GROWTH response from THINNING young even-aged WHITE OAK stands

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THE OAKS rank among the most important hardwoods in this country. They furnish more native timber each year than any other related group of broad-leaved trees. In spite of their wide distribution and importance, we have little growth and yield information for managed oak stands to aid in selecting and scheduling silvicultural treatments.

In cooperation with various universities, state forestry organizations, and private industries, the U. S. Forest Service undertook a series of studies to estimate growth and yield of upland oaks for a range of stocking conditions.

The first studies were begun in 1950; 12 studies incorporating 228 permanent plots now extend over a large part of the upland oak range from Kentucky and Ohio west to Iowa and Missouri. These plots include varying conditions of stand age, species composition, and site quality. They ultimately will be used to develop yield tables for managed upland oaks, but some of the studies are too new to provide conclusive data at this time.

This interim report on two of these 12 studies covers the growth response from 25- to 35-year-old white oak stands on medium sites in southeastern Iowa and eastern Kentucky.

STUDY AREAS AND METHODS

The Iowa Stand

The natural white oak stand in Iowa, located on the Shimek State Forest, was 25 years old when first thinned in 1950. Twenty 1/5-acre plots were located in the stand; about half of them were on the east slope of one main ridge and the others were along the top and north slope of a second ridge. Site index, based on Schnur's 1937 curves, ranged from 55 to 69 and averaged 62.

In 1950, five different levels of stocking, each replicated four times, were created by thinning. Residual stands were left with 30, 40, 50, 60, and 74 square feet of basal area per acre in trees 2.6 inches d.b.h. or larger. Stems under 2.6 inches were not cut. Stem measurements made with a tape at breast height in 1953, 1955, 1958, 1960, and 1962 provide growth data for 12 years.

Before it was thinned, the stand averaged 84 square feet of basal area per acre, and 1,244 trees per acre larger than 0.6 inches diameter. This represents about 115-percent stocking (*Roach and Gingrich 1962, Gingrich 1964*).[1] In trees larger than 2.6 inches diameter, basal area was 77 square feet with 765 trees; this represented 95-percent stocking. Average diameter was 4.3 inches.

The Kentucky Stand

The natural white oak stand in Kentucky, located in Jackson County, was 33 years old when first thinned in 1962. Fifteen 1/2-acre plots were located in the stand adjacent to a small drainage. Site quality was higher than in Iowa. It averaged about 70 for oak and varied between 62 and 77.

Five levels of stocking, each replicated three times, were created by thinning. Residual stands were left with 15, 30, 45, 60, and 66 square feet of basal area in trees 2.6 inches d.b.h. and larger. Annual diameter measurements made with a tape on all trees over 2.6 inches d.b.h. provide growth data for 4 years.

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[1] Stocking percent is used throughout this paper in place of the more familiar basal area because it expresses the same relative degree of stocking regardless of age or site.

Before it was thinned, the stand averaged 87 square feet of basal area and 1,761 stems per acre larger than 0.6 inches d.b.h. This represents about 125 percent stocking. In trees larger than 2.6 inches d.b.h., basal area was 76 square feet with 687 trees; this represented 96-percent stocking. Average diameter was 4.5 inches.

Comparison of Stands

In the main stand (trees larger than 2.6 inches d.b.h.) species composition, stocking, basal area, and number of trees were remarkably similar for the two study areas (appendix). But the Iowa stand was younger; average tree size was smaller; and the trees were shorter because site quality was lower. So cubic-foot volumes were somewhat lower in Iowa.

All plots were well stocked before treatment. Stockings in excess of 100 percent indicate that these stands were somewhat more dense than the average natural stand.

The two stands differed mainly in the understory trees (trees 0.6 to 2.5 inches d.b.h.). The understory in Kentucky contained about 1,074 stems per acre, compared with only 479 in Iowa. Red maple, dogwood, and sourwood—the most abundant species in the Kentucky stand—accounted for about 80 percent of the total. Hickory, the principal species in Iowa, accounted for about 55 percent of all understory stems there.

Thinning Method

We used a "free-thinning" system. Under this system, described by Braathe (*1957*), the marker is free to remove trees from all crown classes; the objective is to leave a suitable number of the best trees as evenly spaced as possible over the area.

