by Martin E. Dale

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EFFECT OF REMOVING UNDERSTORY ON GROWTH OF UPLAND OAK

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ABSTRACT

The amount of additional growth attributed to complete eradication of all woody understory vegetation varied for several widely scattered upland oak stands in the region. Based on paired-plot comparisons of 10 or more years' results, basal-area and cubic-volume growth usually increased slightly when the understory was eradicated. The amount of increase was related to (1) geographical stand location, (2) stand age, and (3) residual stocking of overstory trees. The greatest response to understory removal—an additional 0.75 square feet of basal area or about 12 cubic feet per acre per year—was found in very young stands located in the western part of the oak range where residual density of stocking after thinning was about 50 percent. However, results of this study indicate that for most upland oak stands in the region, understory-removal treatments would not greatly increase stand growth.

SMALL UNDERSTORY TREES and shrubs generally are not removed during a thinning operation in the upland oak type. Understory vegetation responds rapidly to the increased availability of sunlight, soil moisture, and nutrients; thus a vigorous and dense understory soon develops, particularly after heavy thinnings.

Little is known about the ability of this understory in hardwood stands to compete with the overstory trees for moisture or other growth factors, or how much a dense understory affects the growth of overstory trees. Some foresters working with hardwood stands are concerned that competition from a dense understory may retard growth of overstory trees.

In the early 1960s, we began several studies of understory control at widely separated locations in the upland oak region. Each study was designed to find out how much overstory growth was affected by completely eradicating understory in one particular set of stand conditions. All plots in each stand were about the same in stand age, site quality, and species composition; but these factors were different in different stands (table 1).

In this report, the long-term growth response for five understory control studies in the upland oak region are summarized and compared. If published separately, the results from these individual studies may seem contradictory because the growth response associated with understory removal differed with

Table 1.—Average stand characteristics per acre after initial thinning for treated and untreated understories by location

Stand location	Understory treatment	Plots	Plot size	Principal species	Average age	Site index	Basal area	Trees	Stocking	Total volume
		No.	*Acres*		*Years*	*Feet*	*Sq. ft.*	*No.*	*Percent*	*Cu. ft.*
Eastern Kentucky	Treated	4	0.25	White oak	34	70	30	284	36	778
	Not treated	4	.25		34	70	31	283	38	827
Southeast[a] Ohio	Treated	3	.25	Mixed oak	51	73	69	177	64	2,212
	Not treated	3	.25		52	72	69	176	64	2,211
Southeast Missouri (1)	Treated	6	.50	Black oak	20	72	36	568	49	891
	Not treated	6	.50		22	70	41	418	50	942
Southeast Missouri (2)	Treated	6	.50	Black oak	40	68	50	167	48	1,386
	Not treated	6	.50		42	66	50	145	47	1,404
Southeast[b] Iowa	Treated	5	.20	White oak	37	59	67	332	70	1,568
	Not treated	5	.20		37	59	69	316	71	1,636

[a] Study established in cooperation with and on land owned by Mead Corporation.
[b] Established on Shimek State Forest in cooperation with Iowa Conservation Commission. All plots had received an earlier thinning in 1950.

(1) geographical location, (2) stand age, and (3) residual stocking level. However, based on the aggregate response of all studies in the upland oak region, a definite growth pattern begins to emerge, which leads to more apparent generalizations about the effect of understory treatments in most of the upland oak type.

METHODS

Study Design

All study plots were located in young even-aged upland oak stands of about average site quality. They were all well stocked before the initial thinning except the Iowa plots, which differed in stocking because of a thinning in 1950. The basic idea was to determine for each stand the effect on growth of complete understory removal by comparing the response of paired plots. In Kentucky and Ohio, each plot in the pair was adjacent, and the plots differed very little in age, site, number of trees, and basal area after thinning. In Iowa and Missouri, the plots in a pair were not necessarily adjacent; but we tried to pair the plots to keep stand conditions as uniform as possible in each pair. Then the understory-removal treatment was randomly assigned to one plot, and the other plot served as the control.

We anticipated that residual stocking would affect the density and rate of understory development. Percent stocking was calculated from Gingrich's (*1967*) equation (tree area in milacres $= -0.0507N + 0.1698\ \Sigma D + 0.0317\ \Sigma D^2$) and was expressed on a percentage basis by letting 1,000 milacres equal 100 percent stocking.

