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DIAMETER GROWTH OF UPLAND OAKS AFTER THINNING

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Abstract

Diameter growth rates of the 40 largest trees per acre on 154 permanent plots in Kentucky, Ohio, Missouri, and Iowa were analyzed to determine the effects of thinning in upland oak stands. The plots were established over a wide range of stocking levels, stand age, and site conditions. Thinning resulted in increased diameter growth of the residual trees, regardless of age or site. The heavier the thinning, the greater the response. Diameter growth rates, and growth response after thinning relative to a control, were better in younger stands. Growth rates were higher on better sites, but the growth response relative to a control was not influenced much by site. In most instances the largest 40 trees per acre responded as well or better to thinning than the second 40 largest.

INTRODUCTION

THE MOST EXTENSIVE HARDWOOD timber type in the United States is the upland oak forest type—nearly 116 million acres, or about one-quarter of the commercial forest land is occupied by this forest type. A series of studies was begun in 1949 to estimate growth and yield from this timber type for a range of stocking levels. The studies were designed to help forest-land managers resolve the many questions about growth response in managed upland oak stands. An evaluation of these thinning studies is not complete without considering the sizes of the trees produced rather than only the volume they represent. The purpose of this paper is to determine the effects of thinning on the diameter growth rates of the residual trees.

The studies were established in different geographical areas, and the diameter growth rates reported in this paper cover a wide range of stocking levels, stand age, and site conditions. The results of thinning experiments over a narrower range of conditions have been reported for the upland oak type. Dale (1968) found that 25- to 33-year-old stands in Kentucky and Iowa responded well to thinning. Trees growing in heavily thinned areas grew almost twice as fast in diameter as those at maximum stocking, and those in medium-stocked areas grew 35 to 70 percent more. Minckler (1957) reported that pole-size white oak trees released from overhead shade grew 46 percent faster in diameter than the unreleased trees. The age of the trees, 35 to 100 years, did not influence the response to release. Formerly fast-growing trees showed no differences in diameter growth between sites, but formerly slow-growing trees grew 27 percent faster on better sites.

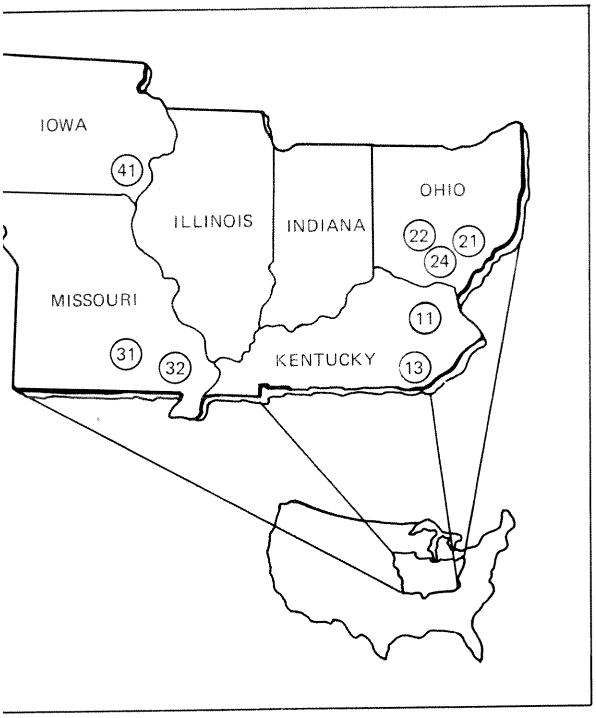
STUDY AREAS

Data from eight growth and yield studies from Kentucky, Ohio, Missouri, and Iowa were used to determine diameter growth rates (Fig. 1 and Table 1). There were 154 permanent plots in the analysis. The objectives, methods of treatment, and criteria for plot selection were about the same for all study areas.

All plots were initially located in fully stocked, even-aged upland oak stands that showed little evidence of recent logging or natural disturbances. Plot sizes ranged from 0.2 acre (0.081 ha) for study area 41 to 1.0 acre (0.405 ha) for study area 13.

Detailed measurements of at least 10 sample trees per plot provided age and site information. The site index for each plot was determined from Schnur's (1937) site index curves for upland oaks. The index ranged from an average of 59 for study area 41 to 73 for study areas 21 and 22. There was a wide range in stand age among the study areas—from age 24 in area 31 to age 80 in area 13.