In both Kentucky and Iowa, thinning was primarily to improve spacing around the better quality trees of the most desirable species (fig. 1), and thinning was much the same in both stands. However, two exceptions should be noted. The Kentucky stand had a few older residuals (an average of two or three per acre), and these were the first trees marked for cutting. Also, in Kentucky all stems less than 2.6 inches d.b.h. were cut in the lower

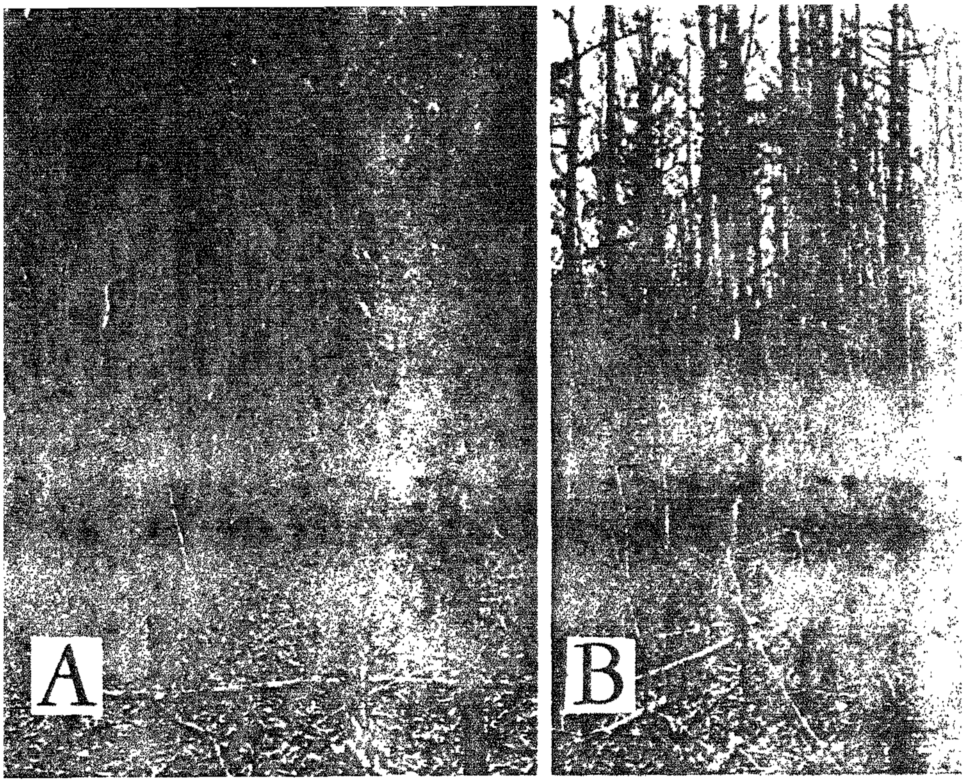
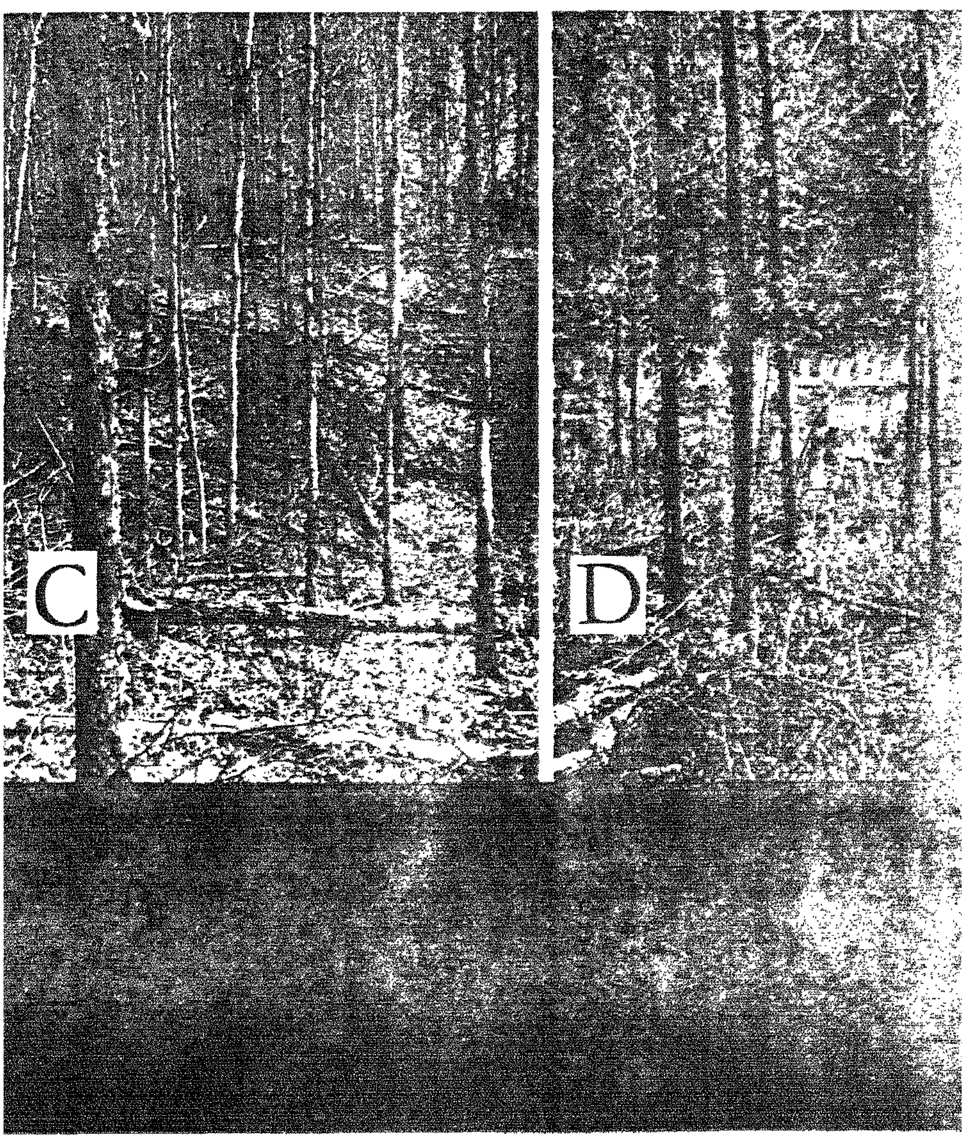


