NITROGEN FERTILIZATION AND THINNING OF OAK STANDS IN THE OZARKS: EFFECTS ON SOIL NITROGEN, GROWTH, AND NITROGEN UPTAKE OF UNDERSTORY VEGETATION

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Abstract.--Effects of overstory thinning and fertilization with ammonium nitrate in overstocked stands of oak (*Quercus* spp.) were investigated. Total soil N was significantly increased by overstory thinning. Slight increases in total soil N resulted from fertilization, but these changes were not significant. However, fertilization significantly increased N uptake and understory production over the span of the study. These increases were greatest at the 40 percent stocking level and least in nonthinned stands.

Keywords: Soil nutrients, biomass, forest soils, forest fertilization, wildlife habitat.

INTRODUCTION

With few exceptions, most hardwood fertilization research has primarily been concerned with evaluation of growth responses and nutrient uptake of the overstory. Effects on soils and understory vegetation have received little attention.

It is well documented that thinning stimulates development of understory vegetation in typical Ozark upland oak types (Crawford 1971, 1976). While increases in the understory component serves as an increased source of food and cover for wildlife, competition with overstory trees for soil and fertilizer nitrogen may also occur. On the other hand, the understory may provide a valuable sink for fertilizer nitrogen (N) that will be released over time through decomposition and mineralization.

This paper examines the short-term effects of overstory thinning and N fertilization of upland oak stands on: 1) total soil N at the 0 to 15 and 15 to 30cm depths, 2) production of understory vegetation, and 3) N content of understory vegetation.

METHODS

Study Area

Stands utilized for the study were located on the Ozark National Forest in

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the Boston Mountain region of northwest Arkansas. The Boston Mountains are remnants of an old plateau which is characterized by a series of steep slopes formed by interbedded shales and benches formed by sandstones. Soils within the area are classified as Typic Paleudults, Typic Hapludults, and Lithic Hapludults. They include the Enders, Linker, Mountainburg, and Nella series. Elevations range from 275m in the valley bottoms to 790m above sea level at the highest point.

Annual precipitation ranges from 1160 to 1220mm with March, April, and May having the highest precipitation. Extended summer dry periods are common, and autumn is usually dry. There are normally 180 to 200 frost-free days.

Sample Plots and Treatments

Thirty-six fertilized-nonfertilized sample plots in 18 upland oak stands thinned in 1976 and 1977 were selected for evaluation of understory responses to thinning and fertilization[4/]. Stand ages ranged from 40 to 70 years, and red oak site index ranged from 15.2 to 24.4m at 50 years. Before thinning, stand basal areas averaged 25 m^2/ha with a range of 21 to 31. Most stands were overstocked before thinning, and prethinning stocking levels varied from 99 to 135 percent of full stocking (Gingrich 1967) with an average of 116 percent.

The overstory of the 18 stands was dominated by three species: white oak (*Quercus alba* L.) northern red oak (*Q. rubra* L.) and black oak (*Q. velutina* Lam.). These three species contributed more than 80 percent of the basal area before thinning and more than 90 percent after thinning. Less abundant species included hickory (*Carya* spp.), blackgum (*Nyssa sylvatica* Marsh.), black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), red maple (*Acer rubrum* L.), post oak (*Q. stellata* Wang.), black walnut (*Juglans nigra* L.) and black locust (*Robinia pseudoacacia* L.).

Understory stems taller than 1.37m and 2.5 to 10.2cm dbh were abundant on all plots and averaged 1630/ha. Major understory species included flowering dogwood (*Cornus florida* L.), red maple, hickory, blackgum, serviceberry (*Amelanchier arborea* (Michx. F.) Fern), redbud (*Cercis canadensis* L.), hophornbeam (*Ostrya virginiana* [Mill.] K. Koch), Carolina buckthorn (*Rhamnus caroliniana* Walt.) and pawpaw (*Asimina triloba* (L.) Dunal). Understory vegetation 1.37m or less in height was characterized by the browse species Virginia creeper (*Parthenocissus quinquefolia* [L.] Planch.), poison-ivy (*Rhus radicans* L.), grape (*Vitis* spp.), blueberry (*Vaccinium* spp.), greenbrier (*Smilax* spp.) and numerous herbaceous species. More detailed descriptions of stand structure and species composition of the treated stands have been provided by Graney (1980) and Snyder (1980).

