TREATMENT OF CHLOROTIC OAKS AND RED MAPLES BY SOIL ACIDIFICATION[1]

by Steve Messenger

Abstract. Rooting zone soil pHs and foliar nutrient imbalances were determined for chlorotic pin oaks, white oaks, and red maples. Soil pHs were significantly different between green and chlorotic tree sites of each species to a depth of 18-22 inches. Nutrient imbalances consisted of high phosphorus, potassium, and magnesium depending on season and species; and low manganese, iron, copper, and zinc depending on season and species. Abatement of chlorosis was accomplished by soil acidification with or without nutrient or mulch additions. Acidifications with sulfuric acid rapidly reduces the pH of alkaline soils to desired levels which may persist in treated subsoil zones for as long as four years.

Chlorosis of tree leaves may take the form of uniformly pale green to yellow leaves or a variety of patterns including pale green to yellow splotches, tips, margins, or interveinal areas (8). Chlorosis associated with high pH soils has frequently been referred to as *lime-induced* chlorosis and is commonly of the interveinal type (1,8). Iron or manganese deficiency is usually held responsible for this condition and abnormally high concentrations of leaf nitrogen, potassium, magnesium, or phosphorus are coincident with it (1,4,6). Such a leaf nutrient imbalance is largely explained by the well-established principle that iron and manganese are most available at soil pHs below approximately 6.2 and nitrogen, potassium, magnesium, and phosphorus are most available above approximately 6.2 (7).

One approach to abatement of interveinal chlorosis in trees is to assume that the cause is iron and/or manganese deficiency and to apply these nutrients to the soil, in the tree trunk, or onto the foliage. Another approach is to check the soil pHs in samples from throughout the root zone and, if they are too high, lower the soil pH to between 4.5 and 6.2 in as much of the root zone as is practical in order to increase the uptake of iron, manganese, zinc, and copper and to curtail excessive uptake of nitrogen, potassium, phosphorus, and magnesium. The materials commonly used to acidify soils are elemental sulfur, ammonium sulfate, and aluminum sulfate. Hacskaylo and Struthers (2), however, used sulfuric acid in soil auger holes around two small chlorotic pin oaks. Both trees became green within six weeks.

The research reported here was conducted, first, to determine the soil acidity/alkalinity conditions and the leaf nutrient imbalances associated with interveinal chlorosis of pin oak, white oak, and red maple; and, second, to determine the effectiveness of various techniques, especially soil acidification, in correcting the imbalances.

Materials and Methods

Soils beneath the crowns of chlorotic and healthy green trees were sampled to a depth of at least three feet. Among the healthy green trees were six pin oaks, ten white oaks, and four red maples. Samples were taken from each soil horizon and the depths recorded, or in highly disturbed soils, two to four profiles were sampled around each tree at standard depth intervals. Soil pHs were determined on fresh samples using a glass electrode pH meter and a 1:1 soil-water ratio.

Numbers of leaf samples taken for nutrient analysis are given in Table 1. Only fully developed leaves were sampled, in approximately equal amounts from the outermost branches of the upper, middle, and lower crown. The north side of each tree was avoided. No attempt was made to select the most chlorotic leaves of the chlorotic trees. Immediately following the collection of leaves, they were oven-dried for 24 hours at 70 degree C, then ground in a Wiley mill. Chemical element concentrations were determined spectrographically except for nitrogen, which was analyzed by the micro-Kjeldal technique.

A four-point leaf rating scheme was adopted in order to monitor and record the degree of

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chlorosis in treated and untreated trees. A rating of 0 denotes no chlorosis; 1 denotes light green interveinal tissue with dark green veins; 2 denotes yellow-green interveinal tissue with light green veins; 3 denotes uniformly yellow to necrotic leaves. Necrotic spots were noted on some 2-rated leaves; these were assigned the rating of 2.5. In order to access the degree of chlorosis of an entire tree, weighted leaf rating averages were calculated by estimating the percentage of the entire crown dominated by each leaf rating category. The resulting single number for each chlorotic pin oak was plotted on a time scale graph along with treatments applied.