Figure 1.—The 33-year-old Kentucky white oak stand as it appeared 2 years after thinning. *A*, on unthinned plots; *B*, on plots with 50 percent residual stocking; *C*, on plots with 40 percent residual stocking; and *D*, on plots with 20 percent residual stocking.



three density classes, and none was cut in the two higher densities. In contrast, none of these smaller trees was cut in Iowa in any density class.

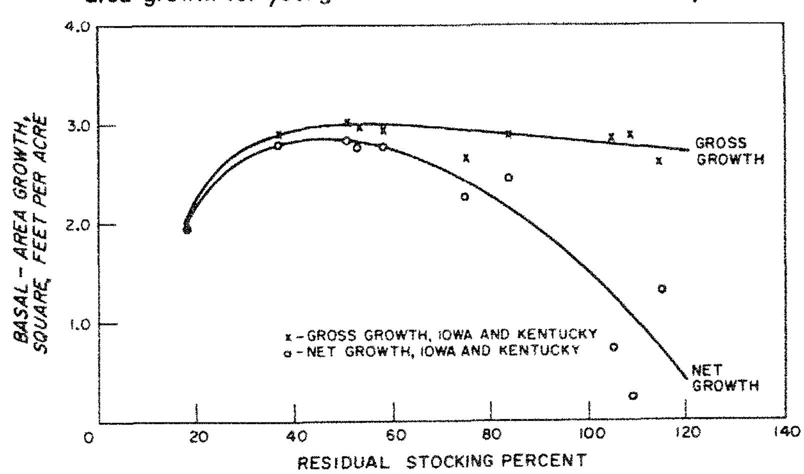
RESULTS

Basal-Area Growth

Basal-area growth was about the same in the Iowa and Kentucky stands for plots of similar residual stocking (tables 1 and 2). Likewise, the basal-area response in relation to stocking followed the same general pattern in the two stands (fig. 2). Growth response and total stocking in figure 2 are based on all trees 0.6 inches d.b.h. or greater occupying the area, so the curves probably describe the full growth potential for this particular age and site.

At densities between about 50- and 100-percent stocking, gross growth of these young oak stands averaged about 2.75 to 3.0 square feet of basal area per acre per year. This supports Moller's (*1954*) theory that the gross annual increment of intensively managed even-aged stands is substantially uniform for a fairly wide range of stand densities. However, gross basal-area growth seemed to drop slightly at maximum stocking; although this difference may not be statistically significant, a similar drop was noted by

Figure 2.—Relation between stocking percent and basal-area growth for young oak stands in Iowa and Kentucky.



Braathe (*1957*) for beech and Norway spruce stands in Europe.

This wide range of stocking for full site utilization means that foresters have considerable latitude to manipulate stocking and still achieve the full growth potential of an area. As long as enough trees are present to use all available growing space, stocking determines not how much wood is produced, but rather how it is distributed among the trees in the stand. Minimum stocking for full site utilization (about 50 percent) produces the same gross quantity of wood as maximum stocking, but the growth is on fewer trees. So individual trees grow faster in diameter, permitting shorter rotations.