Stands were thinned in late winter of either 1976 or 1977 to create three levels of stocking. These were residual stands with 40, 60 or 100+ (nonthinned control) percent of full stocking as described by Roach and Gingrich (1968). Stands were thinned mostly from below to favor the highest quality overstory

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4/ Sample plots utilized in this study were selected from 105 permanent plots installed between 1976-1978 in conjunction with upland oak growth and yield and understory development research studies by USDA Forest Service, Southern Forest Experiment Station, Fayetteville, AR.

stems. Larger culls and poor quality stems were removed first, followed by intermediate and suppressed trees of low quality or vigor. Higher quality desirable species were cut if necessary to obtain the desired residual stocking and spacing.

From each of the 18 paired plots receiving the same overstory thinning treatment, one plot was randomly selected to receive a fertilizer treatment one year after thinning. The 18 plots were fertilized with ammonium nitrate (NH_4NO_3) at the rate of 336kg of N/ha in late April or early May of either 1977 or 1978.

The plots were square and varied in size from 0.16 to 0.20ha. Sixteen understory quadrats, each measuring 2.01 x 2.01m, were arranged on each plot, with four quadrats located on each of four equally spaced transects. Understory vegetation and soils data were collected every August over a period of 3 years. The first collection was conducted prior to fertilization but after thinning, and the last two were completed after the fertilization treatment.

Sampling and Analyses

The yield of understory vegetation on each timber plot was determined by a double-sampling technique. Green weights of current annual growth of woody species were visually estimated to a height of 1.52m on each understory quadrat. Herbage production was estimated on the NW quarter of each quadrat. The relative amount of each species' annual growth that was browsed (utilized) by herbivorous wildlife was also visually estimated. Two quadrats were selected randomly from the 16, and annual growth was clipped, composited, and weighed following the visual estimation of green weights. Fruits were not included in the forage yield.

Plot samples of clipped vegetation were taken to the laboratory, oven dried at 65°C, and weighed. The ratio between actual dry weight and estimated green weight on clipped quadrats was then determined and used to correct the green weight estimates to a dry weight per hectare production basis.

Because 2 of the 16 quadrats on each timber plot were destructively sampled, new quadrat locations were established each year.

Soils were sampled annually on four of the understory quadrats on each plot at depths of 0 to 15 and 15 to 30cm, using a bucket auger. Loose, nondecomposed litter was carefully brushed away prior to sampling. The decomposed litter was a constituent of the 0 to 15cm sample. Two of the sample quadrats were those on which the understory had been clipped; the other two quadrats were initially chosen at random and were the same on all plots.

Soil samples were air dried, crushed, screened to pass through a 2mm sieve, and analyzed for total N by semi-micro Kjeldahl procedures (Bremmer 1965).

Understory vegetation samples were separated into leaf and twig fractions of woody plants, and herbaceous tissues. Individual samples of oven-dried material were then ground in a Wiley mill to pass through a 20-mesh screen, and wet-ashed in sulfuric acid and hydrogen perioxide. N analysis of the digestate was performed using semi-micro Kjeldahl distillation.

The statistical design for the understory yield portion of the study was a split-plot with stocking levels serving as the whole plots and fertilizer treatments as the subplots. Differences among treatment means were determined at the .05 level of significance using Fisher's F-protected L.S.D. (Chew, 1977).

Soil and understory N data were collected each year on fertilized plots but were available for nonfertilized plots only in 1978. Design for the soil and understory N portions of the study was completely randomized with separate analyses of variance for both soil depths and the three understory vegetation components.

RESULTS AND DISCUSSION

Soil Nitrogen

Overstory thinning significantly increased total soil N at both depths over the three growing seasons. The surface soil had the greatest N levels. At both soil depths, nonthinned stands had the lowest soil N levels, the 40 percent stocking was intermediate, while the 60 percent stocking exhibited the highest N levels. Levels of soil N at the 40 percent and 60 percent stocking levels did not differ significantly at the 15 to 30cm depth.