Figure 1.—Location of the study plots.



Species composition of the largest trees varied mostly between states. The trees in the Kentucky study were primarily white oak; in Missouri, black oak; and in Ohio, a mixture of scarlet and black oak. The Iowa study area had 58 percent white oak and 38 percent black oak.

All plots were thinned in 1961 or 1962 except those in study area 13, which were thinned in 1959. Plots in area 41 were first thinned in 1949, but received a second thinning in 1961. The thinning method is best described as "free"—the marker was free to remove trees from all crown classes. The objective was to leave a suitable number of the best trees as evenly spaced as possible throughout the plot. An isolation strip around each plot was also thinned.

The degree of thinning was controlled by reducing the basal area or the stocking level (Gingrich 1967) to the desired percentage. Cutting varied from very light or none to 70 or 80 percent of the original basal area (Figs. 2a through 2c).

Table 1.—Characteristics of study areas used to analyze diameter growth rates of 40 largest trees per acre

Study	Location	No. of plots	Plot size (acres)	Date thinned	Initial average age (years)	Average site index	Growth period analyzed	Species composition of 40 largest trees per acre		
								White oak	Black and scarlet oak	Other
								Percent		
11	Kentucky	23	.5	1961	34	70	1962-1968	73	23	4
			.25	1962						
13	Kentucky	12	1.0	1959	80	64	1962-1968	89	5	6
21	Ohio	16	.5	1961	33	73	1962-1968	9	84	7
22	Ohio	6	.25	1961	51	73	1963-1968	3	97	0
24	Ohio	15	.5	1961	61	64	1962-1968	25	75	0
31	Missouri	24	.5	1962	24	71	1962-1967	2	98	0
		10	.5	1962	25	63	1962-1967	4	96	0
32	Missouri	14	.5	1961	43	70	1961-1967	5	94	1
		14	.5	1961	40	61	1961-1967	3	96	1
41	Iowa	20	.2	1961[a]	37	59	1961-1968	58	38	4

[a]This was the second thinning for study area 41. The first thinning was made in 1949 at age 25.

Figure 2a.—Plot 9 on Kentucky study 11, age 33. Stocking was reduced to 37.13 percent.

Figure 2b.—Plot 9 on Ohio study 24, age 55. Unthinned plot was 94.22 percent stocked.

Figure 2c.—Plot 1 on Kentucky study 13, age 81. Thinned to 58.36 percent stocking.

METHODS

The differences in diameter growth rates of thinned and unthinned stands are often tested by comparing the diameters of the trees of average basal area (quadratic mean dbh). This method is appropriate if the comparisons are made between the average diameter of *equal* numbers of crop trees per acre (Adams and Chapman 1942; Smith 1962). If the numbers of trees are not equal, there may be serious distortions in the comparisons. For this reason I have used the equivalent of the 40 largest surviving trees per acre from each plot for comparisons. The 40 largest trees per acre is commensurate with the European standard of 100 trees per ha. The development of these larger trees is important because they will most likely constitute a large portion of the final harvest volume.

A total of 5,880 trees from the 154 plots were used to determine diameter growth rates. The number of trees in each plot used in the analysis depended on the plot size. For example, for a 1.0-acre plot, it was the 40 largest trees; for a 0.2-acre plot, only the 8 largest trees.

Measurements were not taken in all study areas at the same time. Those measurements taken near the time of the 1962-1968 period were used in the analysis. A measurement period common to all the areas is desirable so that effects of weather can be minimized in the analysis. Data for a 6-year growth period were available for most areas, but only a 5-year period for three areas, and a 7-year period for the Iowa area (Table 1).

The trees in the Kentucky and Ohio plots were remeasured as recently as 1977. Although it would be desirable to study diameter growth over a longer period, the difference in thinning schedules for the various studies precluded the use of the additional data.

For analysis, the experimental plots were categorized by percent stocking. Only those trees $\geq$2.6 inches in diameter at breast height (dbh) were used in calculating plot stocking. I used percent stocking because it expresses the same relative degree of site occupancy, regardless of age or site. Stocking categories used were 0-31, 32-45, 46-55, 66-80, and 80+ percent. These levels resulted in a balanced distribution of plots among stocking levels within a study area. Though there were light thinnings on some of the plots at the very high stocking level, these plots approach normal conditions and serve as controls.