Initial treatments of nine chlorotic pin oaks and one chlorotic red maple began in 1978. Seven of the nine pin oaks and the red maple were foliar sprayed with a solution of Hi-Acid, a complete fertilizer (28-18-8) with chelated iron, manganese, zinc, and copper. The solution was also poured into polyvinylchloride (p.v.c.) tubes implanted in the soil around the seven pin oaks. Two additional chlorotic pin oaks were treated by pouring 3 N sulfuric acid into soil-implanted p.v.c. tubes. Based on periodic visual ratings and chemical analysis of leaves from treated and untreated trees, treatments of chlorotic pin oaks, white oaks, and red maples in subsequent years consisted of various combinations of: 1) topsoil and subsoil applications of sulfuric acid, aluminum sulfate, copper sulfate, and manganese sulfate; 2) iron or manganese Medicaps; 3) copper and/or zinc foliar sprays; 4) topsoil applications of ammonium sulfate; and 5) acid-forming mulches. To isolate the effect of sulfuric acid, applications to the topsoil and subsoil were made around three previously untreated chlorotic pin oaks in March, 1983.

To help assess some of the treatments used in a more uniform environment, replicated 5X5′ square plots were established on a moderately fine-textured alkaline soil supporting lawn grass. Each of several acidifying materials were applied at three different rates in late April, 1982, in order to test their ability and the time required to lower the soil pH from 7.7 to 6.2. In this paper, only the most rapidly effective materials are evaluated, namely, sulfuric acid, granular sulfur, aluminum sulfate, and ammonium sulfate.

Results and Discussion

Soil pHs were higher (above 6.2) in the upper rooting zones of interveinally chlorotic pin oaks, white oaks, and red maples than in the upper rooting zones of green trees (Figures 1-3).

Nutrient concentrations in the leaves of chlorotic trees demonstrate imbalances that reflect several established relationships between soil pH and nutrient availability (Figures 4-6). However, the nature of the imbalances varies somewhat among seasons and species. For example, in late spring, chlorotic pin oaks are characterized by high phosphorus, high potassium, low manganese, and low zinc; in midsummer, by high phosphorus, low iron, low

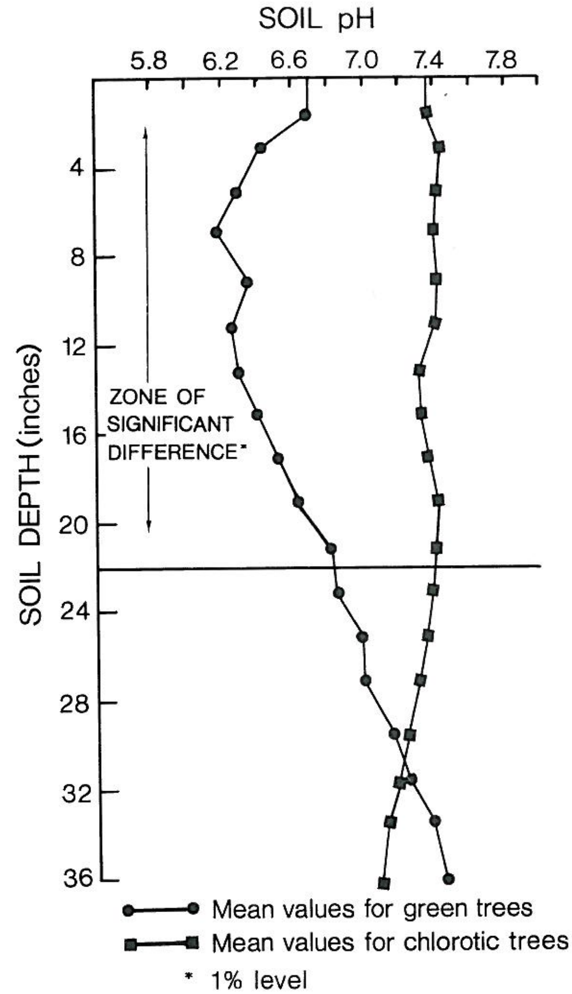

Figure 1. Soil pH differences between green and chlorotic pin oaks sites (from Karl, 1980).

