FERTILIZATION OF OAKS IN THE MISSOURI OZARKS

Robert A. McQuilkin[1]

Abstract.-- Three fertilization studies were conducted in the Missouri Ozarks on *Quercus velutina*, *Q. alba*, and *Q. coccinea* using nitrogen (N), phosphorus (P), potassium (K), and limestone. Diameter growth and foliar nutrient concentrations of the trees were measured for three to five years. In one study, nutrient concentrations of the ground and surface runoff water were measured for three years after fertilization.

In all studies, N fertilization significantly increased tree diameter growth. Growth responses varied greatly by location, species, year of application, and quantity of fertilizer used, but in all cases, lasted only two or four years after application. Foliar concentrations of N increased from around 1.65 to 2.50 percent with the higher rates of N fertilization. With one minor exception, no significant growth increases were attributable to the P fertilization. Foliar P concentrations were increased only slightly above the average .15 percent contained in the unfertilized trees. Neither the K nor the limestone affected tree growth.

Runoff water analyses, soil N tests, and foliar analyses all indicated that much of the added N was lost from the fertilized plots within three years after application, but that very little of the added P was lost even after five years.

Fertilization with N could be an effective method of increasing tree growth in the Missouri Ozarks, but less soluble, longer lasting fertilizers will need to be used.

Keywords: *Quercus velutina*, *Q. alba*, *Q coccinea*, nitrogen, phosphorus, foliar nutrient concentration, water quality.

Increasing emphasis on forest productivity has stimulated interest in fertilization as a means of increasing tree growth. Significant growth increases in oaks have been obtained by fertilization with nitrogen (N) in New York (Mitchell and Chandler 1939, Karnig 1972), the Tennessee Valley (Farmer *et al.* 1970), Pennsylvania (Ward and Bowersox 1970), West Virginia Auchmoody and Smith 1977, Lamson 1978), and Arkansas (Graney and Pope 1978). Several of these studies also included phosphorus (P) as a fertilizer treatment, which, except in one case, did not result in any significant increases

---

1/Research Forester, North Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture, Columbia, Missouri.

in growth, either alone or in combination with the N. The low to moderate levels of both soil fertility and tree growth in the Ozark Plateau in Missouri suggest that fertilization might increase forest productivity in this region also. This report summarizes three recent experiments to evaluate the effects of fertilizers on tree growth and water quality in the Missouri Ozarks.

Upland soils in the Missouri Ozarks are predominately Typic Paleudults and Typic Fragiudults derived from limestone, dolomite, and sandstone residuum and, on the broader ridgetops, partially from loess. Ozark soils are typically low in moisture holding capacity, cation exchange capacity, pH, base saturation, and nutrient elements--particularly N and P. Surface soils are generally silt loams or loams; many soils have high volumes of chert fragments, and many contain a cherty fragipan. Climate of the region is moderate; average annual precipitation is 100-120 cm, although the latter half of the growing season is often quite dry. Upland forests are predominately oaks (*Quercus* spp.), hickories (*Carya* spp.) and shortleaf pine (*Pinus echinata*). The principal oak species are black (*Q. velutina*), white (*Q. alba*), scarlet (*Q. coccinea*), and northern red (*Q. rubra*).

STUDY I

The first fertilization study was established in the spring of 1969 in five thinned 70-year-old black and scarlet oak stands. Urea and triple superphosphate were applied to individual trees at rates of 0, 256, 510, and 767 kg/ha of N and 0, 170, 340, and 510 kg/ha of P_2O_5 in a complete factorial design. Fertilizers were surface-applied in April with no incorporation. A total of 256 black and 64 scarlet oaks were treated. Diameter growth was followed for five years after fertilization and soil and foliar samples were taken each August during the first three years after fertilization. Both species had very little growth response to the fertilizers the first growing season because of low rainfall. Maximum growth response to the N occurred the second year for black oak when diameter growth increases of 36, 54, and 81 percent were obtained for the three levels of applied N. Maximum growth response to N for scarlet oak occurred the third growing season when diameter growth increases of 19, 28, and 37 percent were obtained for the three levels of applied N. Growth responses in both species diminished after these years, and by the end of the fifth year after fertilization, diameter growth increases were less than 20 percent for all treatments for both species. Total five-year diameter growth increases associated with the three levels of nitrogen were 20, 33, and 46 percent for black oak. Increases for scarlet oak were 9, 15, and 22 percent, or about half those of black oak. There were no significant growth responses in either species associated with any of the P treatments (Watt 1974).

Mean foliar N concentration for the unfertilized black oaks over the three years was 2.42 percent. This increased to 2.85 percent at the highest N fertilization rate the second growing season after fertilization. By the third growing season however, foliar N concentrations for the fertilized trees were not significantly different from the non-fertilized trees. Foliar P values were not significantly affected by the P fertilization and averaged around .20 percent over the three years.

Foliar N concentrations for the unfertilized scarlet oak trees averaged 2.49 percent over the three years, and the maximum N fertilization rate increased this to 2.75 percent the second growing season after fertilization. As with the black oaks, by the third growing season however, there were no significant differences in foliar N concentrations among the treatments. Foliar P concentrations averaged .21 percent over the three years and were not significantly affected by the P fertilization.

