GROWTH RESPONSE OF UPLAND OAK STANDS IN THE BOSTON MOUNTAINS TO NITROGEN FERTILIZATION [1]

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Abstract. Seventy 1-acre plots representing a range of site indexes and stand ages were installed on the Ozark National Forest between 1975 and 1977. Plots were selected so they could be paired according to similarities in age, site index, species composition, and stand structure. The 35 plot pairs were thinned to residual densities of 40 to 100 percent stocking. One plot in each pair was fertilized with 300 pounds per acre of nitrogen applied as ammonium nitrate in the spring of the second growing season following thinning. Plots were inventoried before thinning and 5 and 10 years after thinning. Regression analysis was used to analyze the effect of age, site index, residual basal area, growth period, and fertilizer treatment on basal area and total cubic foot volume growth. The fertilizer application affected survivor growth and ingrowth of both volume and basal area. However, mortality apparently was not affected by fertilization. Some growth components also differed by 5-year growth periods. The findings indicate that these stands will respond to fertilizer treatments for 5 to 10 years after application.

Introduction

In the early 1970's several hundred thousand acres of forest land in northern Arkansas supported overstocked, even-aged, pole-sized stands of oaks and associated species. Although many stands were on medium-to-good sites (with site indexes of 60 to 70 feet at 50 years), diameter growth averaged only about 1 inch in 10 years. Limited outlets for small diameter hardwoods discouraged intermediate cutting in these stands. However, because demands for hardwood sawtimber were increasing and inventories of mature sawtimber were small, some land managers started noncommercial thinning and fertilization programs to accelerate growth of potential crop trees. Results from preliminary fertilizer trials in the Boston Mountains indicated that northern red (*Quercus rubra* L.), black (*Q. velutina* Lam.), and white (*Q. alba* L.) oak crop trees would respond to nitrogen (N) fertilization (Graney 1983, 1987; Graney and Pope 1978a, 1978b). Between 1975 and 1977, the USDA Forest Service, Southern Forest Experiment Station research project in Fayetteville, Arkansas, installed a stocking and fertilization study in the Boston Mountains of northern Arkansas (fig. 1). The purpose of the study was to evaluate growth and yield responses of upland oak stands to thinning and N fertilization.

The objectives of this paper are to describe the 10-year growth response of upland oak stands to N fertilization and how this response is affected by stand age, site index, and residual basal area.

Methods

Study Region

The Boston Mountains are the highest and southernmost member of the Ozark Plateaus physiographic province (fig. 1). They form a band 30 to 40 miles wide and 200 miles long from north central Arkansas westward into eastern Oklahoma. Elevations range from about 900 feet in the valley bottoms to 2,500 feet at the highest point. The plateau is sharply dissected, and most ridges are flat to gently rolling and are generally less than one-half mile wide. Mountain slopes consist of an alternating series of steep simple slopes and gently sloping benches.

Soils common to mountain tops and slopes are shallow to medium in depth and are represented by medium-textured members of the Hartsells, Linker, and Enders series (Typic Hapludults). They are derived from sandstone or shale residuum and are rated medium to low in productivity. In contrast, soils common to mountain benches are deep, well-drained members of the Nella and Leesburg series (Typic Paleudults) that developed from sandstone and shale colluvium. These soils are rated medium to high in productivity.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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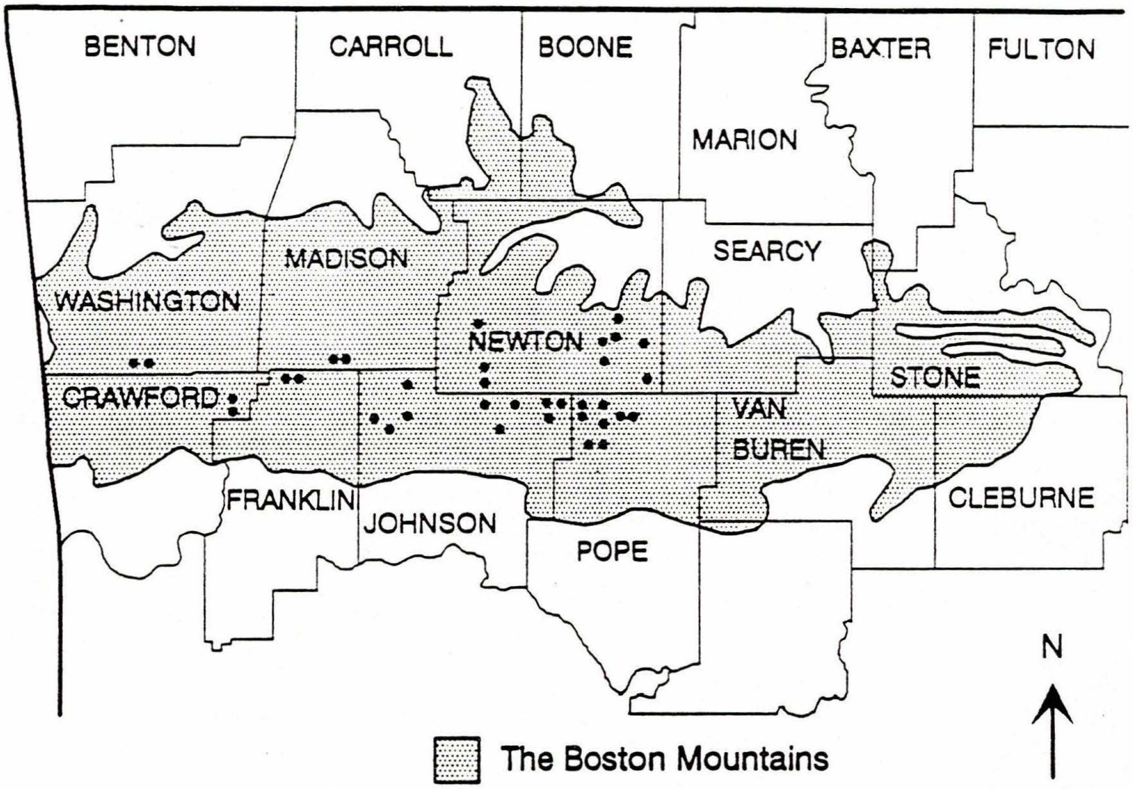