Table 1. The numbers of leaf samples taken for nutrient analysis.

Tree	Late spring green	Late spring chlorotic	Mid-summer green	Mid-summer chlorotic	Late summer green	Late summer chlorotic
pin oak	56	63	28	47	40	49
white oak	40	27	41	21	40	30
red maple	18	18	incomplete		incomplete	

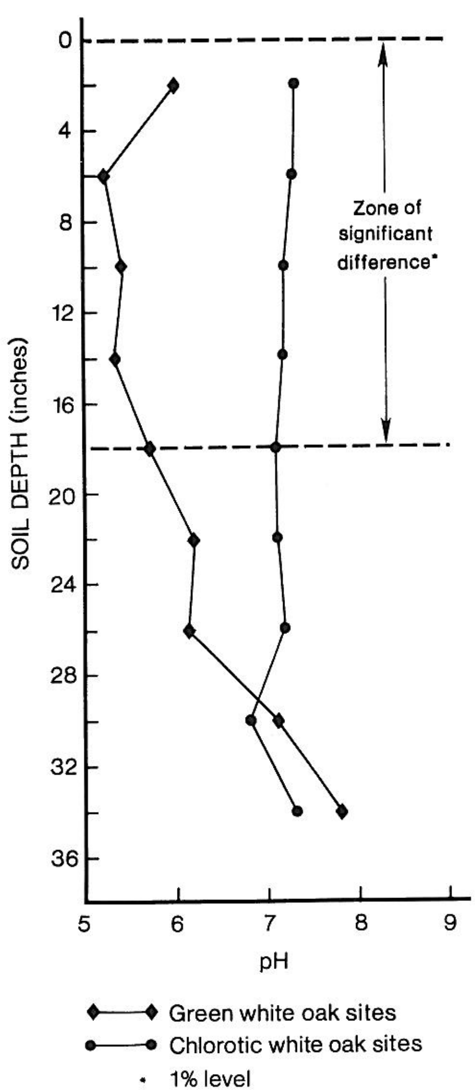

Figure 2. Soil pH differences between green and chlorotic white oak sites.

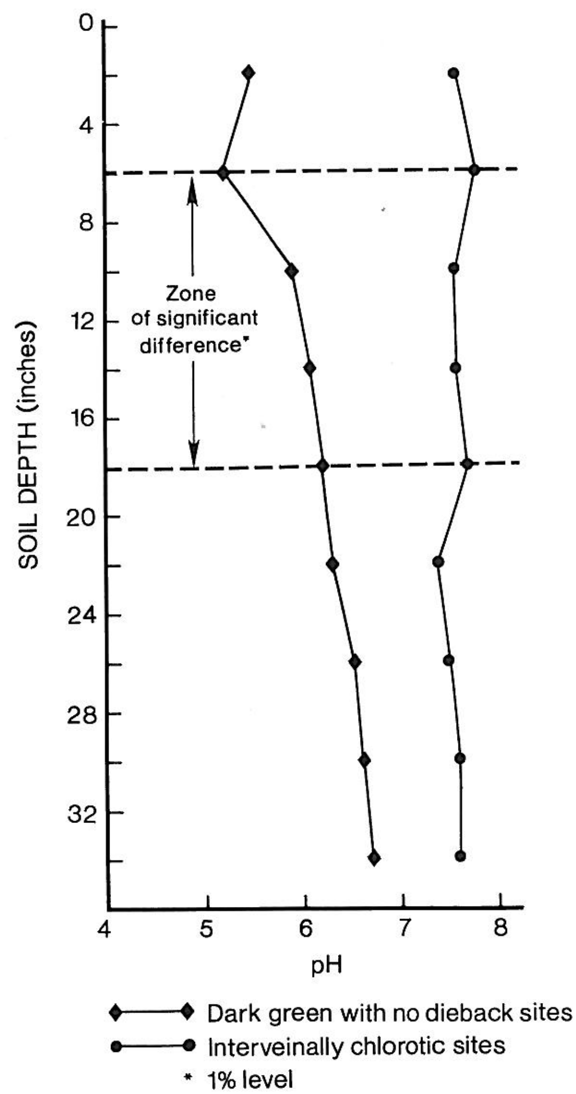

Figure 3. Soil pH differences between green and chlorotic red maple sites.

manganese, and low zinc; and in late summer, by high magnesium, low iron, and low zinc. Chlorotic white oaks, on the other hand, have high foliar magnesium, low iron, low manganese, and low copper throughout the growing season. Although foliar analysis data for chlorotic red maples are incomplete for mid-summer and late summer, the late spring imbalance involves high phosphorus, high potassium, and low manganese. There are no indications of low iron at any season.

