SOIL FACTORS ASSOCIATED WITH MANGANESE DEFICIENCY OF URBAN SUGAR AND RED MAPLES

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Abstract. Manganese deficient and healthy *Acer saccharum* and *Acer rubrum* were sampled for foliar nutrient concentration and rated for chlorosis. Soil beneath trees was analyzed for pH, organic matter content, oxidation reduction potential, texture, calcium carbonate accumulation, and extractable manganese. Soil pH and summer rainfall were most strongly correlated with foliar manganese concentration and symptoms. Soil redox potential, organic matter, and extractable manganese were less strongly correlated.

Manganese (Mn) deficiencies are seldom observed in trees on undisturbed soils, but are common in urban areas of the Great Lakes states (Kielbaso and Ottman 1976). High soil pH and high levels of calcium are the factors often associated with Mn deficiencies of maples (Kielbaso and Ottman 1976, Kreag 1940). Urban soils tend to have elevated pH and calcium levels due to profile disruption (Craul 1982) and disrupted drainage patterns (Kreag 1940) both caused by construction.

Urban soils are thought to have very low levels of organic matter (Antheunis et al. 1982). This has been suggested as a cause of manganese deficiency (Kielbaso and Ottman 1976). In field crops, however, high levels of soil organic matter (OM) are considered essential for development of Mn deficiency (Mulder and Gerretsen 1952).

Other factors that are frequently associated with manganese deficiency are soil moisture, texture, microorganisms, oxidation-reduction potential (redox), and competing cations.

Soil moisture affects the availability of Mn for numerous ill-defined reasons (Mortvedt et al. 1972). One important factor is the transportation of Mn to roots for subsequent uptake. Without speculation as to cause, several authors have mentioned that deficiencies tend to be associated with low soil moisture levels (Kreag 1940, Mulder and Gerretsen 1952, Rich 1956). Others have suggested that symptoms are more severe in moist conditions (Smith 1976). Moisture variability may account for year to year differences in symptom development.

Redox potential is a measure of the concentration of electrons in the soil. This effects the valence of Mn, which in turn effects Mn solubility and availability. The common valences of Mn in soil are +2 and +4. The +2 form is more mobile in the soil, thus, is more easily transported to roots or leached from the rooting area.

The objective of this study was to define and quantify the site factors related to manganese deficiency of urban maples.

Materials and Methods

Foliage from randomly selected red maples (*Acer rubrum*) and sugar maples (*Acer saccharum*) were sampled during July, August and early September of 1982 and 1983. Samples were from street and park trees in the cities of Stevens Point, Wisconsin; Highland Park, Lake Forest, and Rockford, Illinois; Grand Rapids, Ann Arbor, Lansing, East Lansing, Flint, Saginaw, and the Michigan State University campus—E. Lansing, Michigan. Red maple foliage samples were also collected from the street tree collection at the Ohio Agriculture Research and Development Center, Wooster. Trees with small, uniformly chlorotic leaves, and columnar varieties were not sampled.

Data collected on-site were: tree species and variety, diameter, chlorosis rating, and soil profile characteristics. Redox potential was determined for trees sampled in 1983. The entire tree was rated for chlorosis by visually dividing the crown into thirds and rating the worst leaf on five randomly selected terminals in each third. Terminals with healthy, green leaves were given a rating of zero. Leaves having slight indistinct interveinal chlorosis were rated as one. Leaves with indistinct chlorosis from the edge of the leaf to not closer

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than 3 mm of a major rib were rated two. Leaves distinctly chlorotic from the edge to within 3 mm of the midrib with some green minor veins, were rated three. If the majority of the leaf was extremely chlorotic, with only the central vein and major veins remaining partially green, and with no more than two necrotic spots, a rating of four was made. Necrotic or partially necrotic leaves were rated five. An overall chlorosis rating was determined by averaging all 15 ratings. A mean chlorosis rating of less than 0.5 was considered healthy. If the rating was greater than 0.5 the tree was considered chlorotic.

Ten 2.5 cm diameter × 15 cm deep soil cores were collected between the dripline and the tree trunk (Ruark et al. 1982). The following soil characteristics were recorded: soil texture—determined by hand; and effervescence—detected by addition of one drop 10% HCl to determine the presence of calcium carbonate. Surface soil redox measurements were made using three platinum micro electrodes and a Specific Ion Meter (McKenzie and Erickson 1954).