Although gross basal-area growth was nearly constant from about 50-percent to maximum stocking, mortality caused the net growth within this range to vary. In both Iowa and Kentucky, net basal-area growth reached a maximum between 40- and 60-percent stocking. Below 40-percent stocking, net basal-area growth was reduced. Although individual trees grew faster, there were too few of them to occupy the site fully. Above 60-percent stocking, net growth was reduced also, because natural mortality increased. Mortality, represented in figure 2 as the difference between the gross-growth and net-growth curves, amounted to only 5 percent of gross growth at 50-percent stocking. Mortality increased with higher stocking and finally reached 75 percent or more at the higher densities. Net basal-area growth on plots that had little or no thinning was comparable to that reported by Schnur (*1937*). He reported a periodic increase of about 1.1 square feet for site 60 between ages 25 and 35 and about 0.8 square feet for site 70 between ages 30 and 40.

Mortality occurred mostly among the smaller trees, and even exceeded net growth in the lower diameter classes. Because these small trees are not merchantable and will never be needed as part of the final stand, they are generally disregarded by foresters when they examine net growth. Excluding these small 1- and 2-inch trees alters the form of the net-growth curve so that it does not drop off as sharply at the higher densities.

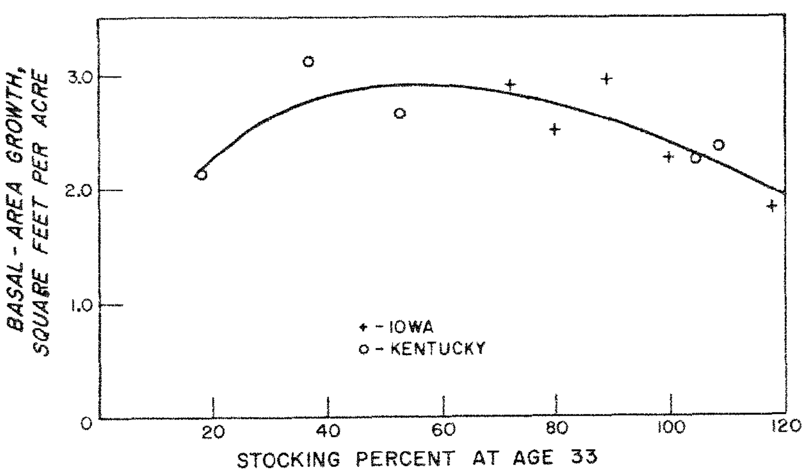
After two or three thinnings, we would expect all trees left in the stand to be merchantable. In that case, failure to thin will mean actual loss of products through natural mortality; and the more dense the stand is permitted to become, the greater the loss.

Because only the larger trees are very likely to become merchantable, net basal-area growth has been recalculated for those trees that reached at least 4.6 inches d.b.h. between ages 33 and 37. This new computation of the independent variable also limits the data to trees of similar age because it utilizes growth accrued only during the 4 years when the trees were between 33 and 37.

With this calculation, net growth dropped off at the highest densities much more gradually than before (fig. 3). This illustrates that most mortality losses were limited to the smaller trees. The new curve also shows that increases in net growth to be expected from thinning are less than indicated in figure 2. However, the increases in net growth between 60-percent stocking and 120-percent stocking are still substantial (about 2.9 versus 1.9 square feet per acre per year).

Although the highest density plots had about 100 more trees per acre (4.6 inches or more d.b.h.) than plots with 50-percent stocking, basal-area growth on these latter plots was approximately 50 percent greater.

Figure 3.—Relation between stocking percent and net basal-area growth of trees reaching 4.6 inches d.b.h. and larger between ages 33 and 37.

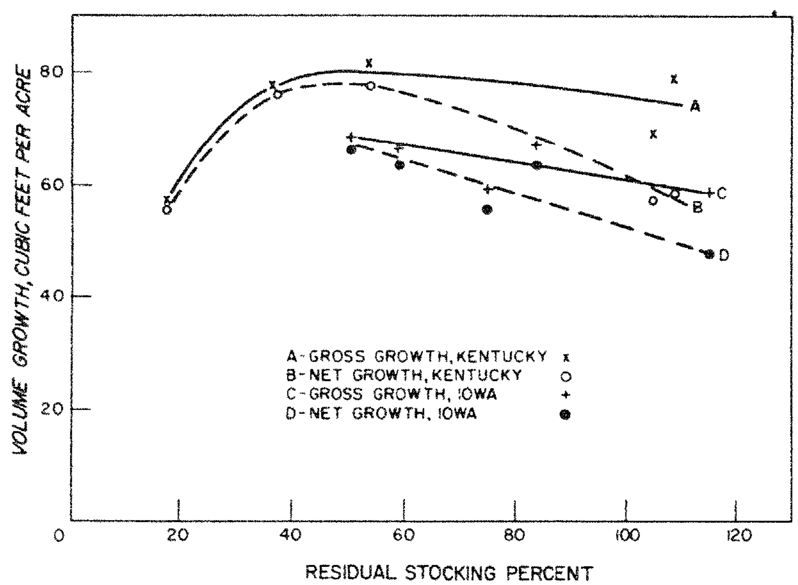


Cubic-Volume Growth

Gross cubic-volume production was relatively constant between about 50-percent stocking and maximum stocking for both stands (fig. 4). As with the gross basal-area curve, this again illustrates that the full productive capacity of the site is utilized with stocking of 50 percent or more. Cubic volume was computed using trees 2.6 inches d.b.h. and larger, and this may account for the slight drop in gross growth at the higher densities. If the 1- and 2-inch trees had been included in the the volume computations, gross growth probably would have remained even more constant.

