.5 inch dbh)

Stand age	Treatment	No. acres	No. trees in 1976	Basal area in 1976
Years	Percent stocking			Square feet
13	30	0.6	339	24.3
13	50	.6	732	37.0
13	60	.6	1004	40.4
13	100	.6	3353	58.2
17	30	.5	198	28.7
17	45	.5	422	41.7
17	60	.5	516	52.2
17	100	.5	2228	75.9
21	30	.6	154	29.2
21	50	.5	366	43.2
21	70	.6	539	61.8
21	100	.5	1926	91.4

Each age x treatment plot was divided into 0.1-acre subplots for application of the thinning treatment. This technique assures that the residual density is distributed evenly over the entire 0.5- or 0.6-acre plot. The thinning method used is best described as "free"--the marker was free to removed trees from all crown classes. The objective was to leave the best trees as evenly spaced as possible throughout the subplot. Within this framework, noncommercial species such as dogwood, sourwood, and sassafras, commercial species in the lower crown classes, and larger trees with stem deformities (forks, crook, and sweep) were removed first. Some of these less desirable trees had to be left to achieve uniform spacing. The numbers of trees and basal areas after thinning are listed in Table 1.

Dbh was recorded for all trees greater than 0.5 inch for thinning purposes only. Thereafter, dbh was recorded annually to the nearest 0.1 inch only for those trees that were initially greater than 3.5 inches. These trees were numbered to assure proper identity at the time of remeasurement. Measurements for the 5-year period following thinning were available for analysis.

ANALYSIS

Analysis of mixed species stands is complicated because the species span the full range of growth rates and tolerance. Some of the growth differences due to species competition can be attributed to site. For example, this study was established on sites where oaks have difficulty competing with faster-growing species such as yellow-poplar and aspen. On poorer sites the opposite situation may exist. Yellow-poplar is likely to exhibit slower growth rates and even increased mortality rates due to the lack of moisture, whereas oak does well on these sites (Hilt 1985). The reader is reminded that the analysis and results of this study pertain only to good sites (black oak site index 70 and better).

An even more disconcerting aspect of analyzing mixed species stands is the failure of all species to be distributed uniformly across the study area. Inspection of Table 2 illustrates this point. Some treatments are dominated by yellow-poplar, some by maple, and so on. Uneven spatial distributions of species is a fact of nature that we must live with. In fact, it is probably the main reason why thinnings usually fail to alter species composition substantially--desirable trees just are not located exactly where we want them to be! Nevertheless, we believe that the procedures we have selected for analysis reveal the most important trends and isolate the most significant responses to thinning.

Treatments were not replicated within each age group because suitable study areas with appropriate acreages were not available. The 0.1-acre subplots could possibly have been utilized as replications for the analysis, but the subplots are more representative of subdivisions rather than replications. Instead, the individual-trees were considered as the experimental units. We assume that the relative density for the treatment is the same around each tree. This procedure is realistic because most studies that deal with individual-tree characteristics such as dbh, height, or grade usually pool individual-tree data, even if replication exists.

Individual trees were placed into one of six species groups for analysis: (1) oaks, (2) yellow-poplar, (3) maples, (4) aspen, (5) other commercial species, and (6) noncommercial species. Grouping was based on species growth characteristics and availability of data (numbers of trees). Periodic annual diameter growth rates were then computed for the 1767 trees greater than 3.5 inches dbh (Table 2) that survived the 5-year study period, i.e., trees alive in both 1976 and 1981.

Table 2.--Number of trees per acre and species composition of survivor trees greater than 3.5 inches dbh

Stand age	Treatment	Number of trees	Species					
			Oaks	Yellow-poplar	Maple 1/	Bigtooth aspen	Other 2/ commercial	Non-3/ commercial
Years	Percent stocking		Percent of trees					
13	30	116	15	21	9	9	43	3
13	50	185	7	46	11	9	25	2
13	60	239	26	1	41	15	8	9
13	100	90	15	21	27	10	16	11
17	30	93	3	61	16	0	20	0
17	45	129	2	19	37	0	40	2
17	60	189	1	37	34	0	27	1
17	100	137	6	29	23	0	34	8
21	30	89	24	26	40	8	2	0
21	50	134	36	3	29	30	2	0
21	70	172	30	21	22	25	2	0
21	100	194	10	13	58	14	4	1
Total		1767						

1/Primarily red maple, some sugar maple.
2/Black cherry, white ash, some hickory.
3/Dogwood, sourwood, sassafras.