Soils were sampled under the fertilized trees in two of the five areas each August during the first three growing seasons after fertilization. Nitrate nitrogen was determined by the colorometric method of Morgan (1937) and available P by the Bray II method.

The N tests yielded unrealistically high estimates of soil NO_3-N, but did indicate average increases in the top 10 cm of soil after N fertilization of approximately 37, 18, and 0 percent over the first three growing seasons, respectively. Although the actual values probably were not valid, the indications of the rapid removal of the nitrogen fertilizers from the surface soils (within two years) presumably were valid, and generally correspond with the response patterns of tree growth and foliar N concentrations over this same time period.

The highest P fertilization rate increased soil P_2O_5 in the top 10 cm of soil from 31 to 330 kg/ha the first growing season after fertilization. These increased soil P levels were maintained much longer than the increased soil N levels; in the third growing season after fertilization, soils receiving the most P fertilizer still had 224 kg/ha of P_2O_5 in the top of 10 cm of soil.

STUDY II

Because growth response in the first study was pactically linear over the range of N fertilization rates and because there was no response to the P, a second study was begun in the spring of 1972 to test higher rates of both N and P. This study was installed in 30- to 40-year-old stands of black and white oaks in four locations in Dent, Reynolds, and Phelps Counties. All stands used in this study have been thinned to approximately 60 percent (B-level) stocking (Gingrich 1967) two to five years before fertilization. Individual trees were fertilized with urea at 0, 1,009, or 1,345 kg/ha of N and triple superphosphate at 0, 673, or 1,345 kg/ha of P_2O_5. Other treatments included in this study were: muriate of potash at 0, 336, or 673 kg/ha of K_2O and agricultural limestone plus magnesium (Mg) at 0 or 1,121 kg of limestone plus 56 kg of Mg per ha. All fertilizer and limestone treatments were arranged in a complete factorial design with one tree per treatment plus three extra untreated trees per replication. For black oak, there were nine complete replications and three replications without the intermediate N treatment for a total of 630 trees; for white oak there were eight replications without the intermediate N treatment for a total of 312 trees. Each area (location) contained two to four black oak replications and two white oak replications. The fertilizers and limestone were surface-applied in April with no incorporation. Diameter growth for two growing seasons before fertilization was determined from increment cores. Diameter growth of all trees and foliar nutrient levels for trees in two of the four areas were measured for five years after fertilization.

Analysis of variance tests of individual tree basal area growth for each year, including the years before fertilization, indicated significant area and species differences both before and after fertilization. Significant differences in basal area growth were associated with the N treatments in all years after fertilization and with the P fertilization the first year after fertilization. Neither the K nor the limestone treatments was associated with any growth differences.

The size of growth differences among treatments, years, and species was determined by comparing regressions of individual tree basal area growth on initial basal area by species, area, year, and fertilizer treatment. Using the mean basal area at the beginning of the growing season of the trees in, for example, a particular fertilizer treatment, we computed an "expected basal area growth" from the regression of the non-fertilized trees of the same area, species, and year. The "actual basal area growth" was then computed from a comparable regression of the fertilized trees of the same area, species, and year, and the difference between the actual and expected basal area growths was attributed to the fertilizers. Statistical significances of such differences were determined by covariance analyses between the two regression equations. Percentage increases (or decreases) in growth were computed by subtracting the expected from the actual basal area growth and expressing this difference as a percentage of the expected basal area growth.

As in the first experiment, there were large growth responses to the N fertilization, but little or no response to the P fertilization. Unlike the first experiment however, in which the maximum growth responses occurred the second growing season after fertilization, the growth responses in the second experiment were equally high during the first two growing seasons but greatly reduced after then. Figure 1 shows, for all four areas combined, the percentage increases in basal area growth for black and white oaks for the pretreatment period 1970-71 and for five years after fertilization.

Figure 2 shows the actual and expected basal area growth for the first two growing seasons after fertilization for the four areas and the two species. Growth differences among the four areas were highly significant. Over both species and all years, Area 4 had consistently greater growth without fertilization and a consistently greater response to the N fertilizer in absolute basal area growth. In contrast, Area 1 had the lowest growth without fertilization, but had the highest percentage increase in basal area growth after N fertilization. Foliar concentrations of N on the unfertilized trees were greater on Area 4 (1.77 percent) than on Area 1 (1.55 percent), but increases after fertilization were greater on Area 1.

Basal area growth, both with and without N fertilization, was generally greater on black oaks than on white oaks, but these differences varied considerably among areas and years. In 1971 (before fertilization), basal area growth of black oak exceeded that of white oak (both species adjusted to a common initial basal area) in Areas 1, 2, and 3 by 7, 5, and 11 percent, respectively. In Area 4 however, white oak basal area growth exceeded that of black oak by 12 percent. Differences in Areas 3 and 4 were statistically significant. In 1972, the first growing season after fertilization, basal area growth of black oak exceeded that of white oak by 2 to 14 percent on Areas 1, 2, and 4, but the only statistically significant differences occurred

on Area 3 where black oak growth was 40 percent greater than that of white oak on both the fertilized and non-fertilized trees. In 1973, black oak growth exceeded that of white oak (both fertilized and non-fertilized) in all areas by an average of 29 percent; these differences were statistically significant in all areas except 2.