In Missouri, we assigned to each of the paired plots one of three different density levels between 30 and 70 percent stocking to see if the effect of understory removal was the same for all densities. All pairs in Kentucky were thinned to about 35 percent stocking, but in Ohio all plots were reduced to about 65 percent stocking. In Iowa, each of the five pairs was assigned a different density, from 50 to 95 percent stocking.

Thinning Treatment

Every plot was thinned to the predetermined stocking level before understory treatment. We followed the same thinning procedure that was used in our stand-density studies. The objective was to leave a suitable number of the best stems as evenly spaced as possible on the plot. In general, we cut the larger cull and defective trees first, then competing trees of poor form and quality, then intermediate and suppressed trees of lower quality and value, and finally, if necessary, the lower value species of the main crown class. High-quality trees of desirable species were also cut when necessary to achieve a uniform spatial distribution. All trees smaller than 1.6 inches dbh were considered part of the understory. These were ignored during the thinning operation.

Plots in which the understory was removed differed very little from the control plots in average age, site index, residual basal area, or number of trees (table 1). Most of the stands were predominantly black or white oak, except in Ohio where the numbers of black, white, and chestnut oak were about equal. Tree size class differed among the stands from sapling to large poles; however, all stands were young, ranging between 20 and 50 years of age.

Understory Treatment

On plots selected for eradication of understory, all woody vegetation less than 1.6 inches dbh was killed in early spring after the thinning operation. The larger understory stems were generally cut by ax, and the stumps were sprayed with herbicide to prevent sprouting. Foliage spray was used to kill the smaller understory trees. Two or three followup treatments in subsequent years were usually required to eliminate all woody vegetation and prevent new growth from developing.

Understory stems were left alone after the overstory was thinned on all the control plots except in the Kentucky stand. In Kentucky, all the understory trees taller than 4.5 feet were cut on the control plots as well; but stumps were not sprayed with herbicides. Stump sprouts, new reproduction, and growth on the remaining understory stems created a dense and vigorous understory on the control plots within 2 years after treatment.

RESULTS

After 10 or more growing seasons, it is evident that some stands respond with an increase in growth when the understory is removed, and other stands show only a slight increase or none at all. Increased growth after understory removal seems to vary with (1) geographical location of the stand, (2) stand age, and (3) residual stocking.

Stand Growth

If the understory-removal treatment had no effect, one would expect the mean growth difference between treated and untreated plots to be about zero. Yet some of the differences were highly significant (table 2). Gross growth is more sensitive for detecting differences between treatments than net growth because the variance is much smaller for gross growth (table 3).

Two stands accounted for most of the differences in growth between treated and untreated plots: the 20-year-old black oak stand in Missouri and the 37-year-old white oak stand in Iowa. None of the other stands produced any significant difference in growth between treated and untreated plots. However, because we had only a few pairs of plots for comparison in each stand, the "t" test we used was not sensitive enough to detect such small differences in growth.

Undoubtedly small differences in growth response do exist; but additional plots would be needed to show whether or not this difference was statistically significant. The values in tables 2 and 3 could be used to compute the number of observations required to detect statistically significant differences. But, for practical purposes, a numerically small growth difference, even if we can show that it is statistically significant, is not important anyway.

Table 2.—Periodic annual growth per acre for treated and untreated understories for five stands

Stand location	Understory treatment	Growth period	Basal area		Stocking percent		Total cubic volume[a]		Merchantable cubic volume[b]	
			Net	Gross	Net	Gross	Net	Gross	Net	Gross
		Years	*Sq. ft.*	*Sq. ft.*	*Percent*	*Percent*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
Eastern Kentucky	Treated	10	2.50	2.60	2.13	2.26	77.8	80.6	57.0	59.0
	Not treated	10	2.38	2.50	1.99	2.15	75.8	78.9	55.5	57.7
	Difference		0.12	0.10	0.14	0.11	2.0	1.7	1.5	1.3
Southeast Ohio	Treated	10	1.41	2.18	0.89	1.63	77.6	102.6	56.6	75.0
	Not treated	10	1.46	2.19	.93	1.63	79.2	102.9	57.9	75.3
	Difference		−0.05	−0.01	−0.04	0.00	− 1.6	− 0.3	− 1.3	− 0.3
Southeast Missouri (1)	Treated	11	3.54	3.82	3.01	3.44	90.9	99.1	69.9	72.5
	Not treated	11	2.76	3.02	2.22	2.59	78.4	85.5	57.3	62.5
	Difference		0.78**	0.80**	0.79*	0.85**	12.5*	13.6*	12.6	10.0*
Southeast Missouri (2)	Treated	10	1.97	2.16	1.43	1.63	81.7	86.8	59.7	63.4
	Not treated	10	1.94	2.05	1.45	1.55	78.9	81.8	57.7	59.8
	Difference		0.03	0.11	−0.02	0.08	2.8	5.0	2.0	3.6
Southeast Iowa	Treated	12	2.67	2.97	2.01	2.34	92.1	99.8	66.1	71.7
	Not treated	12	2.14	2.39	1.59	1.88	76.7	82.6	56.1	60.3
	Difference		0.53	0.58**	0.42	0.46*	15.4	17.2	10.0	11.4