Gross growth for plots with stocking greater than 50 percent ranged from 70 to 80 cubic feet per acre per year in Kentucky; in Iowa the range was 60 to 70 cubic feet per acre per year. With such a small sample, the volume difference between the two states may not be statistically significant, although it does agree with the well-established fact of greater volume production on the better sites. This relationship is found in all yield tables and is primarily due to greater height growth on the better sites.

Figure 4.—Relation between stocking percent and annual gross growth and net cubic volume growth in trees 2.6 inches d.b.h. and larger in Iowa and Kentucky.



Below 40-percent stocking, gross growth and net growth decreased similarly. Net growth also dropped as density increased. Near maximum stocking (110 percent), net growth was about 50 cubic feet per acre per year in Iowa and 57 cubic feet per acre per year in Kentucky, or about 75 to 80 percent of the gross. Comparable net growth reported by Schnur (*1937*) was about 54 cubic feet annually for site 60 between 25 to 35 years, and about 57 cubic feet for site 70 between 30 to 35 years.

The quantity of wood produced in these young oak stands is fairly constant from about 50-percent to maximum stocking. However, not all the wood produced is usable; and, unless these stands are thinned, about one-fifth to one-fourth of the annual volume production is lost through mortality. So, stands maintained at about 60-percent stocking should produce more, or at least as much, periodic net volume growth as stands at higher densities. Even more important, the volume growth will be placed on fewer trees that are, theoretically at least, higher in quality and value.

Cubic volumes in this report are based on local volume tables and no adjustment has been made to accommodate possible changes in stem form at the various stocking densities. Numerous investigators have shown that a heavy thinning regime tends to increase the rate of stem taper (*Newnham 1965, Meyers 1963, Braathe 1957, and Larson 1963*). So, cubic volumes shown for the lightly stocked plots may be overestimated and maximum net cubic-volume growth may actually occur at a slightly higher stocking percent than shown in figure 4.

Growth of Individual Trees

Growth per tree increased as stand density decreased (fig. 5). In other words, the fewer trees on an acre, the faster each grew in diameter. Diameter growth of white oak was slightly higher in Kentucky than in Iowa, especially at the higher stocking levels, but otherwise trends were similar.

The greatest diameter increase was at the lowest density level (18-percent stocking); these trees grew almost twice as fast in diameter as those at maximum stocking. However, total growth per acre was reduced at this low stocking because there were too

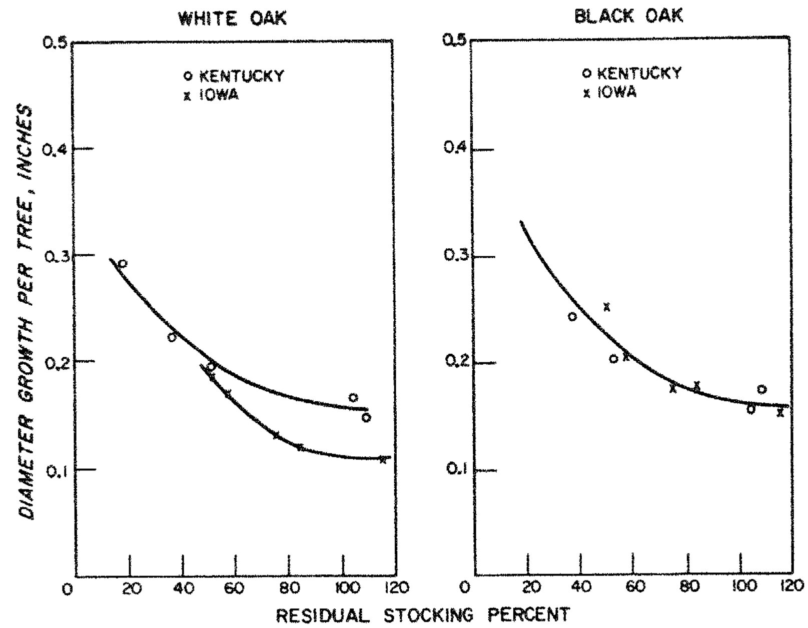


Figure 5.—Periodic annual diameter growth of the largest 100 trees per acre in relation to stocking percent.