Figure 1. *Study plot locations in the Boston Mountains of Arkansas.*

Rocks in the area are sedimentary and of Pennsylvanian age and consist of alternating horizontal beds of shales and sandstones. Annual precipitation averages 46 to 48 inches, with March, April, and May being the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

Study Description

This study is based on 70 permanent, 1-acre plots (a 0.4- or 0.5-acre net plot plus a 33-foot buffer) distributed across the Boston Mountains in Arkansas (fig. 1). Stand age at the time of initial thinning varied from 36 to 75 years. Site indexes for northern red or black oaks ranged from 46 to 82 feet (with a base age of 50 years). All plots were established in fully stocked, even-aged upland hardwood stands that showed no evidence of recent fire or cutting. Plots were installed over a 3-year period between 1975 and 1977.

Measurements consisted of a complete inventory of trees larger than 0.5 inch in d.b.h. measured to the nearest 0.1 inch. Total heights of sample trees, which were selected at random in proportion to the number of stems in each 1-inch d.b.h. class (before and after thinning), were obtained for each plot. Four levels of stocking were created by thinning. Residual stands were left with 40, 60, 80, or more than 100 percent of full stocking based on a tree-area equation for upland oak stands by Gingrich (1967). Thinning was mostly from below. Culls and poor quality stems were removed first, followed by intermediate and suppressed stems of low quality and vigor. High quality stems of desirable species were cut only to attain the residual stocking goal and a uniform spatial distribution.

Although 43 tree species were represented on one or more plots, black, northern red, and white oaks account for 90 percent of the total basal area over all plots after thinning (table 1). Plots with site indexes of 50 and 60 were predominantly occupied by white oaks, those with a site index of 70 were occupied by both red and white oaks, and those with a site index of 80 were predominantly occupied by red oaks. Other desirable species such as black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), and black walnut (*Juglans nigra* L.) were present only as scattered individual trees on most plots and account for only about 1 percent of the total basal area. Hickories (*Carya* spp.), blackgum (*Nyssa* *sylvatica* Marsh.), and other species represented 9 percent of the total basal area after thinning, but these species were more common in the midstory and understory positions on most plots.

Table 1. *Average number of stems and basal area per acre by tree and shrub species group[1] for study plots after thinning.*

Species	Stems /acre	Basal area (ft^2/acre)
Group 1	113	35.7
Group 2	64	31.9
Group 3	3	1.0
Group 4	29	4.7
Group 5	21	1.9
All groups	230	75.2

[1] Group 1: White oak.
Group 2: Black oak, northern red oak, southern red oak.
Group 3: Ash, basswood, black cherry, black walnut, cucumbertree, shortleaf pine.
Group 4: Beech, blackgum, blackjack oak, black locust, chinkapin oak, elm, hackberry, hickory, post oak, red cedar, sugar maple.
Group 5: Blackhaw, buckeye, devils-walkingstick, dogwood, Indian-cherry, hophornbeam, mulberry, Ozark chinkapin, pawpaw, persimmon, redbud, red haw, sassafras, serviceberry, spicebush, tree-huckleberry, umbrella magnolia, wild plum, witch-hazel, miscellaneous understory shrubs.