* Significant at the 5-percent level or greater.
** Significant at the 1-percent level or greater.
[a] All trees 2.6 inches dbh or larger, including bark, stump, and tip, but no branchwood.
[b] All trees 4.6 inches dbh or larger, excluding stump, bark, branches, and tip above 4.5-inch top dob.

Table 3.—Standard deviation of the mean for annual growth differences between treated and untreated plots

Stand location	Basal area		Stocking percent		Total cubic volume		Merchantable cubic volume	
	Net	Gross	Net	Gross	Net	Gross	Net	Gross
	Sq. ft.	*Sq. ft.*	*Pct.*	*Pct.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
Eastern Kentucky	0.17	0.08	0.16	0.05	5.60	3.03	4.06	2.21
Southeast Ohio	.35	.14	.29	.12	9.34	2.96	6.86	2.15
Southeast Missouri (1)	.16	.10	.21	.14	4.86	4.01	6.45	2.92
Southeast Missouri (2)	.16	.12	.15	.09	7.90	5.95	5.76	4.36
Southeast Iowa	.24	.12	.24	.11	9.24	6.99	6.16	4.44

Table 4.—Periodic net and gross annual basal-area growth per acre in Missouri by age, residual stocking, and understory treatment

Age class (years)	Understory treatment	Net growth, by stocking percent			Gross growth, by stocking percent		
		30	50	70	30	50	70
20	Treated .... sq. ft.	3.58	3.80	3.26	3.68	3.91	3.85
	Not treated .. sq. ft. ..	2.94	2.72	2.62	2.95	2.97	3.14
	Increase .. percent ..	22	40	24	25	32	22
40	Treated .... sq. ft.	1.96	2.28	1.66	2.08	2.31	2.08
	Not treated .. sq. ft. ..	1.88	1.95	1.98	2.11	1.99	2.04
	Increase .. percent ..	4	17	− 16	− 1	16	2

There are too few plots to determine whether the effect of understory removal differed with stand age or with residual stocking at each stand location. However, one-half of all our plots were located in black oak stands in Missouri; and these plots, representing two age classes and three stand-density levels, provide some clues about the effect of age and stocking level. Average growth for two treated and two untreated plots at each combination of age and stocking does indicate differences in response.

The absolute increase and the percentage increase in periodic annual growth due to understory treatment was greatest in the 20-year-old stand. This was true in terms of basal-area growth (table 4) and total cubic-foot volume growth (table 5). Gross basal-area growth in the younger stand increased on the treated plots by about 22 to 32 percent or about 0.7 to 1.0 square foot per acre per year, depending on stocking. The basal-area response was much less in the older stand, varying from a 1-percent decrease to a 16-percent increase. Gross volume growth was increased by as much as 21 cubic feet or 25 percent per year in the younger stand compared to 14 cubic feet or 18 percent in the older stand.

Gross growth, which includes mortality, is probably a better indicator of the treatment effect than net growth because net growth may fluctuate more because of an erratic mortality pattern. We had less mortality than expected on the untreated plots in the older stand with 70 percent stocking; but in gen-

Table 5.—Periodic net and gross total cubic-foot volume growth per acre in Missouri by age, residual stocking, and understory treatment

Age class (years)	Understory treatment	Net growth, by stocking percent			Gross growth, by stocking percent		
		30	50	70	30	50	70
20	Treated .... cu. ft.	93	102	78	96	105	96
	Not treated .. cu. ft. ..	82	77	76	82	84	90
	Increase .. percent ..	14	32	3	16	25	7
40	Treated .... cu. ft.	73	94	79	76	94	90
	Not treated .. cu. ft. ..	65	79	93	71	80	95
	Increase .. percent ..	12	19	−15	8	18	− 5

eral, the same trends were established, using either the net or gross values.