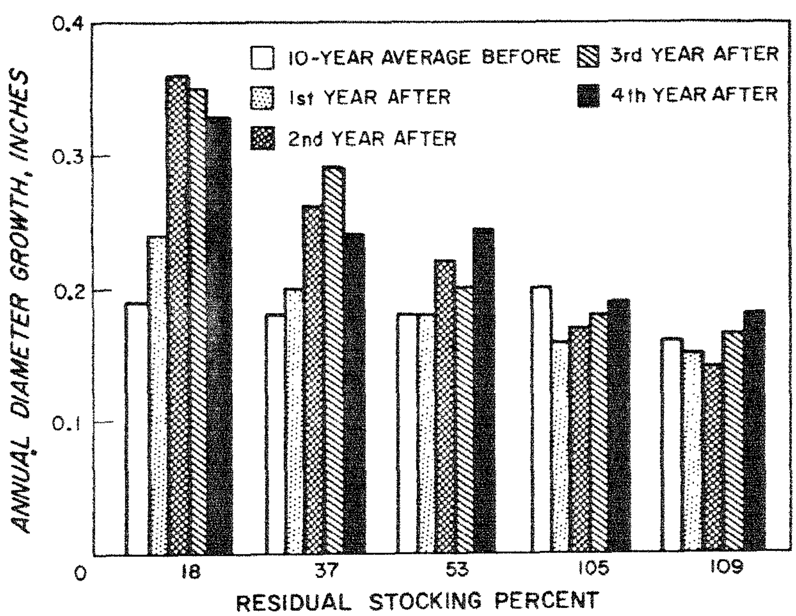
few trees to utilize the site fully. Annual diameter-growth rate of white oak at 50-percent stocking was about 0.08 inches more than at maximum stocking in Iowa, and about 0.05 inches more for Kentucky—an increase of about 70 percent and 35 percent respectively.

The black oak group, which included a few northern red oaks, grew faster in diameter than white oak for any given stocking level. Similar differences in growth rate of oak species were reported in West Virginia (*Trimble 1960*). Thirty-five percent of the 100 largest trees per acre were black oak in Iowa and only 20 percent in Kentucky. Black oak grew at about the same rate in Iowa and Kentucky.

Evidently white oak trees respond quickly to release. Minckler (*1957*) found that pole-sized white oaks in Illinois grew 41 percent faster the first year after release and that a similar increase over the first year's growth occurred the second year. Our study in Kentucky indicates that most of the growth response was achieved by the second year and that this increased growth has been maintained through the third and fourth years (fig. 6). Annual variations in weather conditions will, of course, cause fluctuations from the average. With no thinning, or a very light thinning, growth was about the same as the 10-year average before thinning.

Differences in growth rate among species may explain some of the variation in basal-area or cubic-volume growth found among plots. For example, a predominately black oak stand would be expected to grow faster than a white oak stand. Nelson (*1964*) presented a theoretical model for adjusting growth when species mixture varies. Because this is an interim report pending accumulation of data from a longer growth period, this adjustment was not deemed worthwhile.

Figure 6.—Annual diameter growth for different stocking levels each year since thinning the 33-year-old white oak stands in Kentucky.



Effect of Stocking on Tree Quality

Thinning affects quality of trees in a stand as well as their growth. Average stand quality tends to improve when cull, defective, and inferior trees are removed; but this improvement may be offset if the thinning stimulates epicormic branching of the residuals. Four years after thinning the Iowa plots, Brinkman (*1955*) reported that for trees in the main crown canopy epicormic branches were fewer for (1) dominant trees, (2) single stems as compared with multiple-stem clumps, and (3) rather heavily-stocked stands. On trees bordering a clearcut forest opening in West Viriginia, epicormic branching was more prevalent on white oaks than on eight other species (*Northeastern Forest Experiment Station 1966*). Generally, these branches are more prevalent on trees of lower crown class and on the upper stems (*Smith 1965, and Brinkman 1955*).

In both Kentucky and Iowa stands we observed that white oak, when thinned to the lower densities, is subject to severe epicormic branching. Quality losses will undoubtedly more than offset any gains from increased volume when stocking is reduced below about 50 percent (fig. 7).