Two-way analysis of covariance tests were first run separately for each of the three stands. Treatment and species group were the two factors, and dbh was the covariant. While species was recognized as a major factor, the main purpose of these tests was simply to determine if treatment was significant, and if so, at what age. The magnitude of the treatment effects is best revealed through regression techniques.

Data from all three stands were pooled for the stepwise regression analysis. Periodic annual diameter growth was the dependent variable. Independent variables included: (1) dbh, (2) stand age (AGE), (3) treatment (TMT), i.e., percent stocking (4) five dummy variables representing species groups 2-6, and (5) the 39 possible interaction terms for these variables. Dummy variables have a value of 1 if the tree is that species, 0 otherwise. Dummies measure the difference in diameter growth response for that species group from the mean response for the first species group, in this case, oak. Five other independent variables were included in the analysis to account for the possibility of nonlinear treatment responses: TMT/AGE, DBH*TMT*TMT, AGE*TMT*TMT, AGE*LN(TMT), and DBH*LN(TMT). LN is the natural logarithm. This stepwise procedure is similar to the screening methods proposed by Gujarati (1970).

While regression techniques that include dbh account for much of the dbh effect, we also used only the largest 40 trees per acre (Table 3) for the same regression analysis. The largest 40 trees per acre is commensurate with the European standard of 100 trees per hectare. It is important to use a fixed number of trees when analyzing individual-tree characteristics (Hilt 1979; Smith 1962; Adams and Chapman 1942). To ensure that the largest trees were distributed evenly over the plot and not all clustered in one area of exceptional site, we used the largest four trees per 0.1-acre subplot. We also plotted the growth rates of some of these larger trees on an annual basis to determine when the effects of thinning are most prevalent, and when they begin to subside.

RESULTS

All Survivors

Average periodic annual diameter growth rates are plotted over dbh in Figure 1 for two treatments in three age classes. Averages were computed by 1-inch dbh classes for plotting purposes only. While species is not considered in Figure 1, several important trends can be recognized. First, the main purpose of presenting Figure 1 was to reveal the linear relationship between diameter growth and dbh. Dbh must be included as a covariate in any analysis of diameter growth. Second, the younger the stand, the greater the dbh growth for a specified dbh x treatment category. Third, the increase in diameter growth due to

Table 3.—Species composition of the 40 largest survivor trees per acre

Stand age	Treatment	Species					
		Oaks	Yellow-poplar	Maple[1/]	Bigtooth aspen	Other[2/] commercial	Non-[3/] commercial
Years	Percent stocking	Percent of largest 40 trees per acre					
13	30	4	50	13	4	29	0
13	50	0	67	4	4	25	0
13	60	55	0	33	8	4	0
13	100	21	29	25	4	17	4
17	30	5	45	10	0	40	0
17	45	0	35	25	0	40	0
17	60	0	25	15	0	60	0
17	100	10	40	30	0	20	0
21	30	25	37	13	25	0	0
21	50	10	5	5	80	0	0
21	70	17	17	4	56	4	0
21	100	6	13	0	68	13	0

1/Primarily red maple, some sugar maple.
2/Black cherry, white ash, some hickory.
3/Dogwood, sourwood, sassafras.

treatment appears to be larger in the older age classes. The faster growth rates exhibited by the 30-percent treatment in the 17-year-old stand is most likely due to the abundance of yellow-poplar on this plot (Table 2).

Results of the analysis of covariance tests for each stand are shown in Table 4. The importance of these tests is that they consider the significance of treatment responses by age classes. Regression analyses address only the magnitude of the responses in relation to age. Treatment x species interaction terms are significant at the α=0.05 level in the 13- and 17-year old stands. This result indicates that treatment is significant, depending on the species. Since the interaction term is significant, main effect terms are not meaningful (Neter and Wasserman 1974). The interaction term is not significant in the 21-year-old stand, so we can look at the main

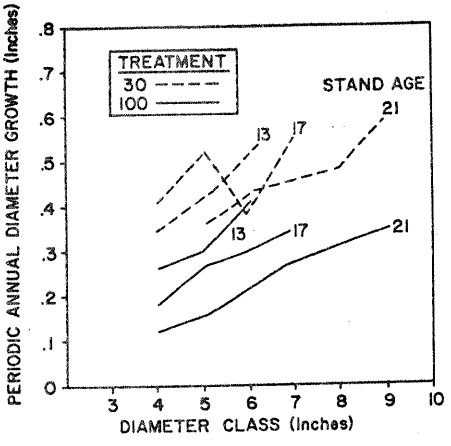

Figure 1.--Relationship between periodic annual diameter growth and dbh for two treatments in three age classes for all survivor trees greater than 3.5 inches dbh.