The difference in growth response between treated and untreated plots was closely related to the residual stocking after thinning. The largest growth difference was observed in both age classes when stands were thinned to a residual stocking of about 50 percent (tables 4 and 5). Although residual stocking for these plots was 50 percent initially, it averaged 65 percent over the entire growth period for the 20-year-old stand and about 58 percent for the 40-year-old stand. Thus the stocking percentage that gave the greatest growth difference was near the minimum density required for full site utilization — that is, about 58 percent of full stocking or curve B in the stocking guides for upland central hardwoods *(Roach and Gingrich 1968)*. The effect of removing the dense understory competition from plots reduced to 30 percent residual stocking was not as great, and this may be because each overstory tree already had all the growing space it presumably could use.

Individual Tree Growth

For most of the Iowa and Missouri plots, understory removal led to increased diameter growth of individual trees, but there was only a slight increase in Kentucky and none in Ohio. In Missouri, the increase varied with stand age and stocking much the same as stand growth varied. Average diameter growth of all surviving black oak trees was computed for each diameter class for both stands in Missouri. Average diameter growth per tree for treated and untreated plots is given for the 20-year-old stand in table 6 for each stocking level. Table 7 gives comparable diameter growth rates of black oak for the 40-year-old stand.

When growth rates from tables 6 and 7 are plotted, it is apparent that the diameter growth rate for a given size tree usually decreases as stand age or stocking percentage increases. In most cases, when the understory was eliminated, the growth per tree was greater for a given age, stocking, and tree size; the only exception in Missouri was the 40-year-old stand with 30-percent stocking. At 50-percent stocking, the mean diameter growth rate of all surviving black oak trees was 0.18 inch per year for the 20-year-old stand on the treated plots or about 0.03 inch (20 percent) more than on the plots with understory in place. In the older stand, at 50-percent stocking, the average diameter growth was 0.17 inch per year on the untreated plots, almost 0.03 inch more than on treated understory plots.

The effect of understory removal on annual diameter growth rate of white oak is illustrated in figure 1 for both the Kentucky and Iowa stands. Average diameter growth of white oak on the treated plots in Kentucky was about 0.16 inch per year compared to 0.15 inch on untreated plots — a gain of about 7 percent due to understory removal. Diameter growth of white oak in Iowa was much less, averaging about 0.11 inch per year on understory treated plots and 0.09

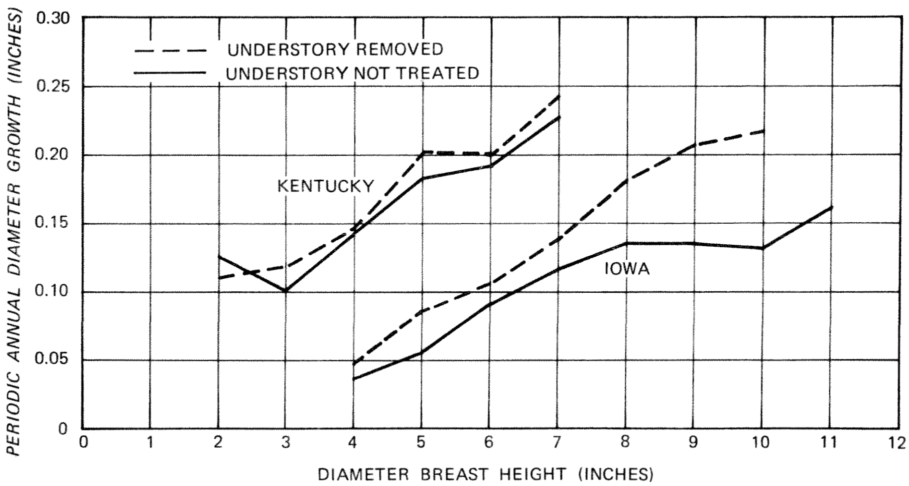
Table 6.—Mean annual periodic diameter growth of all surviving black oak trees by dbh class at age 20 for treated and untreated understory, in inches per year