Plots were selected so they could be paired according to similarities in age, site index, species composition, and stand structure. Individuals of each plot pair were usually contiguous (or located in the same stand) and received the same residual stocking treatment. One plot in each pair was randomly selected to receive a single fertilizer application of 300 lb of N per acre applied as ammonium nitrate (34-0-0) 1 year after the thinning treatment. Fertilizer was broadcast with hand cyclone seeders in late April or early May of 1977, 1978, and 1979 following full leaf-out on the selected plots. Even distribution was achieved by dividing each plot into four equal parts and applying a premeasured amount of fertilizer to each one-quarter plot.

Analysis

Seventy plots (35 fertilized and 35 nonfertilized) were used in this analysis; all plots had two 5-year growth periods for a total of 140 observations. Plot basal area per acre was calculated for all live trees 2.6 inches in d.b.h. and larger for each plot measurement.

Plot volumes were calculated by first constructing height-d.b.h. curves for each plot and each measurement to obtain heights for nonsample trees. All species were grouped because some species were not present in sufficient numbers to make up separate groups. Examination of scatter plots and preliminary regression analyses showed no gain by separating the height-d.b.h. measurements into species groups. Tree volumes were calculated using the equations from Clark and others (1986). All volumes are total cubic foot volume, inside bark, from ground level to tip, excluding branches, for all live stems 2.6 inches d.b.h. and larger.

Basal area and volume growth were the response variables that were measured. However, looking at net growth alone has limitations. First, fertilization can affect growth components differently. For example, fertilization may increase the growth of trees and simultaneously accelerate stand development, which may result in more mortality. These effects can cancel each other, and an analysis of net growth might show no fertilizer effect. Thus, no insight into how fertilization might be affecting stand development is gained. Therefore, the components of growth--survivor growth, mortality, and ingrowth--were observed as response variables rather than net growth.

Ingrowth basal area and volume are for trees that grew past the 2.6-inch d.b.h. threshold during the study measurement periods. Mortality equals the initial basal area or volume of trees that were alive at the initial measurement, but died during the growth period. Survivor growth equals the increase in volume or basal area of trees that were present at the beginning of the growth period and survived during the entire measurement period.

The variables stand age, basal area, and site index are important determinants of even-aged stand growth and development. Although the plots were carefully paired in this study, a mere paired comparison of growth affords little insight into how fertilizer response might vary with changes in these other variables, and it ignores the possible interaction of a fertilizer treatment with stand and site variables. This study also had two growth periods, and stand growth on both fertilized and nonfertilized plots might vary by growth period. Various authors (Auchmoody 1985, Farnum 1979, Lipas 1979, McWilliams 1990) have suggested the use of regression or analysis of covariance to incorporate stand or tree variables into the analysis and as a means to test slope heterogeneity.

Nonlinear regression (SAS Institute 1988) was used to describe the effect of stand variables, fertilizer application, and measurement period on growth and to test slope heterogeneity. Dummy variables were used to represent the fertilized and nonfertilized plots and the growth periods. The initial full model was:

$$Y = \exp[b_0+b_1P+b_2F+b_3B+b_4A+b_5Q+b_6PB+ b_7PA+b_8PQ+b_9FB+b_{10}FA+b_{11}FQ] \qquad (1)$$

where

Y = growth component of interest,
P = growth period (0 = period 1, 1 = period 2),
F = fertilizer treatment (0 = nonfertilized, 1 = fertilized),
B = initial basal area (ft^2/acre),
A = initial stand age (years),
Q = site index (ft, base age 50 years), and
b_i = coefficients to be determined.

A reduced model for each growth variable was then derived from the full model by inspecting the t-ratio of each parameter estimate and deleting those whose probability level was greater than 0.90. The reduced model was then fitted and examined carefully for logical relationships, patterns in the residuals, and correct model specification.

Results and Discussion

Table 2 gives the fit index and root-mean-square error for each equation. The trend was the same for both basal area and volume; survivor growth had the highest fit index, mortality was next, and ingrowth was last. With a fit index of less than 0.11 for both basal area and volume, the ability to explain ingrowth with the observed variables was quite poor.

The resulting equation for basal area survivor growth is:

$$Y1 = \exp[1.1573+0.18622F-0.0082256A+ 0.00082029PB] \qquad (2)$$

where Y_1 is basal area survivor growth in square feet per acre. During the first growth period, only stand age and fertilizer treatment were significantly related to survivor basal area growth (fig. 2). The addition of fertilizer effectively increased growth 20 percent over the nonfertilized plots for each growth period. In the second period, initial basal area became an additional factor (fig. 2). Close examination of the growth data supported the trends indicated by equation (2).