Diameter growth rates were also categorized by site index. Site index 65 was arbitrarily selected as the dividing line between poor-medium and medium-good sites. The objective for a given study was to establish all plots on similar sites. Therefore, the average site index for the study area is the site index category. This average reflects the general situation on the ground, but a few plots on a given area may have had a site index greater than 65 while the remainder had a site index less than 65, or vice versa. Sample plots on the Missouri study areas were deliberately established on both good and poor sites, and the data were categorized accordingly.

There was no breakdown of data by species. Species composition was consistently one major oak species within a study area (Table 1).

RESULTS

The periodic annual diameter growth rates are shown in Tables 2a and 2b for each of the eight studies. The breakdown of the data into age × stocking × site categories resulted in a considerable number of empty cells. Therefore, no statistical analyses were performed. However, the actual diameter growth rates for this wide range of stocking levels, stand age, and site index provide meaningful information about the factors that influence diameter growth in managed stands of upland oaks.

Stocking. The effects of stocking on diameter growth should be judged from the growth rates within a given age (study area) and site category. Direct comparisons between stocking levels within an area should be made with caution because of unequal sample sizes. For example, the diameter growth on the poor-medium site on study 32 increased by 100 percent from 0.13 inch on the very high stocking level to 0.26 inch on the very low stocking level (Table 2b). However, six plots were

Table 2a.—Periodic annual diameter growth rates of 40 largest and second 40 largest trees per acre, average site index >65, by stocking level

Percent stocking	N[a]	Avg. basal area (ft²/acre)	Avg. s.p.[b]	Initial avg. dbh[c]		Periodic annual/ dbh growth	
				40 largest trees	Second 40 trees	40 largest trees	Second 40 trees
				inches			
STUDY 31, MISSOURI (24 plots, avg. age 23.5)							
Very low (0-31)	160	24.68	29.39	6.08	4.98	0.34	0.31
Low (32-45)	20	32.11	43.67	5.26	4.34	0.26	0.24
Medium (46-65)	180	40.58	48.45	6.24	5.12	0.27	0.23
High (66-80)	100	59.93	72.22	6.69	5.75	0.23	0.20
Very high (80+)	20	63.37	80.97	6.13	5.31	0.19	0.17
STUDY 21, OHIO (16 plots, avg. age 32.5)							
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	80	39.74	41.82	7.86	6.36	0.21	0.17
Medium (46-65)	160	51.45	56.40	7.86	6.48	0.15	0.13
High (66-80)	60	66.47	74.01	7.95	6.68	0.16	0.12
Very high (80+)	20	79.95	89.83	8.41	7.12	0.15	0.13
STUDY 11, KENTUCKY (23 plots, avg. age 34.0)							
Very low (0-31)	70	18.82	21.98	6.01	4.91	0.32	0.29
Low (32-45)	130	31.74	37.90	6.29	5.27	0.25	0.24
Medium (46-65)	60	47.52	56.29	6.70	5.74	0.25	0.19
High (66-80)	80	64.24	77.37	7.21	5.68	0.20	0.17
Very high (80+)	40	71.21	87.67	7.16	5.79	0.21	0.17

Continued

Table 2a.—Continued

Percent stocking	N[a]	Avg. basal area (ft²/acre)	Avg. s.p.[b]	Initial avg. dbh[c] 40 largest trees	Initial avg. dbh[c] Second 40 trees	Periodic annual/ dbh growth 40 largest trees	Periodic annual/ dbh growth Second 40 trees
				inches			
			STUDY 32, MISSOURI (14 plots, avg. age 43.4)				
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	—	—	—	—	—	—	—
Medium (46-65)	140	53.12	50.07	9.92	8.24	0.17	0.16
High (66-80)	100	69.65	67.69	9.98	8.36	0.16	0.13
Very high (80+)	40	89.61	86.62	11.10	8.94	0.14	0.12
			STUDY 22, OHIO (6 plots, avg. age 51.2)				
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	—	—	—	—	—	—	—
Medium (46-65)	60	68.94	63.86	10.73	8.80	0.16	0.13
High (66-80)	—	—	—	—	—	—	—
Very high (80+)	—	—	—	—	—	—	—

[a]Number of 40 largest trees per acre used to compute growth rates.
[b]Initial average stocking percent (s.p.).
[c]Diameter in cm = 2.54 × diameter in inches.