Comparative effects of several acidifying agents on soil pHs of lawn plots indicate that sulfuric acid at all three rates lowered the topsoil pH most rapidly, to below 6.2 within three weeks time (Figure 7). These pHs remained below 6.2 for at least 14 months where the two highest rates were applied. Topsoil treated with the dry materials did not reach the desired pH range until mid- to late summer. None of the rates of ammonium sulfate or aluminum sulfate resulted in protracted periods of satisfactory soil pHs. At all three rates of sulfur application, however, topsoil pHs were still below 6.2 and declining after 14 months. At 14 months, the subsoil pH had declined to pH 7.0 or slightly below for all treatments, but granular sulfur was most effective.

All rates of ammonium sulfate stimulated rampant grass growth during the first year. All rates of sulfuric acid turned the grass brown almost immediately; there was no regeneration during the

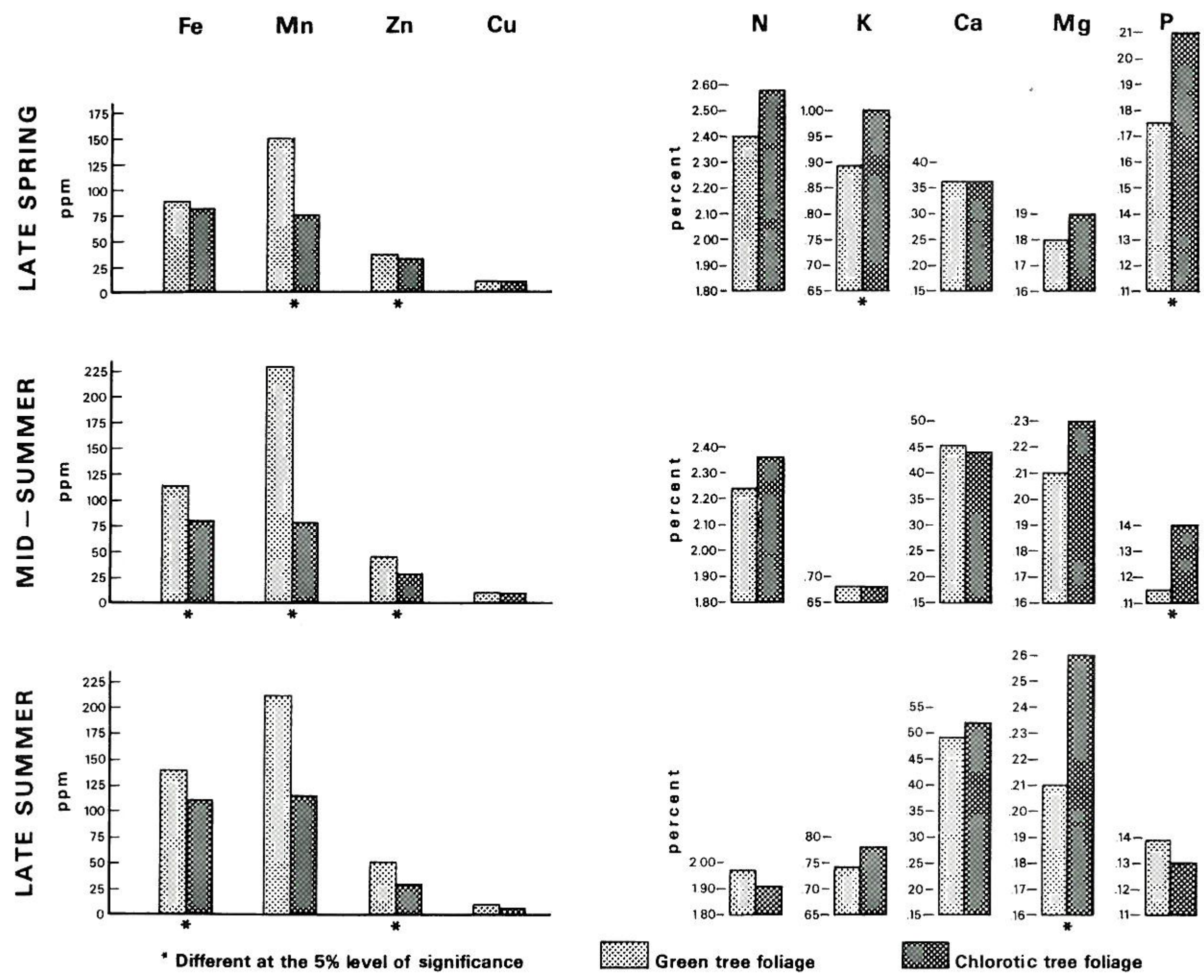

Figure 4. Comparison of seasonal nutrient concentrations in foliage of green and chlorotic pin oak trees.