A slight increase in total soil N occurred at both the 40 and 100 percent overstory stocking levels following fertilization but not at the 60 percent stocking (Figure 1). However, the total soil N levels in both soil depths at the 60 percent stocking showed a large increase one year after fertilization.

Although the effects of fertilization on total soil N could not be tested in this study, it is probable that fertilization maintained the high levels of soil N in thinned stands over the second and third years of the study. Total soil N levels for nonfertilized stands collected in 1978 (representing second year data for 7 stands and third year data for 11 stands) indicated that soil N levels at the 0 to 15cm depth for 40 and 60 percent stocking treatments were 0.11 and 0.13 percent respectively at year 2. Nonfertilized stands in their third year had soil N levels at 40 percent stocking that averaged 0.10 percent while stands thinned to 60 percent stocking averaged 0.13 percent. The same relationship also held for the 15 to 30cm soil N levels. This could indicate that soil N levels increase quickly following thinning due to rapid litter decomposition and incorporation of organic N into the soil. This would be followed by a 2 or 3 year decline to pretreatment N levels.

The higher levels of soil N, prior to fertilization, observed in stands thinned to 60 percent stocking may have been caused by a more favorable microenvironment created at that particular stand density. This would have permitted greater mineralization and uptake of soil N reserves the year fertilizer was applied. The year following fertilization, the increase in N at both soil depths (Figure 1) at the 60 percent stocking may be attributed to recycling of N to the soil through decomposition of N enriched litterfall, enhanced by an abundant microflora (Wollum and Davey 1975; Kelly and Henderson 1978).

The surface soil N levels for the nonthinned stands averaged about 0.1 percent (Figure 1) and were generally much lower than N levels reported for upland oak forests in other regions (Table 1). Such low soil N values for nonthinned forest stands would explain the significant short-term growth responses of overstory (Graney and Pope 1978) and understory vegetation to N fertilization in the Boston Mountain area.