Table 2. *Goodness-of-fit statistics for growth component equations.*

Growth Component	Fit index[1]	Root Mean Square Error
Basal area:		Ft^2/*acre*
Survivor growth	0.40	0.37
Mortality	0.36	0.61
Ingrowth	0.10	0.13
Volume:		Ft^3/ac
Survivor growth	0.68	10.1
Mortality	0.31	13.5
Ingrowth	0.11	1.4

[1] $\text{Fit index} = 1 - \frac{\sum (y_i-\hat{y}_i)^2}{\sum (y_i-\bar{y})^2}$

Comparisons of growth responses in this study with other upland oak fertilization results are difficult because the present study is based on stand level growth, whereas previous studies have reported responses of individual dominant and codominant crop trees (Auchmoody 1986). However, the 20-percent increase in basal area growth observed here is comparable to responses reported for individual oak crop trees in the Boston Mountains (Graney 1983, 1987) and elsewhere (Auchmoody 1986). However, the continued response through the second growth period is unusual in that response to N fertilization is usually maximum for the first 2 years after treatment, then it declines rapidly and ends by the fourth or fifth year. But Graney (1987) reported that whereas responses of white oak crop trees to N fertilization ended after the fifth year, responses of northern red and black oak crop trees remained significant for 9 years. In this study, fertilizer was applied in the spring of the second growing season after plot establishment. Therefore, period one represented a 4-year response to fertilization, whereas period two represented a 5-year response. Younger stands produced the greatest growth responses to N fertilization in each growth period, but the percentage of increase was about 20 percent for all age classes (fig. 2).

Stand response to fertilization during the first growth period may have been significantly reduced by the severe 1980 drought. Although growth of all trees was affected, fertilized trees probably suffered the greatest reductions in growth. Graney (1987) reported

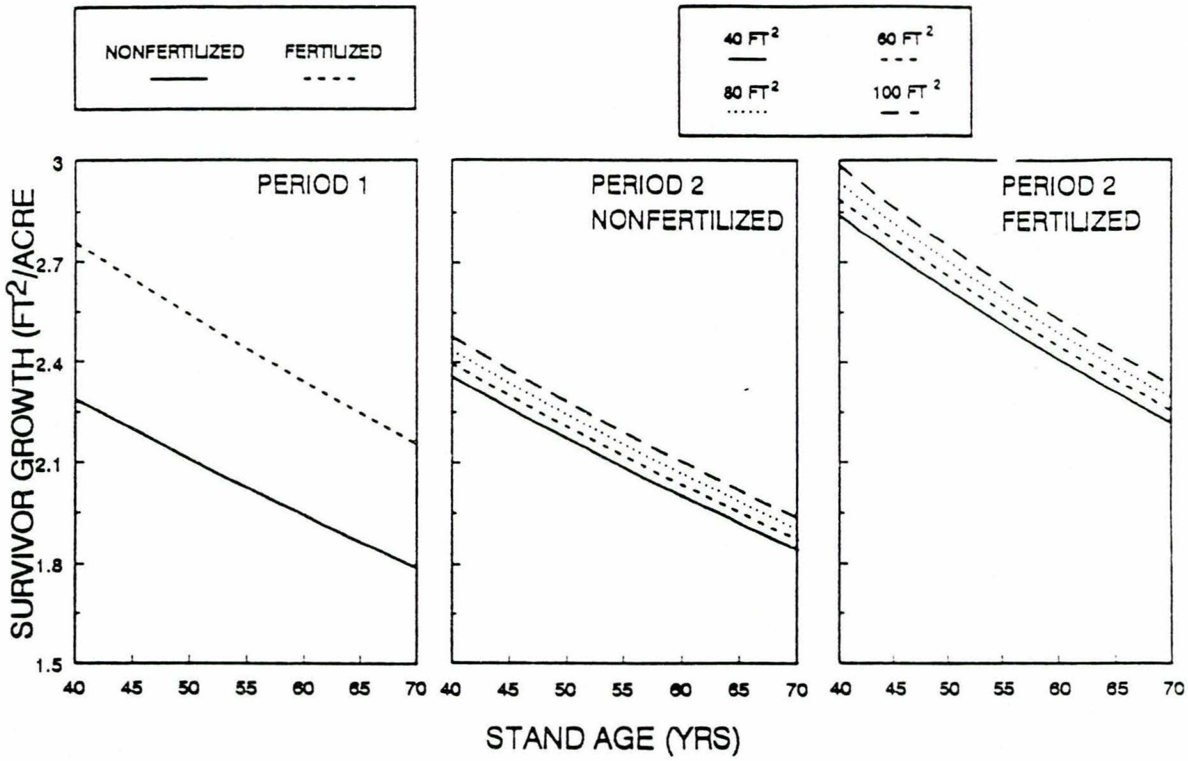

Figure 2. *Average annual basal area survivor growth for 10 years after treatment for upland oak stands in the Boston Mountains.*

that growth of fertilized red and white oak crop trees was 30 to 50 percent greater than nonfertilized trees through 1979, but was equal to or less than nonfertilized trees in 1980.

