EFFECT OF FERTILIZER TREATMENTS ON AN ALKALINE SOIL AND ON EARLY PERFORMANCE OF TWO BOTTOMLAND OAK SPECIES

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Abstract.—Many acres of once productive Missouri farmland along the Missouri River are being planted to bottomland hardwoods. Once trees become established on many of these sites, however, most show symptoms of chlorotis due to high pH levels (>7.5) in soil. Six treatments containing combinations of iron (Fe), sulfur (S), and nitrogen (N) were tested for their effectiveness in ameliorating soil conditions to stimulate nutrient uptake and growth of 2-year-old planted pin oak (*Quercus palustris*) and swamp white oak (*Q. bicolor*). Some chlorosis was still present after 2 years of treatment. Also, treatments with S had significantly (P>0.05) lower pH. Neither Fe nor N treatments affected pH. For leaf nutrient and growth analyses, tree species were not analyzed separately. Treatments with S had lower foliar phosphorus, potassium, and calcium concentrations for all years, but these concentrations were not affected by Fe or N. Deer browsing continues to be a major problem for maintaining height growth. Treatments containing S had smaller basal diameters and lower tree heights than treatments without S. Height loss or height decline, which may have been associated with deer browsing, was greater in treatments with S. Sulfur-containing fertilizers were effective in lowering soil pH, but the depression of pH by these fertilizers may not necessarily coincide with favorable seedling response. Nutrients other than Fe are likely involved in the seedling chlorosis. Prescriptions for nutrient management on bottomland sites such as these will need to be developed for tree plantings to become healthy, mast-producing forests.

INTRODUCTION

Many bottomland old fields planted to hardwoods do not successfully make the transition to becoming productive forests. Many hardwood plantings, including oak, on old field sites have demonstrated high mortality, high stem dieback, and slow growth rates. Studies show that healthy seedlings with large stem diameters (Johnson 1976) and root systems usually have good survival and better growth than smaller-diameter seedlings. More recently, Forest Keeling Nursery has made (root production method) RPM™ seedlings available (Lovelace 1998). RPM seedlings have massive root systems, and some hardwood species produce acorns by the third year under nursery conditions.

Poor weed control and soil fertility likely have contributed much to the poor performance of many failed tree plantings. Of particular interest for hardwood regeneration to enhance wildlife habitat are old crop fields in bottomlands of the Missouri River. The flood of 1993 in Missouri degraded more than 325,000 ha of cropland along the Lower Missouri River floodplain through scouring and the depositing of sand onto crop fields (Grossman and others 2003). The thick deposits of sand have lowered soil productivity so much that field crop production is no longer profitable. Attempts to artificially regenerate these bottomland fields have encountered some difficulty (Schweitzer and Stanturf 1997).

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Many of the soils on these floodplain bottomlands have high pH, high nutrient leaching, intense vegetative competition, and poor drainage, all of which reduce tree performance. When these sites are planted to hardwoods, including oaks, they exhibit leaf symptoms of iron (Fe) deficiency usually induced by poor drainage or by soils with a high calcium (Ca) content and pH levels above 7.5 (Courchesne and others 2005). These bottomland soils contain adequate amounts of mineral Fe, but as soil pH rises above 7.0, Fe changes to an insoluble form that many plants have difficulty taking up. Affected leaves turn to a yellowish color while leaf veins remain dark green. When not corrected, Fe deficiency can cause poor root development, severe stunting, and plant death. Mineral deficiencies other than Fe, such as nitrogen (N), phosphorus (P), magnesium (Mg), manganese (Mn), copper (Cu), zinc (Zn), or boron (B) may also result in chlorosis symptoms. Symptoms of Mg deficiency, in particular, may be similar to those of Fe deficiency. The two can be distinguished by broad bands of normal green color that remain next to the major vein if Mg is lacking. Furthermore, leaves on the ends of the branches of Mg-deficient trees generally are not affected until late in the summer after growth has stopped.

OBJECTIVES

Iron chlorosis is commonly alleviated by application of Fe sulfate and Fe chelates. This perennial problem may require several Fe applications per year (Ryan and others 1975). As Fe availability in calcareous soils is influenced by pH (Hodgson 1963), a reduction in soil pH through the use of acidifying amendments should, theoretically, eliminate chlorosis and make it unnecessary to repeat applications. In the study reported herein, various treatments of Fe, S, and N were broadcast-applied and compared after 2 years as to their effect on soil pH and nutrient uptake and growth of planted pin oak (*Quercus palustris*) and swamp white oak (*Q. bicolor*).