Table 4.--Analysis of covariance tables for each age class; treatment (TMT) and species are the two factors being tested, DBH is the covariate; periodic annual diameter growth is the response variable being tested

Stand age	Source of variation	DF	F-value	PROB>F
Years				
13	DBH	1	186.2	0.001
	SPECIES	5	91.4	.001
	TMT	3	18.6	.001
	TMT*SPECIES	15	6.4	.001
17	DBH	1	161.8	0.001
	SPECIES	5	122.1	.001
	TMT	3	2.5	.062
	TMT*SPECIES	15	1.9	.037
21	DBH	1	279.4	0.001
	SPECIES	5	37.9	.001
	TMT	3	41.0	.001
	TMT*SPECIES	15	1.6	.09

effects. Both treatment and species are significant.

We conclude that thinning significantly increases diameter growth, regardless of stand age. However, the significance of the effect may be dependent on species. We now turn our attention to regression analysis to reveal more specific age, treatment, and species effects.

Results of the stepwise regression screening for all trees are presented in Table 5. Based on the trends illustrated in Figure 1, dbh was always designated as an included variable in the regression. While considerably more variables met the 0.01 significance level of entry, adding these variables did little to increase the overall R-square value.

Table 5.--Results of the stepwise regression analysis for all survivors greater than 3.5 inches dbh; dependent variable is periodic annual diameter growth

Independent variable to enter	DF	Reduction in sums of square	F to enter	Prob>F	Cumulative R-square	Regression coefficient
Intercept	1					0.204777
DBH	1	7.2	561	0.01	0.13	.050632
YELLOW-POPLAR	1	11.3	877	.01	.33	.237960
AGE*TMT	1	7.1	551	.01	.46	-.000403
ASPEN	1	2.9	223	.01	.51	.196134
MAPLE	1	3.2	247	.01	.57	.111849
AGE*TMT*TMT	1	1.4	109	.01	.59	.00000211
Total	1767					

After dbh was included, the added effect of yellow-poplar (YP) entered as the most significant variable. This result indicates that species--simply being a yellow-poplar or not--has more effect on diameter growth than any other factor. Treatment followed as the next most significant variable, but entered as an interaction term with age. Treatment effects, therefore, depend on stand age. The added effects of aspen and maple entered next, and, again, indicate the effects of species on diameter growth. The final term, AGE*TMT*TMT, indicates that diameter growth is not a linear function of treatment.

Results of the regression analysis can be written more succintly in equation form:

$$\begin{aligned} DGROW = &+ 0.204777 + 0.050632(DBH) \\ &+ 0.237960(YP) - 0.000403(AGE*TMT) \\ &+ 0.196134(ASPEN) + 0.111849(MAPLE) \\ &+ 0.00000211(AGE*TMT*TMT) \end{aligned} \quad (1)$$

The dummy variables, YP, ASPEN, and MAPLE, are assigned a value of 1 if the tree is one of those species, respectively. Otherwise, the dummy variables are assigned a value of 0. The root mean square error was 0.1135. The R-square value of 0.59 was increased to 0.70 when we used tree basal-area growth rates and tree basal areas rather than diameter growth and dbh (results not shown). This increase in R-square is somewhat artificial (West 1980), but in our opinion approaches the maximum we can expect for mixed species stands of varying ages.

Treatment effects are shown in Figure 2 for yellow-poplar at ages 13 and 21, and for oak at age 21. Careful inspection of this figure illustrates our major study results for all survivor trees greater than 3.5 inches dbh: (1) species has a major effect on diameter growth, (2) diameter growth is greater in younger stands for a given dbh and relative density, (3) treatment effects are larger in the older stands, and (4) treatment effects are not linear on treatment, i.e., diameter growth differences between 30 and 50 percent stocking are larger than differences between 80 and 100 percent stocking. Also, the earlier analysis of covariance indicates that treatment is significant even for the smaller effects indicated at age 13 (however, the treatment x species interaction terms revealed by the covariance analysis were not significant for the pooled data).