The delayed response to thinning (initial basal area) may be attributed to prethinning stocking levels, which ranged from 100 to 130 percent (Graney 1980). With the exception of a few dominant and codominant trees on each plot that were free to grow, most trees (especially white oaks) were tightly grown, small crowned individuals whose diameter growth averaged less than 1 inch in 10 years. Though all stands were thinned from below and lower vigor stems were prime targets for cutting, these smaller crowned trees still represented 40 to 80 percent of the residual stocking on most plots after treatment. When these smaller crowned lower vigor trees are released by thinning, growth response to increased growing space is slow to develop. Graney (1987) found that it took 3 to 5 years for tightly grown, small crowned, codominant red and white oak crop trees to produce a significant diameter growth response to thinning. But then, annual rates of diameter growth continued to increase through the 10th year.

Basal area growth during the first 5-year growth period could have also been reduced by the relatively dry growing seasons of 1976 and 1978 (when May through September rainfall was two-thirds of normal) and the severe drought of 1980 (when combined low rainfall and high temperatures resulted in significant and widespread mortality in forest stands throughout the Boston Mountain Area).

Basal area mortality is described by the equation:

$$Y_2 = \exp[-1.2503+0.030429B -0.014572A-0.014244Q] \quad (3)$$

where Y_2 is basal area mortality in square feet per acre per year. As would be expected, stands with more basal area will experience more mortality than those with less basal area because of the greater competition. Stand mortality also apparently declines with increases in age because younger stands are in a more dynamic phase of their life and they display intensified competition. Mortality is inversely related to site index, and this relationship might be the result of poorer sites being drier with the relatively shallow, sandy, and clayey soils that result in higher levels of moisture stress during the frequent summer droughts that affect this area (fig. 3). Nitrogen fertilization did not significantly affect mortality over the 10-year period.

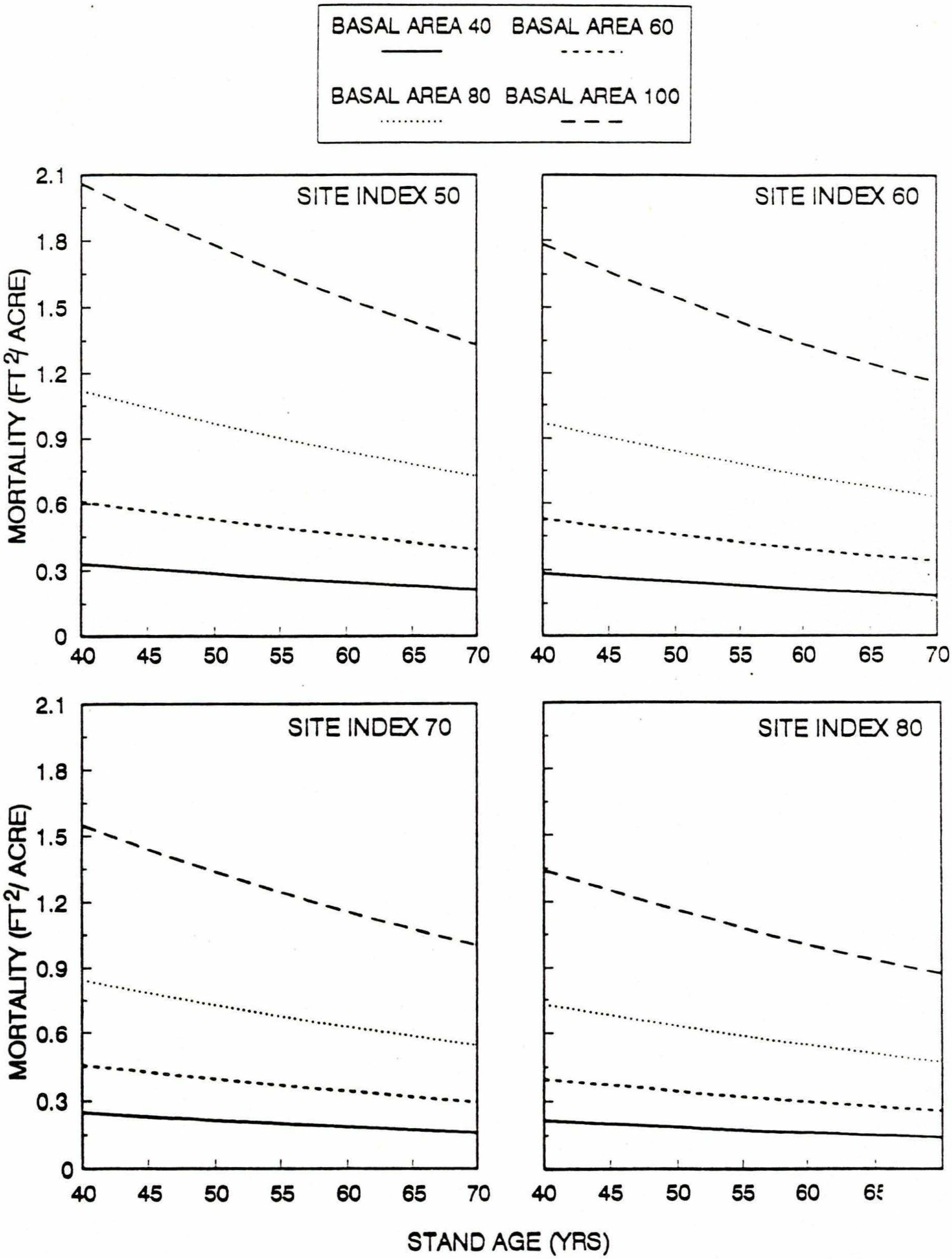

Figure 3. *Average annual basal area mortality for 10 years after treatment for upland oak stands in the Boston Mountains.*