year of application, but complete regeneration took place the following spring. None of the sulfur rates harmed the grass in the year of application. However, sulfur-treated grass turned brown the following spring and did not recover by late summer.

Foliar and soil application of Hi-Acid fertilizer to chlorotic pin oaks in 1978 resulted in no visible improvement in leaf color even though foliar iron and copper increased relative to controls. Therefore, more intensive use of soil acidifying agents and specific nutrients was begun.

During 1979, untreated chlorotic pin oaks became worse (Figure 8: Tree 17). Some improvement took place in trees treated with some of the combinations that included manganese, or in trees treated by subsoil applications of sulfuric acid (Figure 8: Trees 13 and 19).

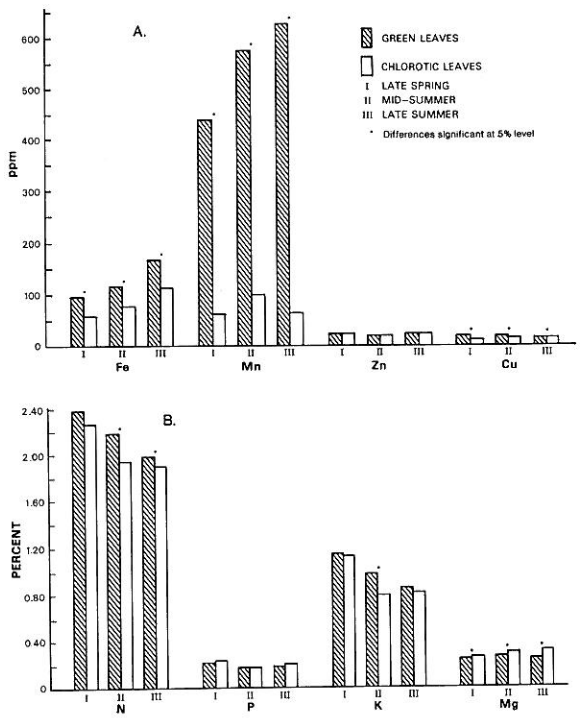

Figure 5. Comparison of seasonal nutrient concentrations in green and chlorotic white oak foliage: (A) micronutrients, (B) macronutrients.

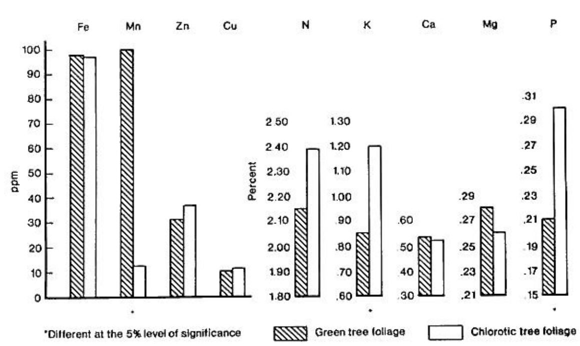

Figure 6. Comparison of late spring nutrient concentrations in green and chlorotic red maple trees.