Precipitation data were collected from the National Oceanic and Atmospheric Administration Climatological Data reports of stations closest to the study sites. Summer totals were the sum of June, July, and August values.

Foliage and soil samples were analyzed using standard techniques (Smiley et al. 1985). Only data from intact, unshaded trees were analyzed.

Results

Of 131 red maples and 167 sugar maples sampled, diameters ranged from 5 to 31 cm, with a mean of 14 cm. Red maples, mainly 'Red Sunset' and 'October Glory,' were combined for analysis.

Of all soil factors, surface soil pH was the variable most strongly correlated with foliar Mn. With increasing pH, foliar Mn decreased. The majority of the chlorotic sugar maples grew on soils with pH greater than 6.8 (Figure 1). The majority of the chlorotic red maples were on soils of pH 6.6 and above.

Sugar maples on soils with effervescent reactions had a mean foliar Mn concentration of 56 ppm. Those on soils without carbonate cementation had a significantly higher mean of 169 ppm Mn. The means of red maples were similar, with the effervescent group having 33 ppm and the non-effervescent group 59 ppm Mn.

The mean pH of effervescent soils was 7.1. The mean pH of non-effervescent soils was significantly lower at 6.8.

Precipitation varied from 200 to 302 cm per year for the 15 study areas. Total precipitation showed no correlation with foliar Mn levels. However, there was a significant correlation with summer rain. Areas with low rainfall tended to have sugar and red maple with lower Mn concentrations (Figure 2).

Soil redox potentials (pe) ranged from −3.1 to 7.0 (−182 mv to +413 mv). Healthy sugar

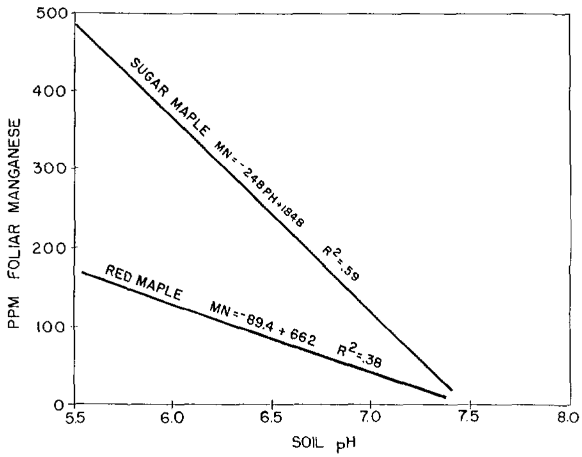

Figure 1. Relation between soil pH and foliar manganese concentration in urban sugar and red maples.

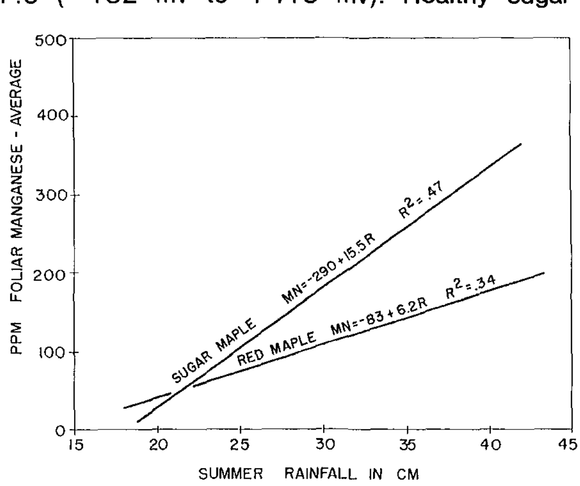

Figure 2: Relation between summer rain and foliar manganese concentration in urban sugar and red maples.

maples were on soils with a mean pe of 3.1; chlorotic trees were significantly lower at 1.2. Healthy red maples were on soils of significantly higher pe, having a mean of 4.1, while chlorotic trees had a mean of 1.3.

Significant positive correlations existed between foliar Mn and soil pe in both sugar and red maple (Figure 3). Generally, as soil pe increased, so did foliar Mn.