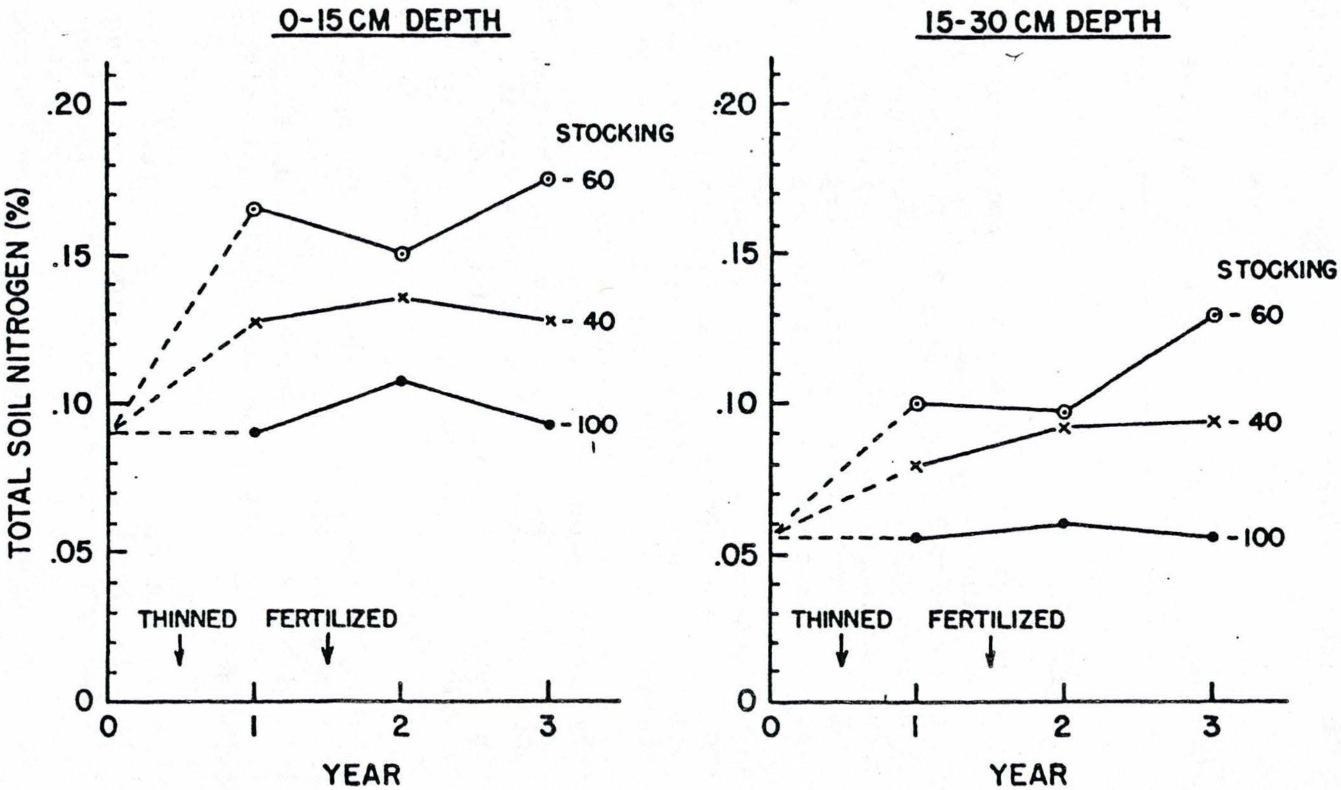

Figure 1.--Change in total soil nitrogen content of the 0 to 15 and 15 to 30cm depths following thinning and fertilization in the fertilized stands.

Table 1.--Soil orders, location, and total surface soil nitrogen levels of upland oak and oak-hickory forests from selected literature.

Soil Order	State	Total Soil N(%)	Reference
Ultisol	Tennessee	0.21	Kelly and Henderson 1978
Alfisol	North Carolina	0.20	Montes and Christenson 1979
Alfisol	Missouri	0.26	Rochow 1975
Inceptisol	Pennsylvania	0.20	Ward and Bowersox 1970

Understory Vegetation Production

Browse Production.--Thinning overstocked upland oak stands resulted in significant increases in dry weight production of woody understory species, and production increased significantly over the next 2 years (Table 2, Figure 2). Fertilization of thinned stands resulted in significantly greater production than attained with thinning alone, and production increased significantly with time since fertilization (Table 2, Figure 3). In nonthinned stands, the dry-weight production of understory vegetation was about the same in fertilized and nonfertilized stands.

Increases in browse production in the thinned stands were primarily due to sprouting of cut overstory and understory stems as well as from increased growth of vines such as grape, poison-ivy, and Virginia creeper. Much of the additional production in fertilized stands probably resulted from increased growth of vines and possibly from additional twig and leaf production of individual sprouts (George and Powell 1977). Understory growth in overstocked stands is probably restricted by a number of factors, including heavy shade, inadequate soil moisture during summer dry periods, and low levels of available soil N. Since dominant and codominant overstory oak species in overstocked stands respond significantly to N fertilization (Graney and Pope 1978), it is probable that light and soil moisture were the primary factors limiting understory growth in the nonthinned stands.

Differences in understory response to intensity of thinning were not apparent until the third growing season following thinning. While increases in dry weight production at the 40 percent stocking level were essentially linear from years 1 through 3, the rate of increase for the 60 percent stocking treatment began to decline by the third growing season.

Although dry weight production on both fertilized and nonfertilized thinned stands increased significantly over the 3-year period, the percentage of twigs and leaves changed only slightly and was not influenced by fertilization. Leaf weight averaged about 70 percent of the annual dry weight production for stands thinned to 40 percent stocking. In stands thinned to 60 percent stocking, leaves made up 70 percent of the total weight during the first year after thinning and 80 percent of the total during the second and third years. In nonthinned stands, leaves contributed 80 to 85 percent of annual production each year.

Table 2.--Effects of thinning and fertilization on mean annual dry weight production of browse and herbage.