Dbh class (inches)	Residual stocking percent					
	30		50		70	
	Treated	Not treated	Treated	Not treated	Treated	Not treated
2	0.23	—	0.12	0.12	0.09	0.07
3	.25	0.20	.15	.12	.13	.09
4	.29	.23	.20	.14	.17	.11
5	.33	.26	.23	.16	.21	.14
6	.32	.27	.26	.20	.24	.17
7	.37	.27	.27	.20	.23	.19
8	—	.29	—	—	—	.21
All trees	0.287	0.247	0.182	0.152	0.139	0.121

Table 7.—Mean annual periodic diameter growth of all surviving black oak trees by dbh class at age 40 for treated and untreated understory, in inches

Dbh class (inches)	Residual stocking percent					
	30		50		70	
	Treated	Not treated	Treated	Not treated	Treated	Not treated
5	0.15	0.18	0.14	—	0.08	—
6	.18	.22	.19	0.13	.08	0.09
7	.14	.22	.16	.12	.13	.10
8	.24	.24	.16	.16	.12	.11
9	.28	.23	.16	.15	.13	.11
10	.28	.22	.19	.15	.14	.13
11	.28	—	.14	.20	.20	.14
12	—	—	.17	.22	.19	.14
13	—	—	.17	.22	—	.15
All trees	0.202	0.223	0.170	0.143	0.116	0.114

Figure 1.—Periodic annual diameter growth of white oak in Kentucky and Iowa, by diameter class.



inch on the untreated plots. This is an average increase in diameter growth of about 22 percent due to removal of understory vegetation.

Individual white oak trees grew faster in Kentucky than in Iowa, but this was partially because the residual stocking was lower. All plots were thinned to about 37 percent stocking in Kentucky, and in Iowa stocking ranged between 50 and 90 percent and averaged 70 percent. Growth of individual trees in Iowa increased as stocking percentage decreased.

DISCUSSION AND RECOMMENDATIONS

Our results indicate that growth in some stands may be increased by nearly one-third if a dense hardwood understory is eliminated; but for other stands in the upland oak type, we may expect only slight, if any, growth increase. The most important factors that determine growth increase seem to be (1) geographical stand location, (2) stand age, and (3) residual stocking after the initial thinning.

Stands located in the western part of the upland oak region gave the greatest growth response when the understory was eliminated. The key to the amount of growth response is probably the availability of soil moisture for growth, which depends upon precipitation and soil properties, as well as temperature, relative humidity, and other factors.

Zahner (*1958*) found that soil moisture may be depleted 25 percent faster in pine stands with hardwoods left in place as compared to stands with hardwoods removed.

Precipitation, particularly during the critical spring and summer growth period, is usually less in the western part of the oak region. Ozark forest soils also are typically shallow and rocky and have a limited capacity for storing moisture, so summer drought conditions are more frequent and of longer duration than are conditions further east. More favorable soil-moisture conditions could be the reason why we found only a slight growth increase or none at all for the stands in Kentucky and Ohio. Karnig and Stout (*1969*) reported only a slight growth increase due to understory removal for a 70-year-old red oak stand in New York.

Similar studies in pine stands have shown that growth response due to understory removal of hardwoods was greatest in Arkansas and Missouri (*Grano,* 1970; *Bower and Ferguson, 1968; Rogers and Brinkman, 1965*). In contrast, studies of loblolly pine in Louisiana *(Russell, 1961)* and in South Carolina *(McClay, 1955)*; *Klawitter, 1966)* failed to show any growth improvement after the hardwood understory was controlled.

Overstory thinning and understory removal both tend to decrease the competition for the available soil moisture and other growth factors. Growth of individual trees was greatest at the very lowest stocking levels (30-percent stocking); however, the increase in stand growth was greatest with about 50-percent residual stocking or at about the stocking level required for full site utilization. At the lower stocking, there are too few trees to fully occupy the area; but at about 50-percent stocking, the crown canopy is nearly closed. Areas devoid of trees at the lower densities are quickly filled in by understory vegetation; but as stocking increases above 50 percent, the understory competition is reduced, and overstory competition for growth controlling factors intensifies. Hence, the effect on growth of understory removal at the higher stocking levels is less, simply because the understory is too sparse to offer much competition.

Young stands respond more to understory removal treatments than older stands, probably because in young stands the understory is more dense and young trees respond quicker to environmental changes. Many understory stems live through the brush stage into the sapling or small pole stage because overstory competition is not as intense or not of long enough duration to completely kill them.