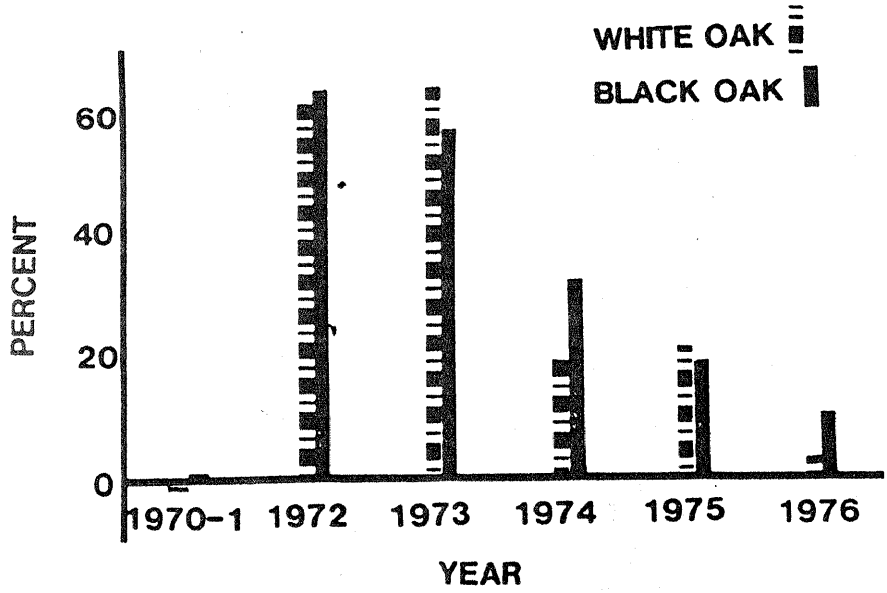

Figure 1.--Percentage increases in basal area growth for black and white oaks for the pre-fertilization period 1970-71 and for five growing seasons after fertilization with urea at 1345 kg/ha N in the spring of 1972; average over four areas.

Growth on the black oaks fertilized with 1,009 kg/ha of N was about 20 percent less than on the trees fertilized with 1,345 kg/ha, but these differences generally were not statistically significant.

Significant basal area growth responses to P fertilization were obtained only in Area 2, and only for white oak. In this case, positive responses were approximately equal through the second, third, and fourth growing seasons after fertilization (figure 3). In the fifth growing season however, a negative growth response occurred that was almost as large as the largest positive response in any single year. The reasons for this sudden growth depression are unknown. Black oak also exhibited a negative growth response to P in the fifth growing season. However, in all years, the growth responses for black oaks were much smaller than those for white oaks, and none was statistically significant. Overall five-year increases in basal area growth attributable to the P fertilization for white and black oaks in this one area were 11 and 1 percent, respectively. We do not know why a positive response to P occurred in this area and not in any of the other three areas. Unfortunately, there were no foliar samples from this area to compare to other areas in which growth responses did not occur.