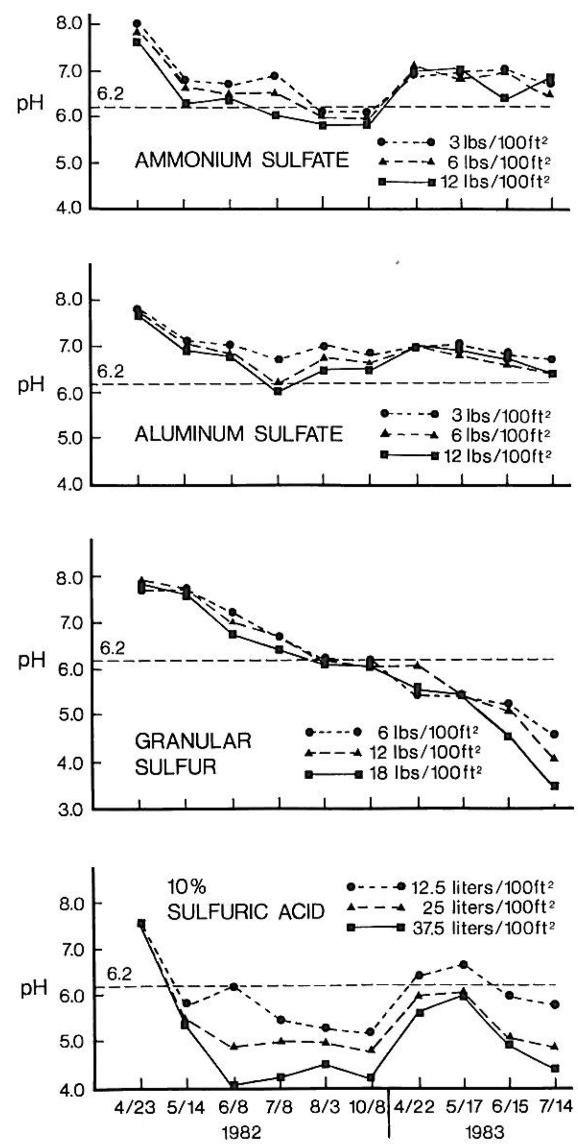

Figure 7. Comparative effects of several acidifying agents on an initially alkaline soil.

Between late spring, 1980, and late spring, 1981, every tree became less chlorotic that had been treated by topsoil application of sulfuric acid in the fall of 1979 or in early spring of 1980 (Figure 8: Trees 10, 11, 13). Within three months after topsoil acid treatment, Tree 10 had no chlorosis at all and Tree 11 had mild chlorosis on only one lower branch. By mid-summer, 1981, with no additional treatments, Trees 11 and 13 also had no chlorosis at all. Tree 19 was given two topsoil treatments with sulfuric acid in 1981. Although chlorosis became less, it did not continue to decrease until after a subsoil application