Would it be wise for timber managers to recommend understory removal treatments as a silvicultural practice in upland oak stands? We lack some of the cost and return data needed to evaluate this alternative; but judging by 10-year growth response of our plots and some reasonable assumptions on treatment costs and expected returns, we feel that the answer in most cases is no. The expected growth increase would very likely be small, usually amounting to less than 1 cord and seldom more than 2 cords in 10 years. If we assume that it costs $8.00 per acre to eliminate understory vegetation, the amortized cost of this treatment for 10 years at 6-percent interest would be $14.33. In most cases, the stumpage value of the extra cord or two of yield would be less than this amortized cost. Individual trees might average 0.1 or 0.2 inch larger in diameter 10 years after treatment than where the understory trees were left in place. Such a small amount of additional growth does not seem to justify the expense of removing the understory vegetation.

Besides the small growth increase and the high treatment cost, additional arguments can be presented that favor leaving the understory in place. Dense hardwood understories provide both food and cover for many wildlife species. For deer habitat purposes, Halls (*1973*) discouraged the practice of spraying herbicides to control hardwood understories in southern pine stands. Possibly the understory is just as important to wildlife-habitat management in upland oak as in pine.

Quality of overstory trees could be affected by understory removal. Shade from a dense understory, 15 to 20 feet in height, might help prevent epicormic branches from developing or might aid in earlier natural pruning of branches on the lower boles. However, the influence of understory vegetation on quality of overstory trees has not been studied.

CONCLUSIONS

Several long-term studies in upland oak stands show that growth may be increased nearly one-third by eliminating a dense hardwood understory, but in other stands there is only a slight growth increase or no growth increase. The largest growth response occurs in very young stands in the western part of the oak range where residual overstory stocking is reduced by thinning to about 50 percent. For most of the upland oak stands in the region, understory control does not seem to be a very profitable forestry practice because of (1) the small growth advantage, (2) the cost of understory treatment, and (3) the possibility of adverse effects on wildlife habitat.

REFERENCES

Bower, D. R., and E. R. Ferguson.
1968. UNDERSTORY REMOVAL IMPROVES SHORTLEAF PINE GROWTH. J. For. 66: 421-422.

Gingrich, S. F.
1967. MEASURING AND EVALUATING STOCKING AND STAND DENSITY IN UPLAND HARDWOOD FORESTS IN THE CENTRAL STATES. For. Sci. 13: 38-53.

Grano, C. X.
1970. SMALL HARDWOODS REDUCE GROWTH OF PINE OVERSTORY. USDA For. Serv. South. For. Exp. Stn. Res. Pap. SO-55. 9 p.

Halls, L. K.
1973. MANAGING DEER HABITAT IN LOBLOLLY-SHORTLEAF PINE FOREST. J. For. 71: 752-757.

Karnig, J. J., and B. B. Stout.
1969. DIAMETER GROWTH OF NORTHERN RED OAK FOLLOWING UNDERSTORY CONTROL. Black Rock For. Pap. 30. 16 p. Harvard Black Rock Forest, Cornwall, N. Y.

Klawitter, R. A.
1966. DIAMETER GROWTH OF MATURE LOBLOLLY PINE UNAFFECTED BY UNDERSTORY CONTROL. South. Lumberman 213 (2656): 154-155.

McClay, T. A.
1955. LOBLOLLY PINE GROWTH AS AFFECTED BY REMOVAL OF UNDERSTORY HARDWOODS AND SHRUBS. USDA For. Serv. Res. Note SE-73. 2 p.

Roach, B. A., and S. F. Gingrich.
1968. EVEN-AGED SILVICULTURE FOR UPLAND CENTRAL HARDWOODS. USDA Agric. Handb. 355. 39 p.

Rogers, N. F., and K. A. Brinkman.
1965. SHORTLEAF PINE IN MISSOURI, UNDERSTORY HARDWOODS RETARD GROWTH. USDA For. Serv. Res. Pap. CS-15. 9 p.

Russell, T. E.
1961. CONTROL OF UNDERSTORY HARDWOODS FAILS TO SPEED GROWTH OF POLESIZE LOBLOLLY. USDA For. Serv. South. For. Notes No. 131, South. For. Exp. Stn., New Orleans, La. 4 p.

Zahner, R.
1958. HARDWOOD UNDERSTORY DEPLETES SOIL WATER IN PINE STANDS. For. Sci. 4: 178-184.