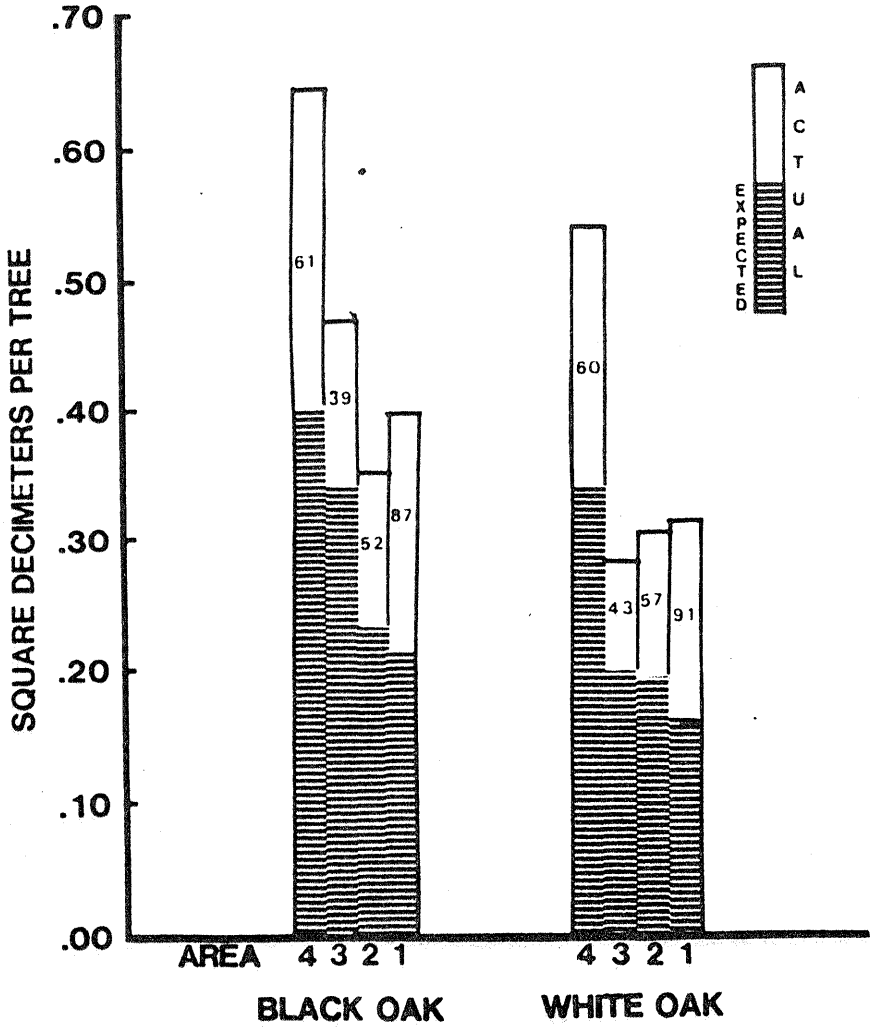

Figure 2.--Expected and actual basal area growth of black and white oaks the first two growing seasons after fertilization with urea at 1,345 kg/ha N, by area; numbers within bars indicate the percentage increases in basal area growth.

Foliar concentrations of N and P for the fertilized and unfertilized black and white oaks in two of the four areas are shown in figures 4 and 5. These data are confounded by the fact that the chemical analyses were done in 1972 by the Ohio Agricultural Research and Development Center (OARDC) and in 1973-76 by the University of Minnesota. Although no direct comparisons were available, concentrations of many elements were consistently higher from the OARDC laboratory than from the Minnesota laboratory. For example, foliar N and P concentrations of unfertilized trees from the first study (1969-71) were 2.46 and .20 percent, respectively, and 2.05 and .22 percent in 1972 from the second study (all analyzed by OARDC). Comparable values from 1973-76 from the

second study (analyzed by the University of Minnesota) were 1.67 and .14 percent. Data from a third study (discussed later) for unfertilized trees on the Sinkin Experimental Forest in Dent County (also analyzed at Minnesota) were comparable to the 1973-76 data of the second study (particularly the trees in Area 4) at 1.76 and .17 percent. Thus, the higher values of N and P in figures 4 and 5 for 1972 may be at least partially associated with differences between the two laboratories. Comparing these data with published foliar N and P values for oaks in Missouri and Tennessee (Farmer et al. 1970, Grizzard et al. 1976, and Rochow et al. 1972) suggests that the lower values from the Minnesota laboratory are more accurate than the higher values from the Ohio laboratory.

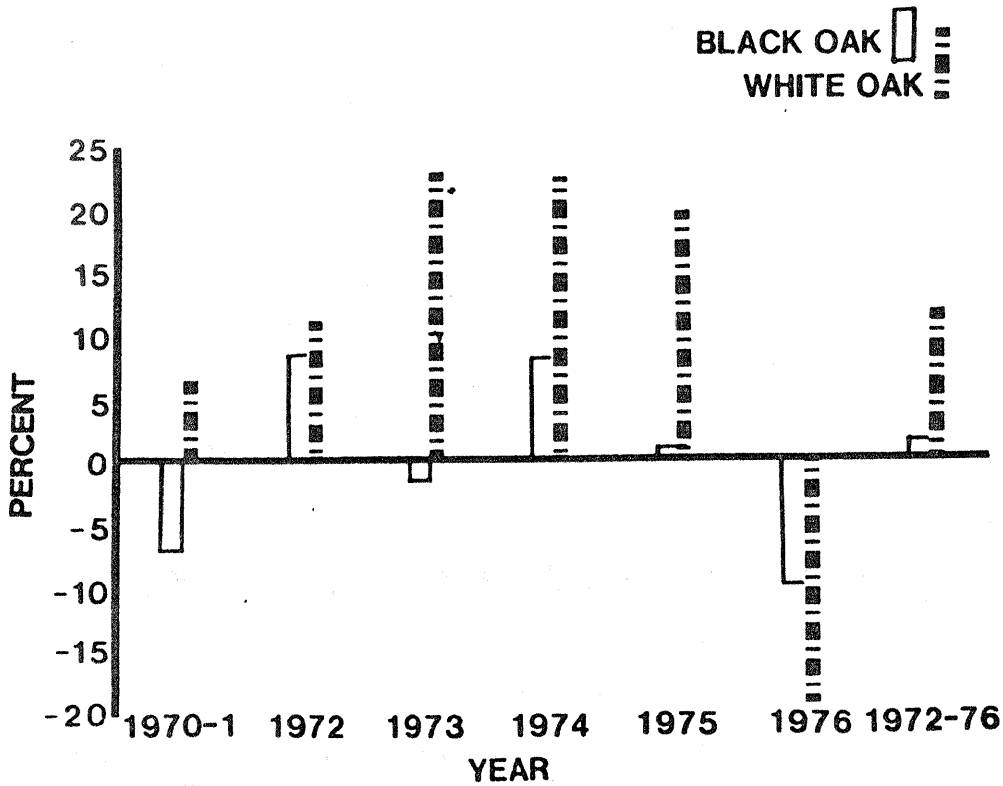

Figure 3.--Percentage increases in basal area growth of black and white oaks in Area 2 for the pre-fertilization period 1970-71, five growing seasons after fertililization with triple superphosphate at 1,345 kg/ha P_2O_5 in the spring of 1972, and net percentage increases in basal area growth for the 5-year period 1972-76.