Whereas much of the mortality observed in higher density stands was associated with low vigor trees in the subdominant sapling and pole classes, mortality resulting from the 1980 drought occurred in all tree sizes and was most severe on poorer sites (site indexes of 50 and 60). Hickory and black oak were especially affected by the severe drought and represented most of the mortality observed for the dominant and codominant crown classes over all sites. Mortality for white oak, northern red oak, and other species was relatively light.

The equation for basal area ingrowth is:

$$Y_3 = \exp[-1.2793-0.12478B+0.28146F] \qquad (4)$$

where Y_3 is basal area ingrowth in square feet per acre per year. Stands with more basal area tend to have less ingrowth because the heavier shade of denser stands suppresses ingrowth. The addition of fertilizer stimulated basal area ingrowth, and fertilized stands had about 33 percent more ingrowth in basal area than nonfertilized stands (fig. 4). Site index apparently did not affect ingrowth in this study.

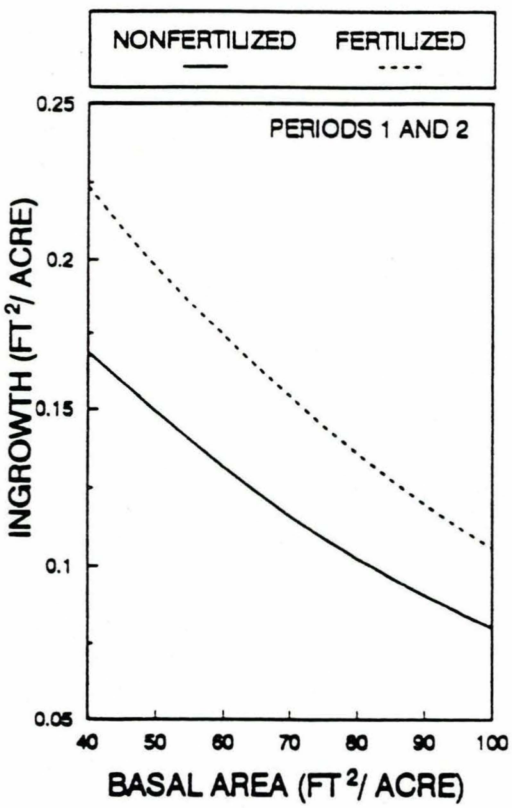

Figure 4. ***Average annual basal area ingrowth for 10 years after treatment for upland oak stands in the Boston Mountains.***

All ingrowth on study plots developed from residual stems in the 1- and 2-inch d.b.h. classes, from large, advanced reproduction, and from sprouts on cut stems. Nearly all ingrowth was in noncommercial or nontree species listed in species group 5 (table 1). Some desirable species such as cherry, ash, and oaks (developed from stump sprouts) grew past the 2.6-inch d.b.h. threshold, but would probably never develop to merchantable size in intermediate-aged stands.

Survivor growth in terms of total cubic foot volume is represented by the following equation:

$$Y_4 = \exp[3.2434+0.14966F+0.0025658B+ 0.011453Q+0.0010014BP] \qquad (5)$$

where Y_4 is annual survivor growth in cubic feet per acre. Fertilizer application resulted in a 16 percent increase in growth. Site index and basal area also affected volume growth, and volume growth, as affected by basal area, had a somewhat different response between the two growth periods (fig. 5).

Response of stand volume growth to N fertilization is similar to the relationship observed for survivor basal area growth in each 5-year period--approximately a 20-percent increase in basal area growth, and a 16-percent increase in volume growth. Most of the observed response in survivor volume growth is probably due to the effect of fertilization on diameter growth rather than height growth. Whereas significant increases in height growth of fertilized reproduction and saplings have been reported for fast growing, intolerant species such as white ash, black cherry, and yellow poplar (Auchmoody 1982, 1986; Graney and Rogerson 1985), height growth of oaks has been less responsive to N fertilization (Graney and Rogerson 1985).

The increase in volume growth during the second 5-year growth period is consistent with the delayed response to thinning previously discussed for survivor basal area growth.

The following equation represents volume mortality:

$$Y_5 = \exp[0.028863B+0.20564P] \qquad (6)$$

where Y_5 represents annual mortality in cubic feet per acre. As with basal area, volume mortality was related to basal area and the time period. No relationship was observed with respect to fertilization. Mortality increases with an increase in basal area, and more mortality occurred in the second growth period (fig. 6).