Year[1]	Nonfertilized: Percent Stocking 100	Nonfertilized: Percent Stocking 60	Nonfertilized: Percent Stocking 40	Fertilized: Percent Stocking 100	Fertilized: Percent Stocking 60	Fertilized: Percent Stocking 40
	(kg/ha)			(kg/ha)		
BROWSE						
1	111.1[2]	182.8	180.1	97.1	189.5	198.5
2	110.6	326.1	346.9	118.6	479.5	485.3
3	116.7	494.5	518.8	144.0	670.5	739.4
HERBAGE						
1	21.1	19.9	26.1	9.0	17.4	16.4
2	20.3	42.0	43.3	6.8	41.4	46.2
3	23.2	42.6	65.2	5.9	40.9	98.1

1/ Stands were thinned in year 1 and fertilized in year 2.

2/ Interactions were significant, thus no significant difference comparisons were made.

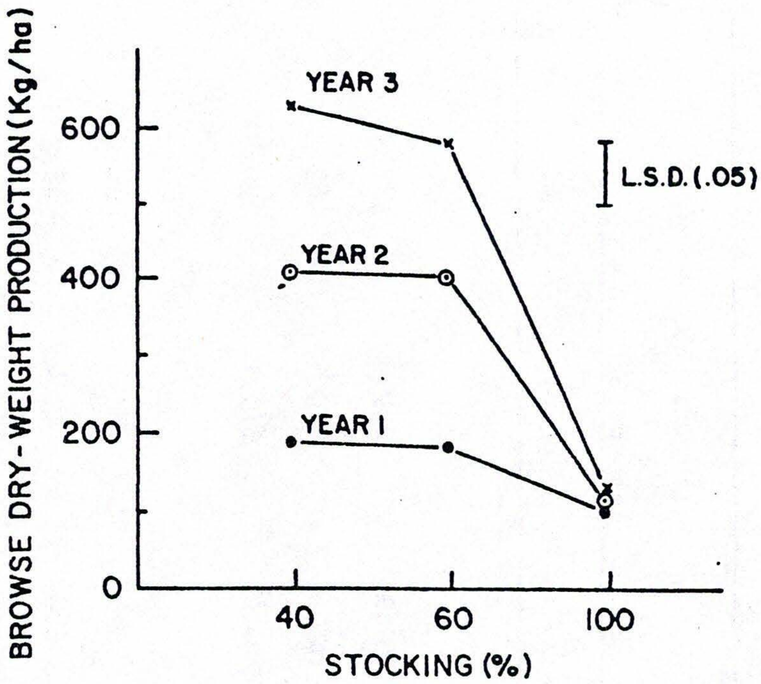

Figure 2.--Effects of thinning and time since thinning on browse production. Data averaged across fertilized and nonfertilized treatments.

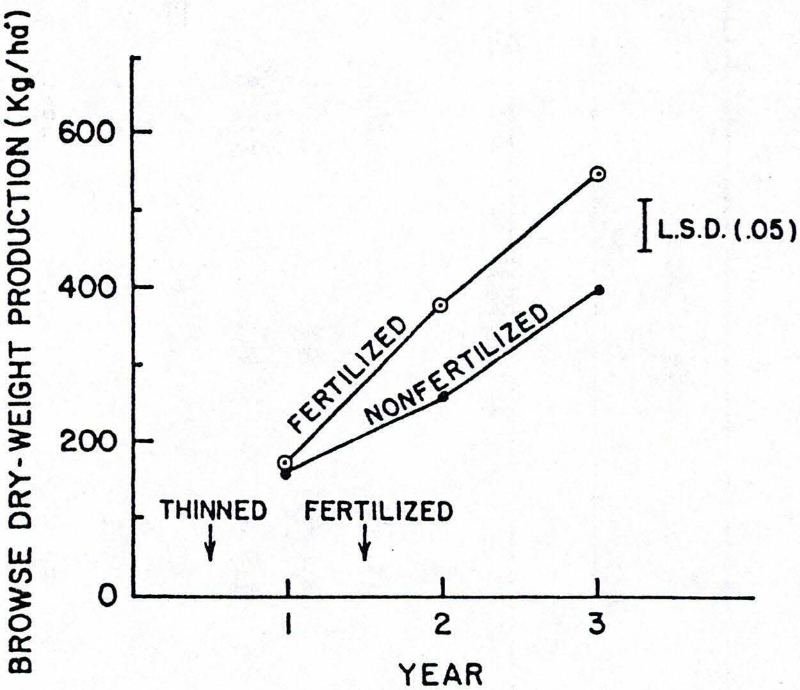

Figure 3.--Effects of fertilization and time since fertilization on browse production. Data averaged across all stocking treatments.