Foliar concentrations of N were increased significantly by the N fertilization for three growing seasons for black oak and for two growing seasons for white oak. Foliar P concentrations were increased approximately 13 percent by the P fertilization, and these concentration increases were maintained uniformly over the five-year period. Foliar concentrations of K, calcium (Ca), and Mg were not increased significantly by additions of these elements.

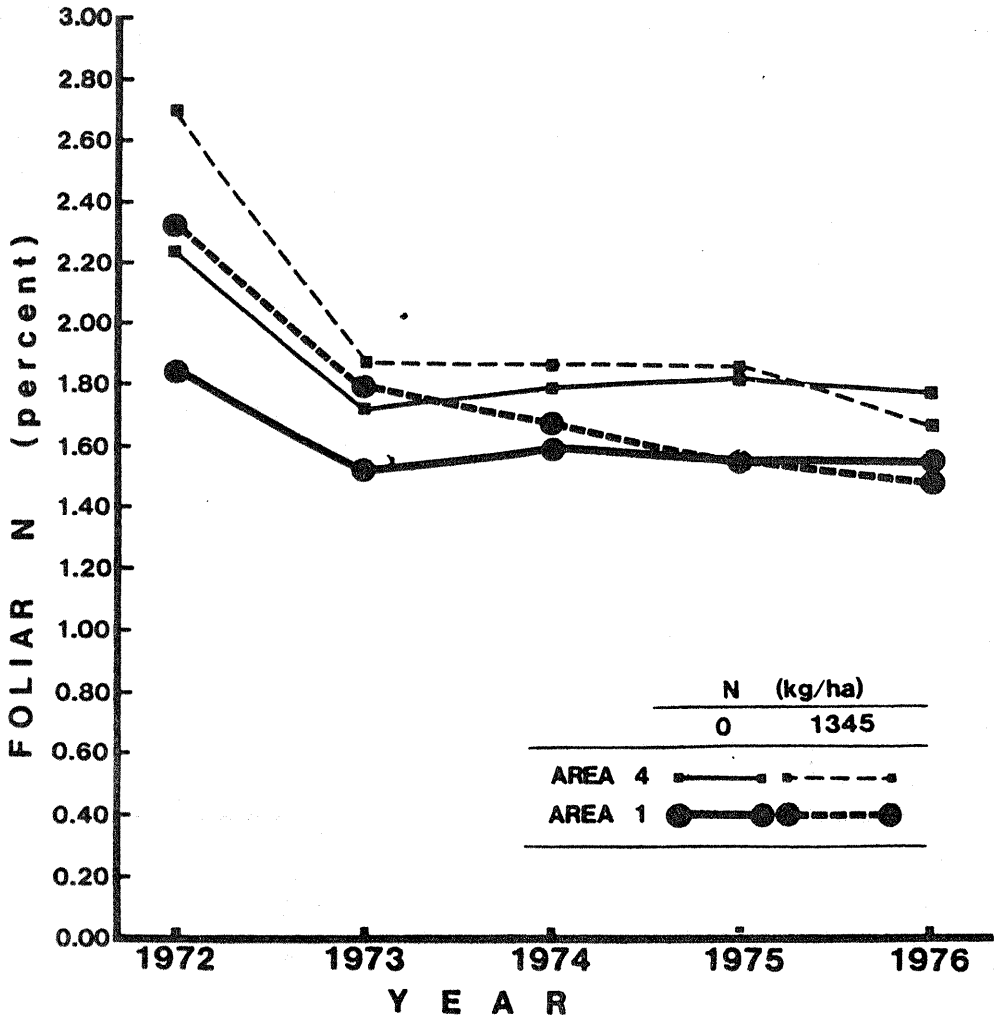

Figure 4.--Foliar N concentrations for five growing seasons after fertilization with urea at 0 or 1,345 kg/ha N in the spring of 1972, by area; data for black and white oaks combined. 1972 chemical analyses by OARDC; 1973-76 analyses by the University of Minnesota.

Unfertilized black and white oaks had similar foliar concentrations of both N and P, but both species had significantly higher concentrations of both these elements plus Ca, iron (Fe), and manganese (Mn) in Area 4 than in Area 1. Mean foliar concentrations of the unfertilized trees for 1973-76 are listed in table 1 by species and area, along with the means and ranges of concentrations reported in the literature for unfertilized black and white oaks. Comparing the foliar concentrations of the Missouri trees to these published values shows that, of the major elements, only N and possibly P were low.