Table 2b.—Periodic annual diameter growth rates of 40 largest and second 40 largest trees per acre, average site index ≤ 65, by stocking level

Percent stocking	N[a]	Avg. basal area (ft^2/acre)	Avg. s.p.[b]	Initial avg. dbh[c]		Periodic annual/ dbh growth	
				40 largest trees	Second 40 trees	40 largest trees	Second 40 trees
				inches			
STUDY 31, MISSOURI (10 plots, avg. age 24.8)							
Very low (0-31)	80	21.50	27.50	5.42	4.34	0.25	0.18
Low (32-45)	—	—	—	—	—	—	—
Medium (46-65)	120	38.11	50.47	5.29	4.66	0.20	0.18
High (66-80)	—	—	—	—	—	—	—
Very high (80+)	—	—	—	—	—	—	—
STUDY 41, IOWA (20 plots, avg. age 37.0)							
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	16	38.06	36.54	8.38	7.44	0.26	0.21
Medium (46-65)	40	53.58	53.42	8.99	7.52	0.20	0.17
High (66-80)	40	70.53	70.83	9.02	7.68	0.18	0.17
Very high (80+)	64	85.48	91.10	8.61	7.18	0.16	0.15
STUDY 32, MISSOURI (14 plots, avg. age 40.4)							
Very low (0-31)	120	30.00	29.67	8.28	6.94	0.26	0.23
Low (32-45)	—	—	—	—	—	—	—
Medium (46-65)	100	50.19	48.68	9.26	7.76	0.18	0.16
High (66-80)	40	69.87	71.43	9.17	7.57	0.15	0.13
Very high (80+)	20	85.19	88.14	9.08	7.62	0.13	0.11

Continued

Table 2b.—Continued

Percent stocking	N[a]	Avg. basal area (ft²/acre)	Avg. s.p.[b]	Initial avg. dbh[c]		Periodic annual/ dbh growth	
				40 largest trees	Second 40 trees	40 largest trees	Second 40 trees
				inches			
			STUDY 24, OHIO (15 plots, avg. age 61.2)				
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	80	47.66	42.21	11.26	8.50	0.15	0.11
Medium (46-65)	140	60.81	54.34	11.41	9.09	0.12	0.10
High (66-80)	60	80.22	71.43	11.69	9.55	0.11	0.09
Very high (80+)	20	100.42	94.22	11.16	9.37	0.11	0.09
			STUDY 13, KENTUCKY (12 plots, avg. age 80.0)				
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	160	45.18	40.38	11.54	7.65	0.17	0.14
Medium (46-65)	160	62.09	55.71	12.18	9.00	0.14	0.11
High (66-80)	160	79.07	69.80	12.98	9.91	0.15	0.11
Very high (80+)	—	—	—	—	—	—	—

[a]Number of 40 largest trees per acre used to compute growth rates.
[b]Initial average stocking percent (s.p.).
[c]Diameter in cm = 2.54 × diameter in inches.

used to determine the average at the very low stocking level, but only one plot was used to determine the average at the very high stocking level. One plot does not provide sufficient information to make concrete conclusions. We should look more for general trends in the data in Tables 2a and 2b, as opposed to specific comparisons

Diameter growth at the very low stocking levels (0 to 31 percent) was considerably greater than at the higher stocking levels. The 0.34-inch annual increment at this very low stocking level on study area 31 (Table 2a) approaches the maximum diameter growth that we can expect in upland oak stands. This area was in a young black oak stand growing on a good site. However, such a severe thinning is not a common practice in the field and is not recommended. This stocking level closely resembles a seed-tree cutting, and the volume growth per acre is greatly reduced.

Accelerated growth was maintained at the low stocking levels (32 to 45 percent), but dropped some from the very low. Again, this stocking level represents a severe thinning not commonly practiced, and it is not recommended.

The diameter growth rates at the medium stocking levels (46 to 65 percent) are most informative. In practice, most medium to heavy thinnings today result in this stocking level. There was some increase in the diameter growth on all study areas except study 21, but no sensational differences from the diameter growth on the very highly stocked plots. We probably cannot expect more than a 0.03- to 0.05-inch increase in annual increment at this medium stocking level. This response is somewhat below what many foresters would anticipate but, on the average, it represents about a 20 percent increase over unthinned stands.

Growth rates at the high stocking levels (66 to 80 percent) showed only a slight increase in relation to the very highly stocked plots. Many light to medium thinnings in the field result in this level of stocking. Only about a 0.01- to 0.02-inch increase in diameter growth can be expected at this stocking level, which is about a 10 percent increase on the average.