Soil organic matter levels ranged from 0.4% to 9.9% with a mean of 5.6% for 291 samples. The majority of chlorotic sugar and red maples were on soils of more than 5.5% OM (Figure 4). The mean for healthy sugar maple was 4.8% OM, while the mean for healthy red maple was 4.7% OM. The mean for chlorotic sugar maple was significantly less at 5.6% OM. No red maples were found in soils with lower than 3% OM. A significant linear relation between organic matter and foliar Mn was found for both species.

Concentrations of soil manganese ranged from 13 to 234 ppm. Both healthy and chlorotic sugar maples were found on soils with less than 70 ppm Mn. On soils with greater than 70 ppm Mn only healthy sugar maple were found. On soils with greater than 110 ppm Mn only healthy red maple were found.

After accounting for pH differences using an analysis of covarience, soil texture was found to be unrelated to foliar Mn concentration in sugar or red maple.

When all quantitative soil factors were included in a stepwise multiple linear regression with foliar manganese as the dependent variable, the regression line which could best predict Mn concentrations in sugar maple was:

$$Mn = 8658\,(1/pH) - 11094\,(OM^2) + .1817\,(Eh^*) - 1111$$

($n = 48$, $r^2 = 68\%$) where Mn equals the foliar manganese concentration in ppm, OM equals the soil organic matter concentration in percent and Eh equals soil redox potential in mv. For red maple the regression which best predicted foliar manganese was:

$$\text{Log}_{10}\,Mn = -.69\,(pH) - .43\,(OM) + 6.3$$

($n = 118$, $r^2 = 49\%$).

Discussion

High soil pH is usually associated with chlorosis (Christensen et al. 1950, Mulder and Gerretsen 1952, Page 1962A and B). In this study, pH accounts for approximately 50% of the data variability.

Chlorotic trees were more often found on effervescent soils, i.e., soils with high levels of calcium carbonate. This is probably due to chemisorption and precipitation of Mn at $CaCO_3$ surfaces as well as formation of $MnCO_3$ (rhodocrosite) reducing the availability of Mn

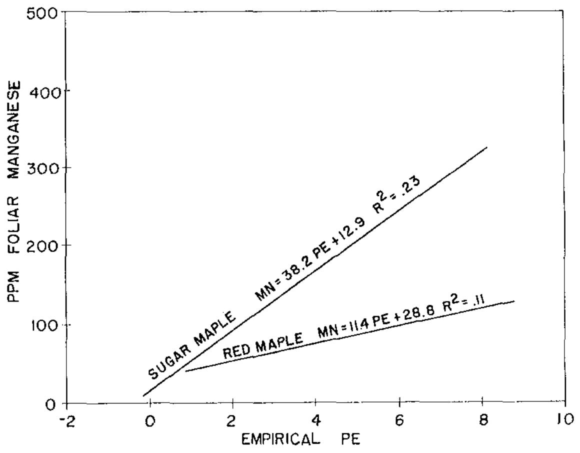

Figure 3. Relation between soil oxidation-reduction potential and foliar manganese concentration in urban sugar and red maples.

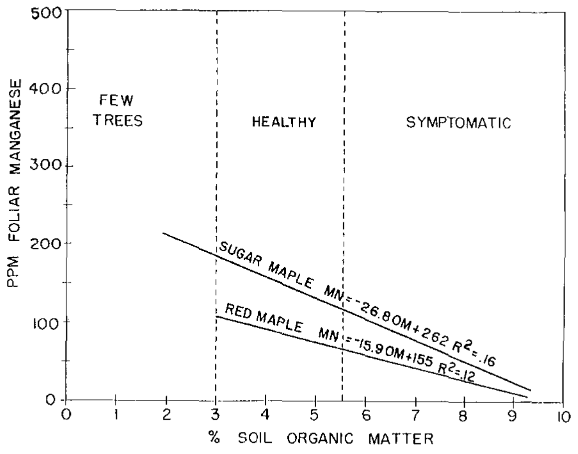

Figure 4. Relation between soil organic matter and foliar manganese concentration in urban sugar and red maples.

*pe = Eh/59.2

(Jones 1957A and B, McBride 1979). There was not a one-to-one correlation between effervescence and chlorosis due to differences in pH, pe, and organic matter (Christensen et al. 1950).