Foliar concentrations of the minor elements were within the ranges reported in the literature for oaks except for boron (B) and possibly zinc (Zn). Black, scarlet, and white oaks had concentrations of boron (28-37 ppm)

that were less than half the 78 ppm average reported in the literature. These low values were, however, well above estimated B deficiency levels of 10-15 ppm (Stone 1968). White oak had foliar concentrations of Zn (16 ppm) about half those of black or scarlet oaks (27-34 ppm), although similar low concentrations of Zn in white oaks have been observed in Illinois (Jones et al. 1980), Indiana (Crum and Franzmeier 1980), and Wisconsin (Gerloff et al. 1964). These low Zn concentrations in white oak may be approaching deficiency levels estimated at around 5-10 ppm (Stone 1968), and suggest that growth in white oak might possibly be increased by Zn fertilization.

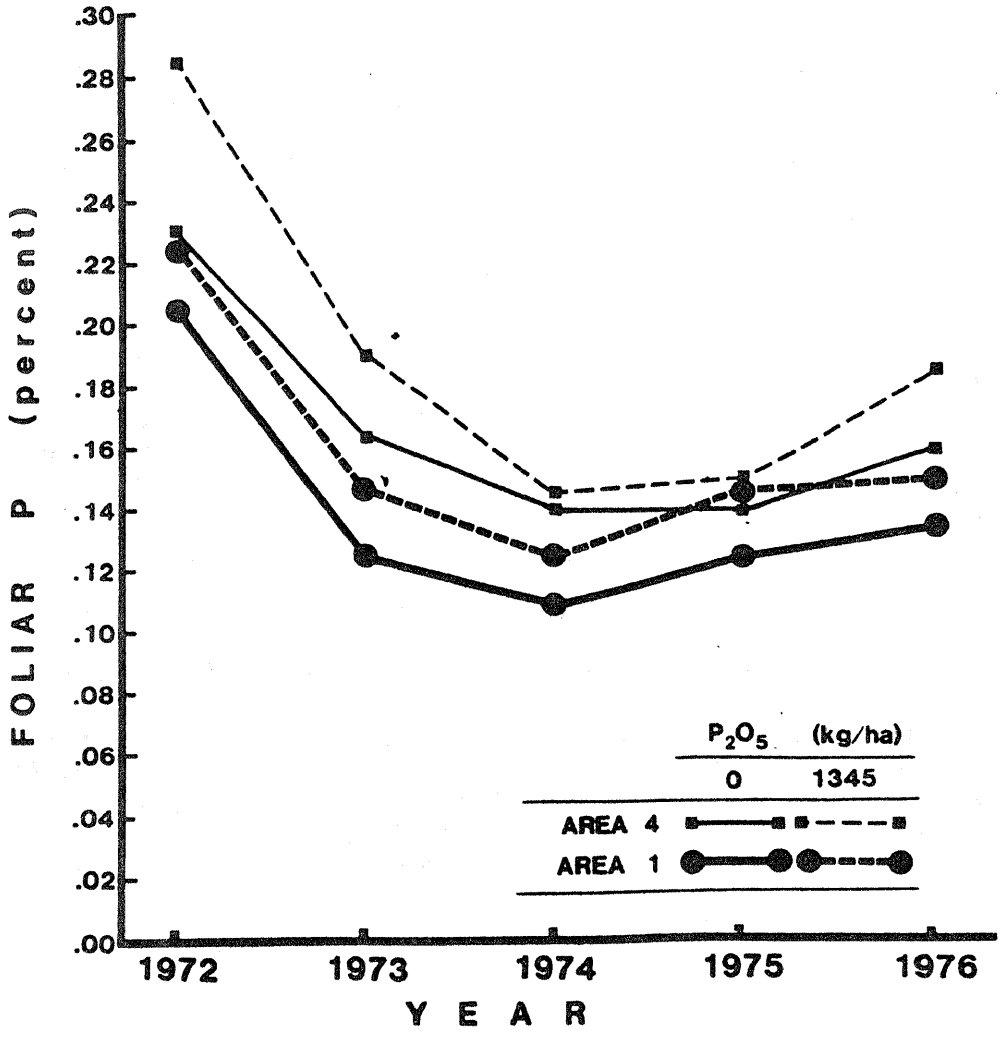

Figure 5.--Foliar P concentrations for five growing seasons after fertilization with triple superphosphate at 0 or 1,345 kg/ha P_2O_5 in the spring of 1972, by area; data for black and white oaks combined. 1972 chemical analyses by OARDC; 1973-76 analyses by the University of Missouri.

Table 1.--Foliar concentrations of elements in unfertilized black and scarlet oaks from the first study and in black and white oaks from the second study, plus means and ranges of foliar concentrations for black and white oaks from other published studies.