METHODS AND MATERIALS

Site

The study site is located on lands owned and managed by the Missouri Department of Conservation. Plowboy Bend Conservation Area is located at latitude 38° 48′ 5”N; longitude 92° 24′17”W in Moniteau County, MO. The area has undergone numerous soil-depositing floods over the years. The soil on the site is Sharpy fine sand (mixed, mesic, Typic Udispsamments). Sharpy soils are classified as hydric, meaning that they are periodically saturated, ponded, or flooded during the growing season.

In 2001, a total of 336 swamp white and pin oak seedlings were planted in a randomized block design in rows at 12 x 12-m spacing. Each block contained 12 pin oaks and 12 swamp white oaks that were of either bare root or RPM™ origin and were planted in mounded or unmounded rows. Combinations of iron, sulfur, and nitrogen were applied in the following treatments: 1) $FeSO_4$ plus water-degradable S; 2) Fe chelate; 3) Fe chelate plus NH_4NO_3; 4) NH_4NO_3 alone; 5) NH_4NO_3 plus $FeSO_4$; and 6) control. Ferrous sulfate was applied at a rate of 2,240 kg ha^{-1} or 336 g/tree, ammonium nitrate at 112 kg ha^{-1} actual N or 49.4 g/tree, Fe chelate (Sprint 330, Becker Underwood, Ames, IA) was applied at a rate of 454g/93 m^2 or 8 g/tree, and water-degradable S at 2,240 kg ha^{-1} or 336 g/tree. Each treatment was applied to 20 randomly selected RPM™ and bare-root trees annually in the spring since 2004. Fertilizer chemicals were broadcast-applied on top of the 1.3-m^2 woven plastic mat used to control weeds around each tree. Trees in the control treatment were not treated.

From each treatment, two soil samples were collected from half of the trees at 10 and 20 cm depths in the fall of 2004 and 2005. Samples were collected beneath the plastic mats approximately 61 cm from

Table 1.—Mean soil pH and nutrient concentrations for alkaline bottomland soil planted to pin oak (*Quercus palustris*) and swamp white oak (*Q. bicolor*) along the Missouri River following applications of soil amendments for 2 years.

Treatments	pH	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
				------------------------------ mg/kg				------------------------------				
Year 1												
Without Fe	8.1	58	266	3156	284	11	21	415	79	4	3	3
With Fe	8.1	59	271	3378	331	13	20	416	77	4	3	3
Without S	8.1	58	288a	3575a	337a	13a	20	412	79	4	3a	3a
With S	8.2	60	226b	2671b	270b	10b	19	425	74	3b	2b	2b
Without N	8.1	58	276	3379	330	13	20	428	76	4	3	3
With N	8.2	59	262	3249	305	12	19	404	79	4	3	3
Year 2												
Without Fe	8.2	28	106	1722	150a	5a	6a	215	39	2	1	0.2
With Fe	8.1	28	105	1723	178b	14b	7b	233	37	2	1	0.2
Without S	8.2a	29	114a	1866a	165	55a	7	212a	38	2	1	0.2
With S	7.9b	26	86b	1402b	180	25b	6	264b	36	2	1	0.2
Without N	8.1	28	108	1758	174	15	7	232	37	2	1	0.2
With N	8.2	29	102	1677	165	7	6	223	38	2	1	0.3

[1]Different letters denote significant differences (p<0.05) between the two treatments for a nutrient.

the base of trees. Samples were oven-dried at 65 °C and sieved through a 4-mm sieve. For foliar nutrient determination, leaf samples were collected in late June to mid-July from the same trees where soil samples were collected. Samples were oven-dried at 65 °C and ground in a Wiley mill to pass through a 2-mm sieve. Samples were analyzed annually for macro-nutrients and micro-nutrients at a commercial laboratory (Agriculture Diagnostic Laboratory, Fayetteville, AR 72704). Height and basal diameter (db) at 2.5 cm from the soil surface and diameter at breast height (d.b.h.) have been measured annually.

We examined the effect of the presence or absence of Fe, S, and N on soil and leaf chemistry and tree growth. Tree species were not separated, nor were differences between mounded and unmounded trees or differences between the six treatments tested. Data were analyzed using analysis of variance, and differences between treatments were tested using Tukey's test.