Herbage Production.--Growth of understory forbs and grassés was significantly increased by thinning but not by application of fertilizer (Table 2). Herbage response occurred the second growing season following thinning. However, herbage production continued to increase through the third year in the heavily thinned stands (40 percent stocking), while production in stands thinned to 60 percent stocking showed little or no change between the second and third years (Figure 4).

The increase in herbage production after thinning was primarily due to proliferation of species most abundant before thinning. Aster (*Aster* spp.), goldenrod (*Solidago* spp.), hog peanut (*Amphicarpa* spp.), tickclover (*Desmodium* spp.), cinquefoil (*Potentilla* spp.), and bedstraw (*Galium* spp.) were the more common forbs before and after treatment. Grasses (*Brachyelytrum* spp., *Muhlenbergia* spp., and *Panicum* spp.) and sedges (*Carex* spp. and *Scleria* spp.) were common on most plots and accounted for about 40 percent of the dry weight in thinned stands. Ferns (*Thelypteris* spp., *Polystichum* spp., and *Botrychium* spp.) were present on most plots but contributed little to total dry weight.

Nitrogen Concentrations of Understory Vegetation

The N concentration of each understory forage component increased significantly following fertilization but was not significantly influenced by overstory stocking. Greatest increases for all understory components occurred the year of fertilization (year 2). However, while the N concentrations of browse leaves remained high during the year following fertilization (year 3), the content for twigs and herbage fell to near prefertilization levels during this period (Table 3). N concentrations for nonfertilized understory components (sampled only during the 1978 growing season) are very similar to prefertilization levels for the fertilized stands.

Total N yield in understory components averaged about 10 kg/ha after 3 years in the thinned and fertilized stands. This was about 40 percent greater than contents in the thinned and nonfertilized stands. With such high N levels in leaves and herbs, sizable quantities of N will be recycled following annual leaf abscission and decomposition.

Understory Utilization

Increased utilization of the understory vegetation by white-tailed deer occurred on all plots following N fertilization. Utilization on nonfertilized plots was generally less than 1 percent of the annual growth and was restricted to more preferred species such as summer grape (*Vitis aestivalis* Michx.) and honeysuckle (*Lonicera* spp.). On fertilized plots, utilization ranged from 20 to 30 percent of annual production with 80 percent or more of the grape and honeysuckle eaten. Other heavily utilized species included poison-ivy, Virginia creeper, greenbrier, and blackgum sprouts.

The only commercially desirable overstory species browsed to any extent was black cherry, and utilization was generally less than 5 percent. Oak sprouts or seedlings were rarely utilized. Browsing of the herbs was variable on all plots, ranging from 5 to 20 percent on nonfertilized plots and 20 to 60 percent on fertilized plots. Utilization was greatest the year plots were fertilized but declined the following year. Apparently the increased N levels and other changes in plant chemistry, due to fertilization, increased the palatability of these plants to deer. Both the quantity and nutritional quality of browse plants increased as a