Element	First study 1/ species means		Second study 2/ species means		Second study 2/ area means		Data from 3/ literature	
	Black	Scarlet	Black	White	Area 1	Area 4	Mean	Range
	percent							
N	2.40	2.49	1.65	1.66	1.55	1.77	2.40	1.56 - 2.67
P	.20	.20	.14	.14	.12	.15	.18	.11 - .22
K	.92	.69	.88	.79	.82	.84	.79	.66 - 1.17
Ca	.94	.61	.86	.90	.84	.92	.64	.42 - 1.73
Mg	.16	.10	.21	.16	.20	.18	.14	.06 - .22
	parts per million							
Al	74	86	62	70	66	65	46	28 - 91
Fe	79	97	84	84	79	88	76	74 - 90
Mn	700	820	1,300	985	850	1,440	1,230	570 -2,500
Zn	29	27	34	16	26	26	32	16 - 41
B	33	37	28	29	28	30	78	64 - 93
Cu	9	9	6	6	5	6	5	5 - 6
Mo	1.4	1.4	--	--	--	--	1.4	1.3 - 1.5

1/ Foliar analyses by the Ohio Agricultural Research and Development Center.

2/ Data from 1973-76; foliar analyses by the University of Minnesota.

3/ Data published since 1970 for unfertilized white and black oaks sampled from July through September. From: Auchmoody and Hammack 1975, Crum and Franzmeier 1980, Farmer *et al.* 1970, Grizzard *et al.* 1976, Helmke *et al.* n.d., Jones *et al.* 1980, Messenger *et al.* 1978, Messenger 1979, Rochow *et al.* 1972, and Ward and Bowersox 1970.

STUDY III

Concern about possible contamination of runoff water from such high fertilization rates prompted the third study. In the spring of 1973 we installed surface and ground water sampling devices on six small (average .5 ha) watersheds on the Sinkin Experimental Forest in Dent County. Forests on these watersheds were unthinned 50- to 60-year-old stands of black and white oaks. In April 1973, three of these watersheds were fertilized with the same fertilizers (except Mg) and at the highest rates used in the second study (1,345, 1,345, 673, and 1,121 kg/ha of N, P_2O_5, K_2O, and limestone, respectively). These fertilizers were surface-applied, without incorporation, over the entire areas of the three watersheds. Two years later, one of each of the three remaining watersheds was fertilized with the same combination of fertilizers and limestone at rates of 1/3, 1/6, and 1/12 of the amount used in the first three watersheds. Tree growth and water quality were measured for four years after the initial fertilization. The water quality analyses showed that at the highest fertilization rate, 53 percent of the fertilizer N but only 6 percent of the P was lost in the runoff water the first three years after application (Harris et al. 1980). Nitrogen losses were particularly high the first few weeks after application because of heavy rainfall that spring and early summer. Volatilization losses of urea were not measured, but may also have been significant (Terman 1980).

Black oaks in the three heavily fertilized watersheds had basal area growth increases over the trees not initially fertilized of 70 and 104 percent for the first two growing seasons, respectively, after fertilization. Unfertilized black and white oaks had mean foliar N and P concentrations of 1.76 and .17 percent, respectively. Fertilization at the highest rate increased foliar N levels to 2.64 and 2.24 percent the first two growing seasons, respectively. Foliar P levels increased to an average of .21 percent over the first two years. Chemical analyses of all of the foliar samples in this study were done by the University of Minnesota and thus are comparable to the foliar data from 1973-76 from the second study.

Runoff water losses of N were much reduced at the three lower fertilization rates, but tree growth responses were also much reduced. Exact analyses of tree growth on these watersheds were not possible because of the lack of unfertilized controls, but average growth increases were low and varied considerably between years and species.

CONCLUSIONS AND RECOMMENDATIONS

Black and scarlet oaks in the 30 to 70 year age range and 30- to 40-year-old white oaks in the Missouri Ozarks increased diameter growth significantly for two to four years after nitrogen fertilization. Black and white oaks responded equally well to N fertilization, but 70-year-old scarlet oaks had growth increases only about half that of black oaks of the same age. Growth increases after N fertilization varied greatly among different locations and years. In general, greater absolute basal area growth increases occurred on sites on which the trees were already growing rapidly, although larger percentage growth increases occurred on sites on which the trees were growing more slowly.

Except for a small net increase in basal area growth by white oak in one area, P fertilization, either alone or in combination with N, did not increase basal area growth in any of the tests.

Foliar concentrations of both N and P in the unfertilized trees were at the low end of the range of published concentrations for unfertilized oaks. Foliar N concentrations increased significantly after N fertilization, but these increases lasted only two to three growing seasons. Foliar P levels increased moderately in two of the three studies after P fertilization, and these increases were sustained for at least five years.

Foliar concentrations of K, Ca, Mg, Fe, Mn, Zn (in black and scarlet oaks), copper (Cu) and molybdenum (Mo) were comparable to published concentrations found in normal, unfertilized oaks in other regions. However, concentrations of boron were lower than published values, although still well above estimated deficiency levels. Concentrations of Zn in white oak, although comparable to some published values for white oak, were much lower than the values for black and scarlet oaks and may be approaching deficiency levels.