RESULTS

Soil pH and Nutrients

Only S application significantly (P<0.05) affected soil nutrient concentrations both years and soil pH in the second year of the study (Table 1). Although differences were small for some micronutrients, differences between treatments with S and without S were significant. For most of these nutrients, extractable amounts were higher without S than with S. Nutrients that were affected included K, Ca, Mg, S, Zn, Cu, and B for year 1 and K, Ca, and S for year 2. Iron, however, was higher with S than without S for year 2. Soil pH was significantly lower with S than without S by year 2. While Fe did not affect soil pH or nutrient levels in year 1, the levels of extractable Mg, S, and sodium (Na) were higher with Fe than without Fe in year 2. Nitrogen did not significantly affect pH or soil nutrient levels in either year (Table 1).

Table 2.—Mean leaf nutrient concentrations for planted pin oak (*Quercus palustris*) and swamp white oak (*Q. bicolor*) on bottomland alkaline soils along the Missouri River following applications of soil amendments for 2 years.

Treatments	N	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
		------------ Percent ------------					------------- mg/kg -----------					
Year 1												
Without Fe	2.0	0.2	0.7	1.2	0.2	0.1	42	79	183	47	10	17
With Fe	2.0	0.2	0.7	1.0	0.2	0.1	38	81	213	53	9	19
Without S	2.0	0.2a[1]	0.8a	1.2	0.2	0.1	41	78	136a	49	9	20
With S	2.0	0.1b	0.6b	0.9	0.2	0.1	36	85	355b	57	9	16
Without N	2.0a	0.2a	0.8	1.1	0.2	0.1	38	77	226	59a	9	19
With N	2.2b	0.1b	0.7	1.0	0.2	0.1	41	83	178	41b	9	18
Year 2												
Without Fe	1.9a	0.2	0.6	2.0	0.3	0.1	7	43	103	57	5	18
With Fe	2.2b	0.2	0.7	1.4	0.2	0.1	7	41	83	55	5	21
Without S	1.9	0.2	0.7	1.7a	0.2	0.1	8	45	68a	54	5	20
With S	2.1	0.2	0.7	1.1b	0.2	0.1	5	35	134b	59	5	20
Without N	1.9a	0.2a	0.7	1.6	0.2	0.1	7	41	97	61a	5	20
With N	2.1b	0.1b	0.7	1.4	0.2	0.1	6	42	78	49b	4	20

[1]Different letters denote significant differences ($p<0.05$) between the two treatments for a nutrient.

Leaf Nutrients

Foliar P and K were significantly ($P<0.05$) higher without S than with S in year 1 while Mn was higher with S than without S (Table 2) in years 1 and 2. Calcium was higher without S than with S in year 2. Foliar N was higher with N both years while P and Zn were higher without N than with N for both years. Except for higher foliar N with N than without N in year 2, nutrient differences betweeen N treatments were not significant.

Tree Growth

Tree growth according to bd, d.b.h., and height was not statistically different between treatments for any of the three nutrients used (data not shown). Mean bd was 1.2 and 1.4 cm without Fe and N compared to 1.6 and 1.5 cm with Fe and N, respectively, while bd was 1.7 cm without S and 1.3 cm with S. Height decline was -0.6, -0.3, and -0.4 m without Fe, S, and N, respectively, compared to -0.2, -0.5, and -0.1 m with Fe, S, and N, respectively.

DISCUSSION

The alkaline pH (>8.0) of the soil on the bottomland site in this study is likely due to the alkalinity of water and sediments of limestone origin that have frequented this landscape over the years during floods (Stallings 1994). Alkaline soils are affected by the lack of nutrient solubility, thereby causing essential elements to become unavailable for plant uptake (Wallace and Lunt 1960). For example, the solubility of Fe at pH 4.0 is 100 ppm but if the pH is increased to 6.0, the solubility drops to 0.01 ppm. Fe solubility is often too low to sustain healthy plant growth above a pH of 7.5. In the present study, the addition of Fe and N without a change in soil pH did not affect the extractable amounts of either nutrient, but the lowering of the pH in year 2 with S resulted in a corresponding increase in extractable Fe (Table 1). The crucial question in the application of fertilizers to soil is the longevity of the effect. All nutrients were applied at recommended rates, but because they were broadcast-applied and their solubility or ability to cause change in the soil was left to be accomplished by the spring rains, losses due to leaching and/or volatilization could be excessive. Because nutrient analyses were done annually rather than at one time, it cannot be determined whether the overall lower values for year 2 represent "actual" lower soil values (Table 1) or result from equipment settings for standardization during the analyses. However, the magnitude of the difference in nutrients between years was not comparable for pH.