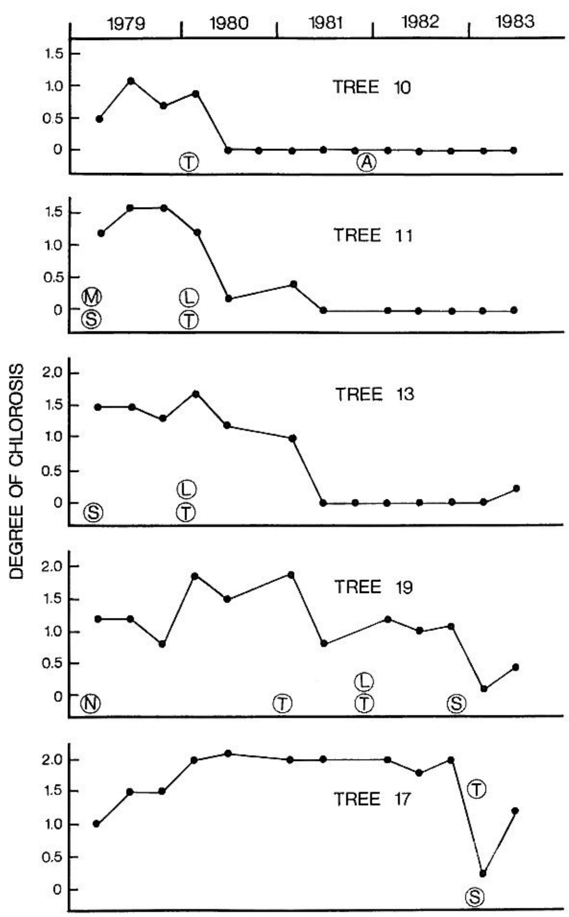

Figure 8. Changes in degree of chlorosis in pin oak crowns following various treatments. T = topsoil application of sulfuric acid; S = subsoil application of sulfuric acid; A = surface application of aluminum sulfate; N = surface application of ammonium sulfate; L = surface application of white pine litter; M = trunk implantation of manganese Medicaps.

of sulfuric acid laced with manganese sulfate and copper sulfate.

The complete elimination of chlorosis in Tree 13 is considered to be primarily a response to soil treatments with sulfuric acid, since the only other treatment was with a white pine needle mulch. Since some contribution by the mulch is possible, three previously untreated chlorotic pin oaks were each given topsoil and subsoil acid applications on March 14, 1983. The surface rate was 5 gallons/100 square feet beneath the crowns; and 2-inch diameter holes, 2 feet deep and 2 feet apart organized in two circles beneath the crown, were filled with sulfuric acid. In early June, each tree was markedly greener than in previous years (Figure 8: Tree 17, e.g.).

Topsoil pHs beneath treated pin oaks were approximately neutral three years after sulfuric acid application. Subsoils treated with sulfuric acid were still considerably acidic after four years. Prolonged maintenance of good leaf color following acidification may therefore be a function of persistently favorable subsoil pHs.

Foliar nutrient concentration changes associated with chlorosis abatement were variable. Reductions in phosphorus and magnesium were common with or without increases in iron, manganese, or zinc. On the other hand, an increase in iron and manganese was occasionally associated with chlorosis abatement without a decrease in phosphorus or magnesium.

Experience is limited in the abatement of white oak chlorosis by soil treatments involving sulfuric acid, but a reduction in potassium and magnesium was most closely associated with the degree of chlorosis abatement in four trees treated in 1982 (5).

Combinations of sulfuric acid, ammonium sulfate, aluminum sulfate, and manganese sulfate have also been used with success on chlorotic red maples. Determinations of best formulations and foliar nutrient responses are not yet complete.

Conclusions

Rooting zone soil pHs above 6.2 and interveinal chlorosis in pin oaks, white oaks, and red maples are closely associated.

Nutrient imbalances of interveinally chlorotic trees are variable, but in general accord with established relationships between soil pH and nutrient availability.

Restoration of nutrient balances and normal leaf color can be accomplished and maintained for several years by topsoil and subsoil acidification using sulfuric acid as the primary soil amendment. Acidification of the subsoil may lower the soil pH to below 6.2 for as long as four years.

Refinements and supplements to soil acidification techniques need to be developed to correct specific imbalances, to determine the most effective spatial patterns of treatment and the most effective timing of treatments.

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ABSTRACT

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The form of trees is perhaps their most distinctive feature as a biological group, yet we have only recently understood quite elementary features of their construction. In this article, I will describe advances in three rather different fields, using different approaches, which collectively have contributed to a better comprehension of tree form. One method is descriptive, another is theoretical, and the third is largely experimental. First, in the realm of descriptive and qualitative morphology, investigation that takes into consideration the diversity of tropical tree species has revealed general principles of construction which show how the shape of the tree crown is established by a combination of deterministic and opportunistic processes. Second, in the field of theoretical and quantitative biology, simulation of crown shape through computer programs has provided insights into the developmental control of tree form. Third, experimental research on water transport in trees has suggested the presence of structrual constraints that control water movement to the hydraulic advantage of major axes as opposed to minor ones, a mechanism that allows trees to grow tall, since the upper branches and especially the trunk are favored in times of water stress.