Surface and ground water removal of the highly soluble urea fertilizer used in these studies was excessive, both in terms of runoff water quality (at the higher fertilization rates) and fertilizer losses (at all rates).

Fertilization with N could be an effective method of increasing forest productivity in the Missouri Ozarks, but methods of selecting specific sites for fertilization will have to be developed (Leonard et al. 1972), and less soluble, longer lasting fertilizers will need to be used.

LITERATURE CITED

Auchmoody, L.R., and K.P. Hammack. 1975. Foliar nutrient variation in four species of upland oaks. USDA Forest Service, Northeastern Forest Experiment Station, Research Paper NE-331. 16p.

Auchmoody, L.R. and H.C. Smith. 1977. Response of yellow-poplar and red oak to fertilization in West Virginia. Soil Sci. Soc. of Amer. J. 44:803-807.

Crum, J.R., and D.P. Franzmeier. 1980. Soil properties and chemical composition of tree leaves in southern Indiana. Soil Sci. Soc. of Amer. J. 44:1063-1069.

Farmer, R.E., Jr., G.W. Bengtson, and J.W. Curlin. 1970. Response of pine and mixed hardwood stands in the Tennessee Valley to nitrogen and phosphorus fertilization. For. Sci. 16:130-136.

Gerloff, G.C., D.G. Moore, and J.T. Curtis. 1964. Mineral content of native plants of Wisconsin. University of Wisconsin Agricultural Experiment Station Research Report 14. 27p.

Gingrich, S.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., and P.E. Pope. 1978. Response of red oaks and white oak to thinning and fertilization in the Boston Mountains of Arkansas. In: Proc. of Second Central Hardwood Forest Conference, West Lafayette, IN. p.357-369.

Grizzard, T., G.S. Henderson, E.E.C. Clebsch, and D.E. Reichle. 1976. Seasonal nutrient dynamics of foliage and litterfall on Walker Branch watershed, a deciduous forest ecosystem. Oak Ridge National Laboratory, Oak Ridge, TN; Environmental Science Division Publication No. 814. 140p.

Harris, A.R., D.H. Urie, R.A. McQuilkin, and I.L. Sander. 1980. Water quality implications of forest fertilization in the Missouri Ozarks. In: Proceedings of Third Central Hardwood Forest Conference, Columbia, MO. p.21-37.

Helmke, P.A., W.P. Robarge, M.B. Schoenfield, P. Burger, R.D. Koons, and J. E. Thresher, N.D. Impacts of coal combustion on trace elements in the environment: Wisconsin power plant impact study. Unpublished report, University of Wisconsin, Madison, WI.

Jones, J.D., G.T. Weaver, and E.L. Lewis. 1980. A preliminary report on nutrient concentrations in sun and shade leaves of nine hardwood tree species in southwestern Illinois. In: Proceedings of Third Central Hardwood Forest Conference, Columbia, MO. p.202-209.

Karnig, J.J. 1972. Nitrogen fertilizer increases diameter growth of northern red oak. J. For. 70:629.

Lamson, N.I. 1978. Fertilization increases growth of sawlog-size yellow-poplar and red oak in West Virginia. USDA Forest Service, Northeastern Forest Experiment Station, Research Paper NE-403. 6p.

Leonard, R.E., A.L. Leaf, and J.V. Berglund. 1972. The role of forest site in fertilizer response. USDA Forest Service, Northeastern Forest Experiment Station, Research Paper NE-243. 7p.

Messenger, A.S. 1979. Tree-soil interaction research progress report of 1979. Unpublished report, Morton Arboretum, Lisle, IL. 8p.

Messenger, A.S., J.R. Kline, and D. Wilderotter. 1978. Aluminum biocycling as a factor in soil change. Plant and Soil 49:703-709.

Mitchell, H.L. and R.F. Chandler, Jr. 1939. The nitrogen nutrition and growth of certain deciduous trees of northeastern United States. Black Rock Forest Bulletin 11. 94p.

Morgan, M.F. 1937. The universal soil testing system. Connecticut Agricultural Experiment Station Bulletin 392. 159p.

Rochow, J.J., P.H. Zedler, L.W. Hess, and F.G. Goff. 1972. Nutrient concentrations of trees, shrubs, herbaceous vegetation, litter, and soil in a Missouri forest. Eastern Deciduous Forest Biome Memo Report 72-1, Oak Ridge National Laboratory, Oak Ridge, TN. 50p.

Stone, E.L. 1968. Microelement nutrition of forest trees: A review. In: Forest Fertilization Theory and Practice; Tennessee Valley Authority, Muscle Shoals, AL. p.132-175.

Terman, G.L. 1980. Volatilization losses of nitrogen as ammonia from surface-applied fertilizers, organic amendments, and crop residues. Advances in Agronomy 31:189-223.

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

Watt, R.F. 1974. Response of oaks in the Missouri Ozarks to fertilization with nitrogen and phosphorus. Unpublished report. USDA Forest Service, North Central Forest Experiment Station, Columbia, MO. 16p.