Age. The general trends in the data indicate a growth response after thinning, regardless of age. However, the response relative to a control was somewhat greater in the younger stands than in the older. In other words, there was some interaction between age and stocking.

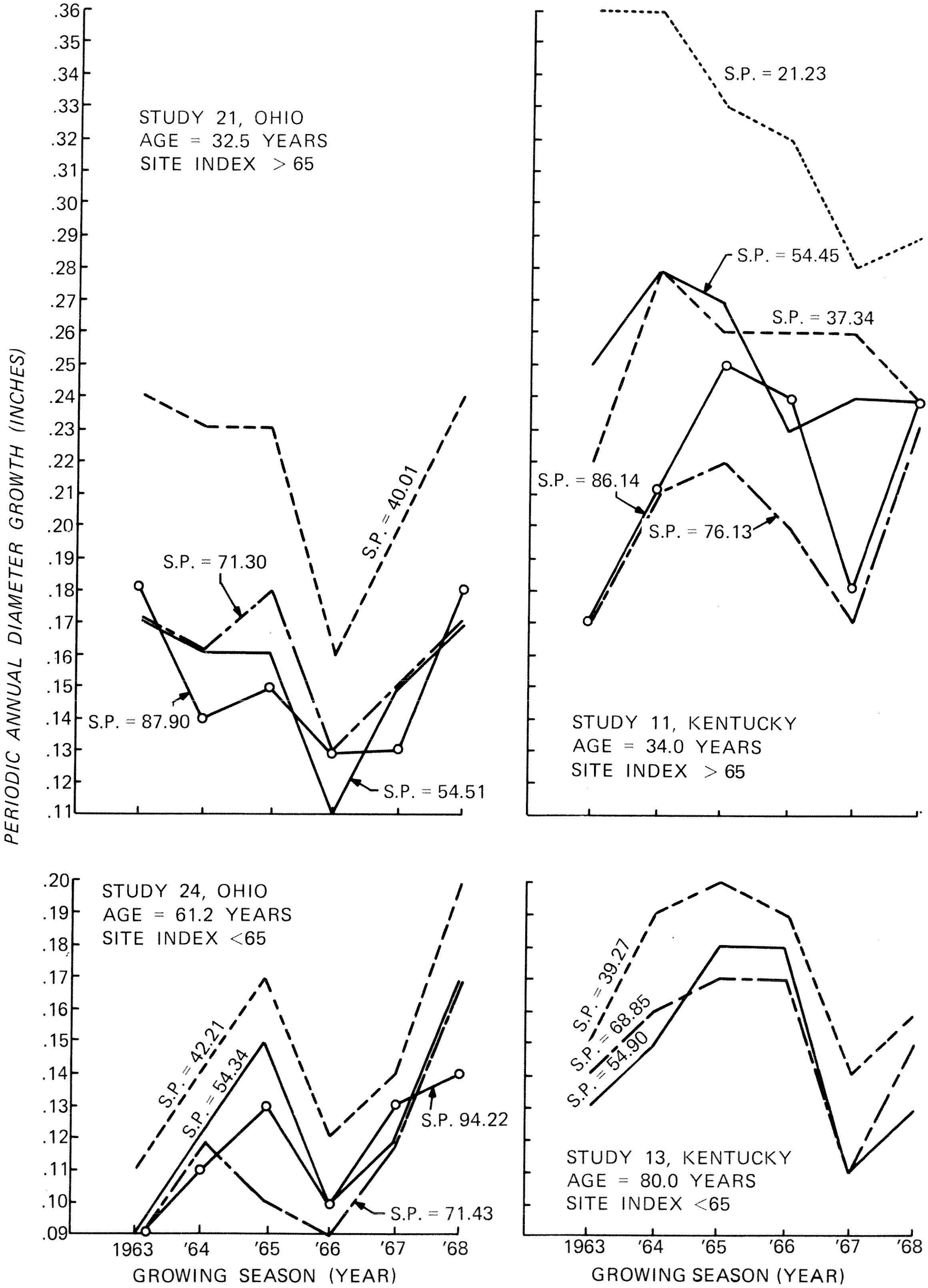
The absolute age effect on diameter growth is also reflected in the data. It is, however, combined with species effects and geographic location (mostly weather) for the different growth and yield studies. The general trend indicates a decrease in diameter growth with increasing age. This result was expected because the older trees were much larger. Studies 24 and 21 in Tables 2a and 2b seem "out of place" in the progression of ages because their growth rates were so small. Consistently poor weather such as drought and late frost over the growth period caused this reduction in diameter growth.