Equation (1) can be used as an individual-tree diameter growth prediction model for young mixed species stands growing on good sites. However, some caution should be exercised if the model is applied to stands that have different species composition than those in this study. Also, a model to estimate mortality is almost essential for growth projections in these young stands.

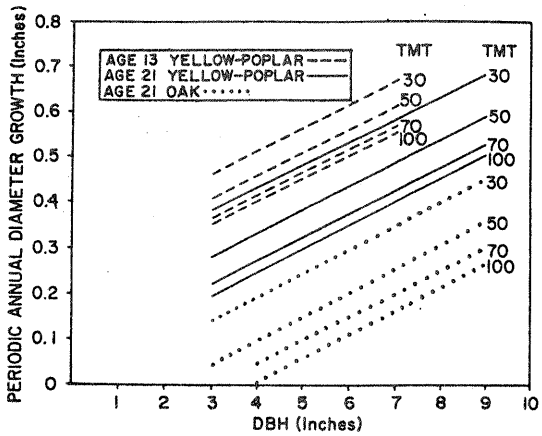

Figure 2.--Treatment, species, age, and dbh effects on diameter growth for all survivor trees greater than 3.5 inches dbh.

Largest 40 Trees Per Acre

Results of the stepwise regression analysis for the largest 40 trees per acre were similar to the results for all trees. The fitted equation,

$$\begin{aligned} DGROW = &\ 0.465016 + 0.025219(DBH) \\ &+ 0.279306(YP) + 0.272608(ASPEN) \\ &+ 0.007403(MAPLE*AGE) \\ &- 0.005502(AGE*LN(TMT)) \end{aligned} \quad (2)$$

had an R-square of 0.66 and a root mean square error of 0.099.

Species was the major factor affecting diameter growth of the larger trees. The added effects due to yellow-poplar and aspen were the first two variables to enter the equation. Their nearly identical regression coefficients indicates that differences between these two species are inconsequential. The third term to enter, AGE*LN(TMT), indicates that diameter growth responses depend on age and are nonlinear with respect to treatment. The final term to enter the equation was MAPLE*AGE. This term indicates that the species effect due to maple is significant, but depends on age.

Equation (2) is plotted in Figure 3 for yellow-poplar and oak. Species effects on diameter growth are apparent even for these larger trees. Treatment effects are still larger for older stands. However, as expected, differences between treatments are not as pronounced for the larger trees as they were for all trees.

Equation (2) should <u>not</u> be used as a prediction equation because it was developed from a selected data base.

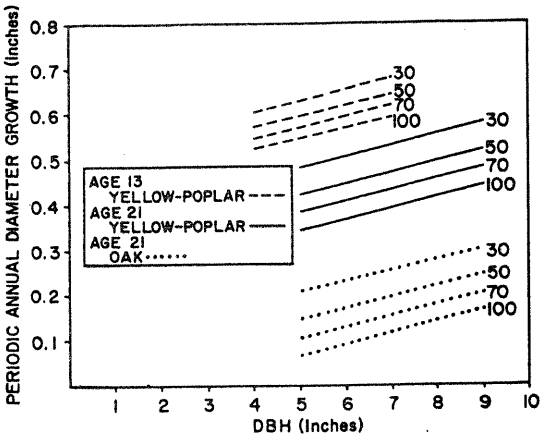

Figure 3.--Treatment, species, age, and dbh effects on diameter growth for largest 40 survivor trees per acre.

Growth Trends Over Time

Diameter growth rates in each of the 5 years of the study are plotted in Figure 4. We used only those species that had sufficient observations for tracking purposes: yellow-poplar in the 13- and 17 year-old stands, and aspen in the 21-year-old stand. Prestudy growth rates were not available. Conclusions from this substantially reduced data base should be made with extreme caution.

While reliable weather records were not available, fluctuations possibly attributable to weather are apparent in Figure 4. Many treatments exhibited sharp declines in growth during the third and fifth growing seasons. A sharp increase in growth is apparent for many treatments during the fourth growing season.

The crossing of the lines is indicative of natural variation and is inevitable in any growth study. We venture to make only one observation regarding these graphs: diameter growth response due to thinning begins the first year after thinning. Other statements regarding the duration of these effects cannot be made with certainty from these graphs.