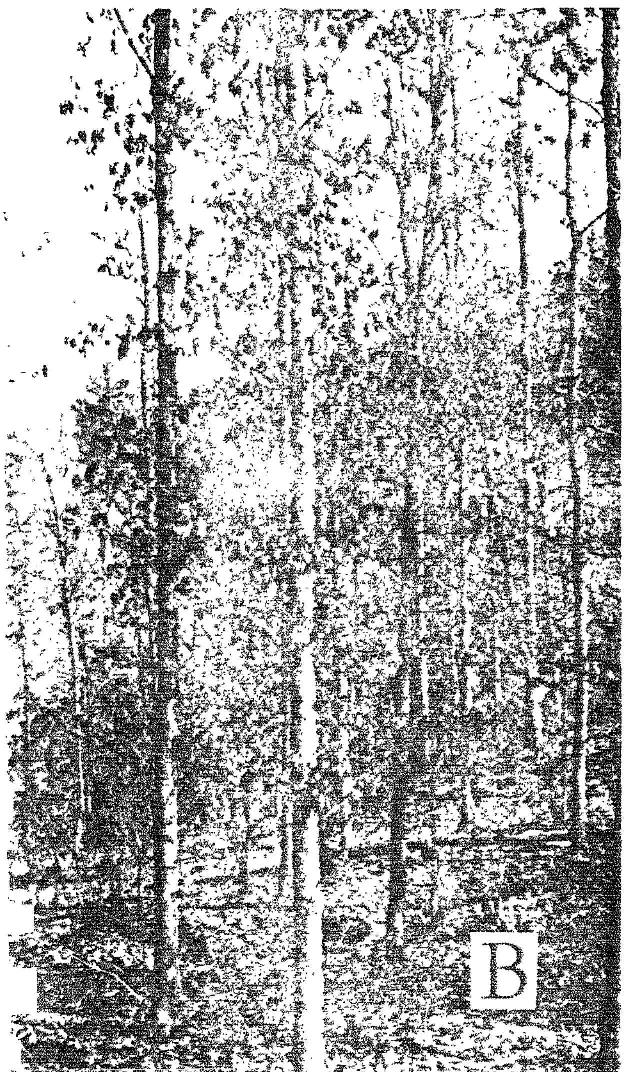
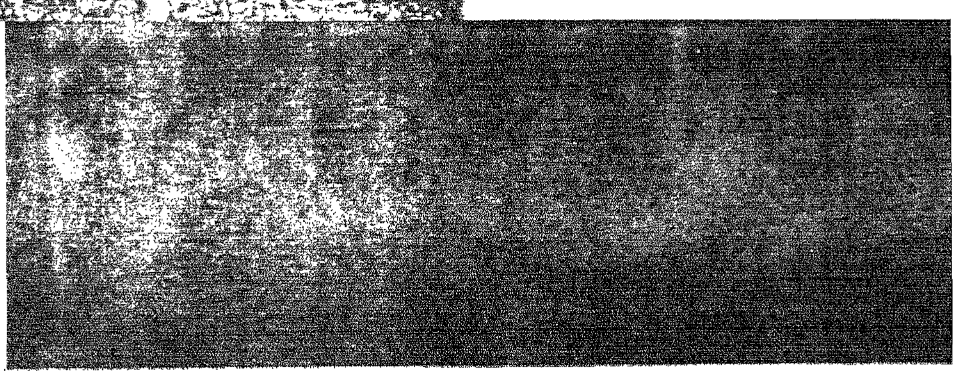


Figure 7.—*A*, white oak stand in Kentucky after being thinned to about 38 percent stocking (30 square feet of basal area per acre). *B*, note epicormic branch development 5 years later.



CONCLUSIONS AND RECOMMENDATIONS

Gross wood growth of 25- to 35-year-old white oak stands expressed either as basal area or cubic volume is nearly independent of stand density within the range from about 50 percent to maximum stocking. Net growth or yield is very likely to be greatest at about 50-percent stocking (45 square feet of basal area) because natural mortality increases rapidly at higher stand densities. If maximum stocking is maintained, 25 percent or more of the potential yield may be lost to mortality. Not only is net growth optimum at about 50-percent stocking, but individual trees grow faster in diameter, permitting shorter rotations.

Any stocking maintained much below 50 percent will not fully utilize the site. Although individual trees grow rapidly, there are too few of them to occupy the area fully. Losses in tree quality due to epicormic branching also become important at lower densities.

Based upon results from these two studies, and pending accumulation of additional data from stands thinned to very low densities, the following silvicultural treatment is recommended for similar young white oak stands managed for production of high-quality sawtimber.

Previously unmanaged fully stocked stands should be thinned to about 65 to 70 percent stocking (50 to 55 square feet of basal area) in trees over 0.6 inches d.b.h. This stocking is purposely somewhat higher than the studies indicate for maximum yields. Nevertheless it is heavy enough to eliminate much of the undesirable growing stock, stimulate growth of residual crop trees, and reduce mortality losses for 8 to 10 years. It is not so heavy as to cause a loss in volume production or profuse epicormic branching.