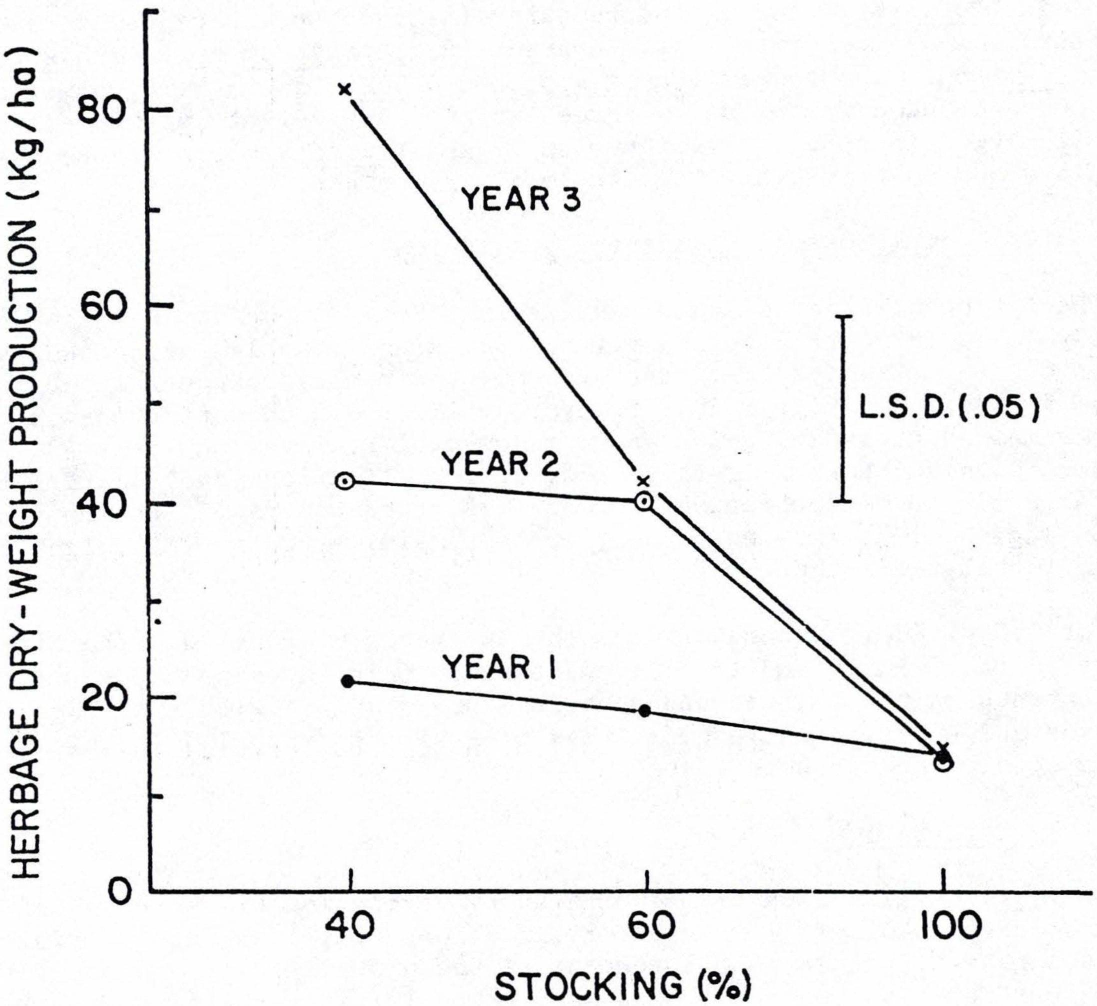

Figure 4.--Effects of thinning and time since thinning on herbage production. Data averaged across fertilized and nonfertilized treatments.

result of overstory thinning and N fertilization. Other studies have shown similar improvements resulting from N fertilization (Abell and Gilbert 1974; Anderson et al. 1974; George and Powell 1977).

Table 3.--Nitrogen concentration of browse leaves, browse twigs, and herbage from fertilized and nonfertilized stands.1/

Year	Browse Leaves	Browse Twigs	Herbage
		Understory Component2/	
		Fertilized Stands	
1	1.358 a3/	0.506 a	1.178 a
2	1.818 c	0.838 b	2.339 b
3	1.685 b	0.611 a	1.425 a
		Nonfertilized Stands	
2	1.404	0.504	1.126
3	1.316	0.617	1.243

1/ Nitrogen concentrations for nonfertilized stands were obtained for the one growing season only (1978), and represent the second (for 7 stands) and third (for 11 stands) years since thinning.