It was hypothesized that healthy trees would be found on soils with low redox potentials since this would favor the formation of Mn+2 (Bohn 1970). This was not the case as healthy trees were found in soils with relatively high potential.

Higher redox potentials are usually related to lower soil moisture levels (Copeland 1957, McKeague 1965, McKenzie et al. 1960, McKenzie and Erickson 1954). Therefore, healthy trees were more often found on sites which were relatively well drained. With borderline soil pH level (6.6-7.0), redox, thus drainage, was of great importance with red maple. The higher the potential, thus the better the drainage, the greater chances of the tree being healthy. Sugar maple showed the same trend.

Effects of precipitation on nutrient uptake of trees have been demonstrated (Barrow et al. 1969, Bickelhaupt et al. 1979). With maples in this study it was found that higher rainfall was associated with higher foliar Mn. One theory for the increase in foliar Mn with increased rain was that high soil moisture levels cause a lowering of the redox, which in turn causes a reduction of manganese oxides. This theory was rejected since the redox data were exactly opposite. Healthy trees tended to be on sites with higher redox potentials.

The alternative hypotheses were: 1) that an increase in rainfall tended to lower pH in well drained soils via leaching basic ions, and 2) that more Mn was transported to roots via greater mass flow of water in moist, well drained soils (Barber, 1981). Both of these hypotheses are supported by the redox and summer rain data. Therefore, optimal conditions for maples were relatively high rainfall and well drained soils.

Most chlorotic maples were found on soils with high (greater than 5.6%) organic matter. Several were also found on soils with low (less than 3%) organic matter. Therefore, the optimum concentration for organic matter for Mn uptake is between 3 and 5.6%. When organic levels are either higher or lower, the potential for Mn deficiency increases.

The most probable reason for reduced Mn uptake at high OM levels is the formation of organic-Mn complexes (Gerring et al. 1969, Heintze 1957, McBride 1982). At low levels there may be a lack of exchangeable organic-Mn complexes (Heintze and Mann 1947, Shuman 1979, Trocme et al. 1950).

The importance of soil texture in manganese deficiency has been demonstrated by many researchers (Rich 1956, Reddy and Perkins, 1976, Teuscher 1956). The reason that it was not prominent in this study may have been the lack of diversity of texture at a given pH. More extensive sampling of soils of differing textures but with similar pH may result in identification of preferred texture groups. The correlation between soil Mn and foliar Mn was weak for sugar maple.

All multiple regressions contained surface soil pH as the most important independent variable. This was followed in importance by the soil organic matter and redox potential. Correlations were negative with pH and OM and positive with redox. Therefore, trees grew better in soils of relatively lower pH, lower organic matter, and higher redox.

Reasons for the decrease in availability of Mn with increasing pH have been widely researched (Lindsay 1979, McBride 1982, Page 1982 A and B, Schwab and Lindsay 1983). Basically, there are three reactions which affect the availability of Mn. Manganese is complexed by organic matter, manganese oxides are formed, and manganese is precipitated by calcium carbonate. With these complexes, disassociation is dependent on pH; the lower the pH, the more Mn available. Therefore, it was theorized that Mn availability to urban maples is controlled by soil pH especially as it affects calcium and organic complexes. The physical processes of translocation of nutrients to the root system also play an important role in Mn uptake when pH is not excessively high.

By construction of basements, sidewalks, and streets with associated removal, addition, inversion, and compaction of the soil, man has altered the soil environment so that it is unsuitable for certain species of trees. This is more prevalent in the Great Lakes States due to the presence of calcareous subsoils. Prior to development, many surface soils in this region were acidic to slightly acidic and subsoils calcareous and neutral to alkaline. Removing the O horizon, reducing other surface layers, spreading subsoils over the surface, and then restricting lateral drainage has created a surface soil with higher than normal pH and has slowed the leaching process which could reduce the pH. These processes have brought about the manganese problems and may limit the growth of other species.