DISCUSSION

Results of this study show that area-wide precommercial thinnings increase diameter growth significantly. However, the magnitude of the response increases with stand age. We have found the opposite trend to be true when 30- to 100-year-old upland oak stands are thinned the same way--diameter growth response due to thinning is greater in the younger stands (Hilt 1983). Although we are comparing study results for different species composition, one might

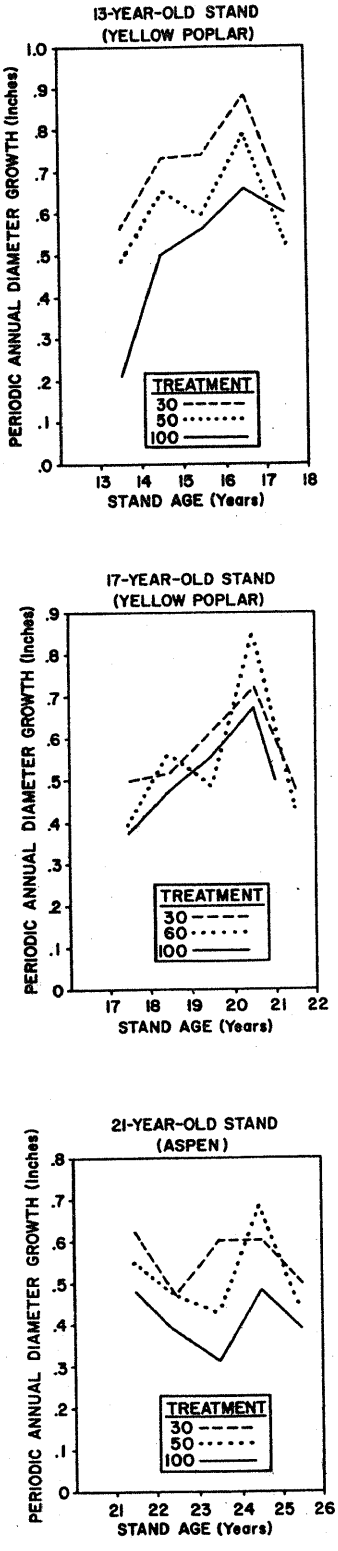

Figure 4.--Diameter growth of selected species plotted over time (age) for all three age classes.

suspect that the effects of area-wide thinning on diameter growth are somewhat marginal at very young ages, peak around 20 to 30 years of age, then begin to slowly drop off--all the while significant, however. This notion is supported by the nonsignificant thinning effects we reported for neighboring mixed species stands thinned on an area-wide basis at age 8 (Hilt and Dale 1982).

The effects of thinning on diameter growth in this study were found to be nonlinear with respect to treatment. Inspection of Figure 2 reveals that for a 6-inch, 21-year-old, yellow-poplar tree, the difference in diameter growth between the 30- and 50-percent treatments is 0.1 inch, while the difference between the 50-percent and 70-percent treatments is only 0.07 inch. Although responses in upland oak stands are not of this magnitude, we have found similar trends for upland oaks (Hilt 1983; Dale 1975). We attribute the nonlinear treatment effect to the fact that trees are nearly open grown at 30-percent stocking--crowns receive light not only from all sides, but also all day long. Also, stands take a much longer time to close when thinned to very low densities. Trees begin to be affected by competing trees over a 5-year study period even at 50-percent stocking.

Based only on this report, forest land managers would probably opt for the 30-percent treatment. Growth rates are increased 50 to 100 percent, depending on the dbh and species. However, before thinning, three additional factors must be considered: (1) the effects of thinning on stand growth, (2) the effects of thinning on tree quality, and (3) the costs of thinning. Bailey (1984) showed that total stand basal-area growth was reduced at the 30-percent stocking level. Sonderman (1984, 1985, 1986) found that individual-tree quality generally deteriorated in these same stands if thinning reduced the relative density below 50 to 60 percent. Trees on heavily thinned plots develop epicormic branches that later become live limbs since natural pruning is retarded at low densities. And although we do not have any reliable cost data for area-wide precommercial thinnings, costs certainly increase with heavier thinnings in young stands because substantially more trees must be cut.

Considering all of these factors, at this point in time if forest managers are even considering precommercial thinning in young central hardwood stands, we would recommend thinning to the 50 to 60 percent stocking level. Thinnings delayed until age 20 would achieve maximum responses. However, the question of whether or not to even apply precommercial thinnings cannot be answered untillong-term results become available. For example, the 5-year results of this study may soon dissipate if thinnings are not repeated. And since precommercial thinnings are costly investments, later economic returns must be considerable before precommercial thinning can be recommended as a viable management practice.

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