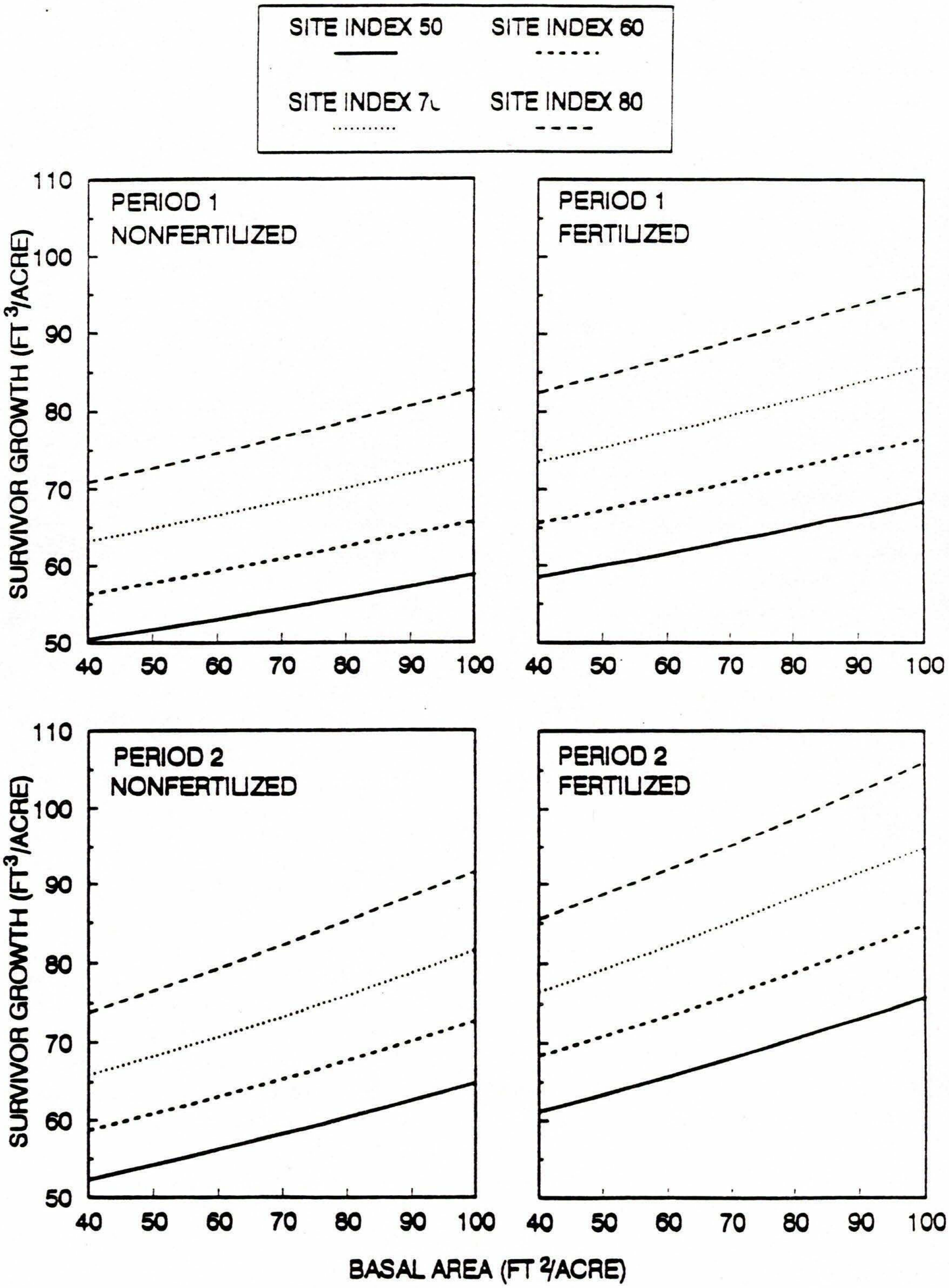

Figure 5. *Average annual volume survivor growth for 10 years after treatment for upland oak stands in the Boston Mountains.*