Site. A definite response to thinning regardless of site is reflected by the data in Tables 2a and 2b. Studies 31 and 32 provide the best information on site effects on diameter growth because the sample plots in these two areas were deliberately established on good and poor sites. Comparison between other study areas of similar ages should be made with caution because the site effects are confounded with species effects and geographic location (weather).

The results suggest that site does not have much, if any, effect on the diameter growth response after thinning, relative to a control. Diameter growth on study area 32 averaged 0.03 inch (0.08 cm) greater on the medium stocking level than on the very high stocking level on the good sites, but 0.05 inch (0.13 cm) greater on the poorer sites.

The absolute site effect on diameter growth is also reflected in the data. Diameter growth of the 25-year-old stand in study 31 averaged 0.09 inch (0.23 cm) more on the good sites for the very low stocking level, and 0.07 inch (0.18 cm) more for the medium stocking level (Tables 2a and 2b). The diameter growth of the 40-year-old stand in study 32 was slightly better on the good site for the high and very high stocking levels only.

Figure 3.—Periodic annual diameter growth rates of 40 largest trees per acre, 1962-1968 (s.p. = stocking percent).



Largest 40 trees per acre vs. second 40 largest. Which trees respond most to thinning is of major importance. Is the growth response greater in the larger future crop trees, or is the response primarily in the smaller future crop trees? To answer this question I calculated the diameter growth rates for the second 40 largest trees per acre (Tables 2a and 2b). The results indicate that in most cases the growth response relative to a control was as much or more for the largest 40 trees per acre than it was for the second 40 largest. The absolute diameter growth, as expected, was always greater for the largest 40 trees per acre. These trends were consistent for all age and site categories.

Growth trends. Diameters were measured annually from 1962 to 1968 on four study areas. The six periodic annual diameter growth rates for each study are plotted by stocking level in Figure 3. Tracing growth rates over time is an attempt to determine how long the response to thinning is sustained.

The fact that the diameter growth for most stocking levels within a study area increased and decreased at similar times indicates that weather had a major effect on the growth of the residual trees. Growth was very poor during 1966 in Ohio and 1967 in Kentucky. It decreased as much as 0.07 inch (0.18 cm) during those years in study areas 21 and 13.

The low stocked plots (31 to 45 percent) had consistently higher growth rates than the other stocking levels in studies 21, 24, and 13. The growth response at this stocking level was apparently maintained for at least the six growing seasons used in the analysis.

The growth rate at the very low stocking level in study 11 was very high for the first two growing seasons, but then declined relative to the other stocking levels. This indicates that the very high growth rate after a severe thinning may be short lived.

Other than the effects of weather on growth, no discernible trends in growth rate are apparent for the other stocking levels. The growth rates for the medium stocking levels even dropped below those for the highly stocked plots in several instances.

SUMMARY

The thinning studies in this analysis cover a wide range of stocking levels, stand age, and site conditions. The variability in responses to thinning was apparent even for this large data set. General trends in the data indicate that the diameter growth of the largest 40 trees per acre showed a distinct response to thinning, regardless of age or site. The heavier the thinning, the greater the response. Diameter growth rates, and growth response after thinning relative to a control, were better in younger stands. Growth rates were higher on better sites, but the growth response relative to a control was not influenced much by site. In most instances the largest 40 trees per acre responded as well or better to thinning than the second 40 largest.

The diameter growth response of upland oaks after thinning is consistent with the response of faster growing species such as ponderosa pine, Douglas-fir, western hemlock, and Sitka spruce (Barrett 1969; Reukema 1972; Hilt 1977; Farr and Harris 1971).

The diameter growth rates at the medium stocking levels for the largest 40 trees per acre were generally 0.03 to 0.05 inch better (approximately 20 percent) than those of very highly stocked plots. If this kind of response can be maintained through repeated thinnings, foresters should be able to lower the current rotation age of 100 years to about 80 years for sawlog management in upland oak stands. Or, if the rotation age is kept at 100 years, there should be considerably more veneer-size logs at the time of harvest. Information on the growth responses after repeated thinnings in upland oak stands will be available soon, as many of the plots used in this analysis have now been thinned two or three times.

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