2/ Data averaged over all stocking levels and presented as % of dry weight.

3/ Means within a column followed by the same letter are not significantly different at the 0.05 level.

CONCLUSIONS

Total soil N levels at the 0 to 15 and 15 to 30cm depths increased significantly following overstory thinning but indicated little change after fertilization. Production of leaves and twigs of woody plants, as well as herbage, increased significantly with increasing intensity of overstory thinning. In thinned stands, N content of leaves, twigs, and herbs increased, and understory production increased for 3 growing seasons after a reduction in overstory stocking. N fertilization increased annual leaf and twig production but did not significantly influence herbage production. Browsing of the understory increased markedly following fertilization.

The total N content in the fraction of understory plant tissue sampled in this study was generally less than 10 kg/ha, and is small relative to the total amount of N in the ecosystem. However, these small quantities may play an integral role in maintaining N cycle balances. Further studies should attempt to determine the long-term effects of thinning and fertilization on nutrient cycles in upland hardwood forests.

LITERATURE CITED

Abell, D.H. and F.F. Gilbert. 1974. Nutrient content of fertilized deer browse in Maine. J. Wildl. Manage. 38:517-524.

Anderson, B.L., R.D. Pieper, and V.W. Howard, Jr. 1974. Growth response and deer utilization of fertilized browse. J. Wildl. Manage. 38:525-530.

Bremner, J.M. 1965. Total nitrogen. p. 1149-1178. In C.A. Black (ed.) Methods of Soil Analysis. Part 2. Chemical and microbiological properties. Agronomy Monograph 9. American Society of Agronomy, Madison, WI.

Chew, V. 1977. Comparisons among treatment means in an analysis of variance. U.S. Agri. Res. Serv. ARS-H-6, 64p.

Crawford, H.S. 1971. Wildlife habitat changes after intermediate cutting for even-aged oak management. J. Wildl. Manage. 35:275-286.

Crawford, H.S. 1976. Relationships between forest cutting and understory vegetation: an overview of eastern hardwood stands. USDA, For. Serv. Res. Pap. NE-349, 9p.

George, J.F. and J. Powell. 1977. Deer browsing and browse production of fertilized American elm sprouts. J. Range Manage. 30:357-360.

Gingrich, Samuel F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. For. Sci. 13:38-53.

Graney, D.L. 1980. Midsouth upland hardwood site-yield potentials. P. 33-49. In Proceedings Mid-south Upland Hardwood Symposium for the Practicing Forester and Land Manager. USDA, For. Serv. Tech. Publ SA-TP 12, 186p.

Graney, D.L. and P.E. Pope. 1978. Fertilization increases growth of thinned and nonthinned upland oak stands in the Boston Mountains of Arkansas. USDA, For. Serv. Res. Note SO-243, 4p.

Kelly, J.M. amd G.S. Henderson. 1978. Nutrient flux in litter and surface soil after nitrogen and phosphorous fertilization. Soil Sci. Soc. Am. J. 42:963-966.

Montes, R.A. and N.L. Christenson. 1979. Nitrification and succession in the Piedmont of North Carolina. For. Sci. 25:287-296.

Roach, B.A. and S.F. Gingrich. 1968. Even-aged silviculture for upland central hardwoods. USDA Agri. Hdbk. 355, 39p.

Rochow, J.J. 1975. Mineral nutrient pool and cycling in a Missouri forest. J. Ecol. 63:985-994.

Snyder, C.S. 1980. The effects of nitrogen fertilization and thinning on soil fertility, and on growth and nutrient uptake of understory in upland oak stands in Arkansas' Boston Mountains. 93p. Unpublished M.S. Thesis. University of Arkansas, Fayetteville, AR.

Ward, W.W. and T.W. Bowersox. 1970. Upland oak responses to fertilization with nitrogen, phosphorous, and calcium. For. Sci. 16:113-120.

Wollum, A.G. and C.B. Davey. 1975. Nitrogen accumulation, transformation, and transport in forest soils. p. 67-107. In B. Bernier and C.H. Winget (eds.). Forest Soils and Forest Land Management. Laval University Press, Quebec.