The extractable amount of several soil nutrients, K, Ca, Mg, and S, was lower with S than without S. However, while the overall extractable S for both years was higher for the treatment without S than with S, when soils were separated by depths (10 and 20 cm), treatments with S had more S than treatments without S regardless of soil depth (data on file at 208 Foster Hall, Lincoln University, Jefferson City, MO 65102). This result is likely associated with the soil acidification process (Courchesne and others 2005). During the acidification process the decrease in pH leads to the release of these positively charged ions increasing their concentrations in the soil solution. However, once the cation exchange surface has been depleted of these ions, their concentrations in the soil solution can become low and are primarily determined by the weathering rate. Although our site is being artificially regenerated, the decrease in soil nutrient cation reserves in unmanaged and undisturbed forests has been attributed to a range of ecosystem processes. Some of these processes pertain to our results, including recent changes in the concentration of base cations in atmospheric deposition (Driscoll and others 1989, Wessenlink and others 1995), soil leaching by acidic compounds of anthropogenic or natural origin (Richter and others 1994, Kirchner and Lydersen 1995), and elemental sequestration in biomass (Binkley and others 1989, Knoepp and Swank 1994, Trettin and others 1999). Rustad and others (1993) reported increased leaching of S and N in soils treated with S and N, accompanied by increased losses of base cations during 2 years of acidification. David and others (1990) and Mitchell and others (1994) reported a concomitant decline in soil pH accompanied by increased sorption of S. In another study using coarse loamy soil, Rustad and others (1996) reported no significant decreases in base cations after 4 years and a small pH decline in the high-S treatment. The reported decline in pH was largely attributed to the significant increase in the concentration of exchangeable Al.

The amount of plant-available nutrients is much harder to determine than the amount of extractable nutrients; foliar nutrient uptake differences may appear to be only loosely related to soil nutrient levels (Tables 1 and 2). Several significant differences in foliar nutrient levels were associated with treatments containing Fe and N. In years l and 2, N and P were higher and Zn was lower in treatments containing N (Table 2). The addition of S was associated with lower P and K in year 1 and Ca in Year 2. Foliar Mn was doubled or more in treatments containing S. Chlorotic leaves developed on all trees, some becoming necrotic before leaf fall. Leaf nutrient analysis was not used to investigate the chemical conditions associated with chlorosis. Mills and Jones (1996) reported the following range of macronutrient element values (percent) for pin and swamp oaks from their survey of apparently healthy forest trees: N, 1.0-2.3; P, 0.2-0.4; K, 0.8-1.3; Ca, 0.4-1.4; Mg, 0.1-0.3; and S, ~0.2, respectively. These authors also reported the following range of micronutrient values (mg/kg) for pin oak: Fe, 45-180; Mn, 218-633; Zn, 29-88; Cu, 7-38; and B, 19-122. The comparison between our data and the survey data indicated that several of the nutrient elements for leaves in our report are less than or in the lower end of the survey range. Except for Zn, this observation includes all of the micronutrients, particularly S and Mn. Messenger (1991) reported that pin oak leaves with uniform chlorosis had low concentrations of N (1.48 percent), S (0.1 percent), P (0.07 percent), Zn (31 mg/kg), and Cu (4.6 mg/kg) which were significantly different from the concentrations in the green leaves. The interveinally chlorotic leaves, on the other hand, had either lower or similar N concentrations, but did not have low S, P, and Cu concentrations compared to green leaves.

In summary, fertilizer treatments did not increase tree growth. All trees were repeatedly browsed by deer; therefore, any trends in growth differences might have been influenced by deer activity. Treatments with S had lower soil pH and trees had higher leaf Mn. Trees in treatments with N had higher leaf N. Obviously, we have not determined that lowering soil pH will effectively increase overall nutrient uptake, alleviating chlorosis and increasing tree growth. Without fencing, it will be difficult to determine growth response. The study is ongoing with plans to measure the chemistry of soil and foliage, including chlorophyll content, over the growing season. These measurements should help to determine the duration of treatment effects on soil and leaves.

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