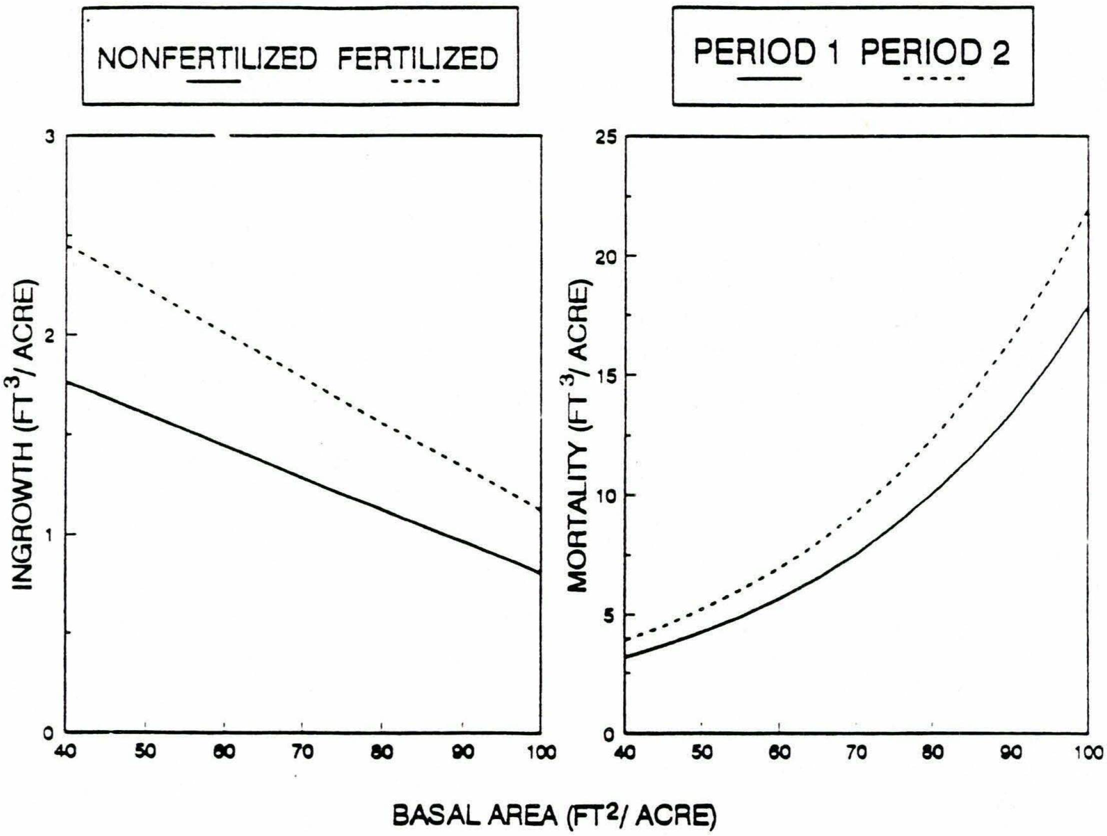

Figure 6. *Average annual volume mortality and ingrowth for 10 years after treatment for upland oak stands in the Boston Mountains.*

The increase in volume mortality in the second growth period is probably caused by the increase in stand density, but some mortality could also be attributed to a lingering effect of the severe 1980 drought. Although much of the 1980 drought mortality occurred during the first growth period, many trees that were severely stressed by the drought survived, but they grew poorly and eventually died during summer dry periods that occurred during the second growth period.

Finally, the equation for volume ingrowth is the following:

$$Y_6 = \exp[1.1035 - 0.012597B + 0.34000F]$$

(7) where Y_6 is annual ingrowth in cubic feet per acre. The ingrowth pattern for volume is similar to that for basal area; it is related to both basal area and fertilization. Volume ingrowth is inversely related to basal area, and the fertilizer application increased ingrowth about 40 percent over nonfertilized plots (fig. 6). Volume ingrowth has the same set of independent variables as basal area ingrowth.

Conclusions

Regression analysis with dummy variables probably increased the sensitivity of the analysis by isolating the effects of stand age, site index, and stand density from that of fertilization. This analysis also facilitated the analysis of growth behavior by time period as the result of interactions between growth period and stand variables. Although requiring more complex interpretation, greater insight into stand behavior was achieved by using regression with dummy variables and looking at each growth component rather than using a simpler analysis technique.

Nitrogen fertilization will increase basal area and volume growth of upland oak stands in the Boston Mountains of Arkansas by about 16 to 20 percent, and the increased growth rate will persist for about 10 years on most upland sites. Fertilization can also have some benefits for wildlife by significantly increasing understory development and deer forage production in thinned upland oak stands (Snyder and others 1982). Limited markets, plus the low value of small, hardwood roundwood, fluctuating oak sawtimber markets, and lack of premium prices for high quality, hardwood sawtimber in this area currently make stand level fertilization unprofitable. Fertilization of individual red and white oak crop trees will produce a significant growth response and has the advantage of concentrating the growth on selected higher quality and potentially higher value trees. However, labor costs for repeated hand applications to scattered individual stems is currently prohibitive.

Individual tree and stand level thinning studies in the Boston Mountains show that red and white oaks will maintain acceptable growth rates if thinnings are started at an early age and maintained throughout the rotation. In considering silvicultural investments in Boston Mountain oak stands on medium to good sites, density control in younger stands should have first priority.

Acknowledgments

Work was done in cooperation with the Department of Forest Resources and Arkansas Agricultural Experiment Station, University of Arkansas at Monticello.

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