This first thinning should be primarily to improve growing conditions around the desirable crop trees. So, some of the cut must be in the main crown class, removing first the culls and overtopping wolf trees, then the lower value species, and finally some of the desirable species if necessary to achieve proper spacing and stocking. We cannot tell now whether the benefits justify the extra expense of cutting the poor intermediate and suppressed trees in this first thinning. So at present these small trees probably should be left for later thinnings. Some may become merchantable, and meanwhile they serve as trainers and help reduce epicormic branching on crop trees.

A second thinning will be needed after 8 to 10 years. The second and subsequent thinnings may more safely reduce stocking to near the level for maximum volume production (50 to 60 percent stocking). By then crop trees will have a well-developed crown and will quickly utilize the additional growing space without as much risk of epicormic branching.

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Table 1.—Growth and yield of an oak stand in Iowa for 12 years after thinning at age 25

Residual stocking percent	Basal-area growth[1]			Cubic-volume growth[2]		
	Net growth	Mortality	Gross growth	Net growth	Mortality	Gross growth
	— *Square feet per acre per year* —			— *Cubic feet per acre per year* —		
51	2.84	0.17	3.01	67.1	1.4	68.5
58	2.76	.17	2.93	64.0	3.0	67.0
75	2.25	.40	2.65	55.4	4.0	59.4
84	2.46	.42	2.88	63.9	3.8	67.7
115	1.31	1.35	2.66	48.0	10.4	58.4

[1] All trees 0.6 inches d.b.h. and larger.
[2] All trees 2.6 inches d.b.h. and larger.

Table 2.—Growth and yield of an oak stand in Kentucky for 4 years after thinning at age 33

Residual stocking percent	Basal-area growth[1]			Cubic-volume growth[2]		
	Net growth	Mortality	Gross growth	Net growth	Mortality	Gross growth
	— *Square feet per acre per year* —			— *Cubic feet per acre per year* —		
18	1.93	0.04	1.97	56.0	0.7	56.7
37	2.84	.07	2.91	76.0	1.2	77.2
53	2.76	.19	2.95	77.7	3.0	80.7
105	.72	2.12	2.84	57.2	12.0	69.2
109	.25	2.63	2.88	59.0	20.5	79.5

[1] All trees 0.6 inches d.b.h. and larger.
[2] All trees 2.6 inches d.b.h. and larger.

Table 3.—*Stand composition for young white oak stands in Iowa and Kentucky before thinning*

Section	Basal area	White oak	Other[1] oak	Hickory	Other[2]	Total
	Square feet per acre			*Trees per acre*		
			IOWA			
Understory	7	139	41	269	30	479
Main stand	77	505	177	60	23	765
Total	84	644	218	329	53	1,244
			KENTUCKY			
Understory	11	167	24	25	858	1,074
Main stand	76	462	118	28	79	687
Total	87	629	142	53	937	1,761

[1] In Iowa: Black, northern red and post oak.
In Kentucky: Black, scarlet and chestnut oak.

[2] In Iowa: Black walnut, American elm and ash.
In Kentucky: Red maple, dogwood, sourwood and black gum.

Table 4.—*Comparison of young oak stands in Iowa and Kentucky before and after thinning (all trees over 2.6 inches d.b.h.)*

Basal area		Stocking percent[1]		Number of trees		Cubic-foot volume[2]		Average d.b.h.	
Before	After	Before	After	Before	After	Before	After	Before	After
Square feet per acre		*Percent*		*Number*		*Cubic feet per acre*		*Inches*	
IOWA — AGE: 25 YEARS									
79	31	97	36	785	251	1,362	555	4.4	4.7
82	40	99	46	735	272	1,441	742	4.5	5.2
72	50	89	58	715	406	1,229	902	4.3	4.8
81	60	97	69	779	466	1,371	1,069	4.4	4.9
74	74	92	92	811	811	1,206	1,206	4.1	4.1
Average									
77	—	95	—	765	—	1,322	—	4.3	—
KENTUCKY — AGE: 33 YEARS									
75	15	97	18	634	125	1,646	310	4.6	4.7
76	32	93	37	700	257	1,587	650	4.5	4.8
73	45	94	53	680	409	1,558	895	4.4	4.5
79	60	100	75	690	653	1,705	1,172	4.6	4.1
75	66	98	81	732	716	1,556	1,288	4.3	4.1
Average									
76	—	96	—	687	—	1,610	—	4.5	—

[1] Based on tree-area-ratio, where tree area $= aN + b \Sigma D + c \Sigma D^2$ where a, b, and c are the regression constants; N is the number of trees per acre; ΣD is the sum of the individual diameters; and ΣD^2 is the sum of squares of the diameters. Regression constants used here are respectively: —.05066, .16977, and .03168 (Gingrich 1964).

[2] Cubic volume entire stem, based on formula: $V = 0.42\ BH$, where B is the basal area and H is the total height. Height read from local height-d.b.h. curves. Constructed specifically for each stand from sample measurements.