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Literature Cited

1. Anthennis, N., N. Malevez, and R. Delmotte. 1982. *Etat nutritif de l'arbre en ville.* Rev. Agric. 35:1822-1836.
2. Barber, S. A. 1981. **In** Chemistry in the soil environment. Soil Sci. Soc. Am. Special Publ. 40. Madison, WI.
3. Barrow, N. J., K. Spencer, and W. M. McArthur. 1969. *Effects of rainfall and parent material on the ability of soils to adsorb sulfate.* Soil Sci. 108:120-126.
4. Bohn, H. L. 1970. *Comparisons of measured and theoretical Mn+2 concentrations in soil suspensions.* Soil Sci. Soc. Am. Proc. 34:195-197.
5. Bickelhaupt, D. H., R. E. Lea, D. D. Tarbet, and A. L. Leaf. 1979. *Seasonal weather regines influence interpretation of Pinus resinosa foliar analysis.* Soil Sci. Soc. Am. J. 43:417-420.
6. Christensen, P. D., S. J. Toth, and F. E. Bear. 1950. *The status of soil manganese influenced by moisture, organic matter, and pH.* Soil Sci. Soc. Am. Proc. 14:279-282.
7. Copeland, O. L., Jr. 1957. *A study of the influence of moisture and compaction on soil oxidation-reduction potentials.* Soil Sci. Soc. Am. 21:269-271.
8. Craul, P. J. 1982. Urban Forest Soils: A Reference Workbook. SUNY Col. Environ. Sci. For. Syracuse, NY. 182p.
9. Geering, H. R., J. F. Hodgson, and C. Solans. 1969. *Micronutrient cation complexes in soil solution.* Soil Sci. Soc. Amer. 38:81-85.
10. Heintze, S. G. 1957. *Studies on soil manganese.* J. Soil Sci. 8:287-300.
11. Heintze, S. G., and P.J.G. Mann. 1947. *Soluble complexes of manganic manganese.* J. Agric. Sci. 37:23-26.
12. Jones, L.H.P. 1957A. *The effect of liming a neutral soil on the uptake of manganese by plants.* Plant Soil. 8:301-327.
13. Jones, L.H.P. 1957B. *The relative content of manganese in plants.* Plant Soil. 8:328-336.
14. Kielbaso, J. J., and K. Ottman. 1976. *Manganese deficiency—contributory to maple decline?* J. Arboric. 1:27-32.
15. Kreag, K. K. 1940. *Nature and control of shade tree chlorosis in Lansing, Michigan.* Proc. Nat. Shade Tree Conf. 16:32-38.
16. Lindsay, W. L. 1979. Chemical Equilibria in Soils. John Wiley and Sons. New York, N.Y. 449p.
17. McBride, M. B. 1979. *Chemisorption and precipitation of Mn+2 at $CaCO_2$ surfaces.* Soil Sci. Soc. Amer. J. 43:693-698.
18. McBride, M. B. 1982. *Electron spin resonance investigation of Mn+2 complexation in natural and synthetic organics.* Soil Sci. Soc. Amer. 46:1137-1143.
19. McKeague, J. A. 1965. *Relationship of watertable and Eh to properties of three clay soils in the Ottawa valley.* Can. Soil Sci. 45:49-62.
20. McKenzie and A. E. Erickson. 1954. *The use of redox potentials in studies of soil genesis.* Soil Sci. Soc. Am. Proc. 18:481-485.
21. McKenzie, L. J., E. P. Whiteside, and A. E. Erickson. 1960. *Oxidation-reduction on the mechanism of B horizon formation in podzols.* Soil Sci. Soc. Am. Proc. 24:300-305.
22. Mortvedt, J. J., P. M. Giurdano, and W. L. Lindsay. 1972. *Micronutrients in agriculture.* Soil Sci. Soc. Amer. Madison, WI. 666p.
23. Mulder, E. G., and F. C. Gerretsen. 1952. *Soil manganese in relation to plant growth.* Advan. Agron. 4:221-277.
24. Page, E. R. 1962A. *Studies in soil and plant manganese. II. The relationship of soil pH to manganese availability.* Plant Soil. 16:247-257.
25. Page, E. R. 1962B. *Studies in soil and plant manganese. III. The availability of higher oxides of manganese to oats.* Plant Soil. 17:99-108.
26. Reddy, M. R., and H. F. Perkins. 1976. *Fixation of manganese by clay minerals.* Soil Sci. 121:21-24.
27. Rich, C. I. 1956. *Manganese content of peanut leaves as related to soil factors.* Soil Sci. 82:353-363.
28. Ruark, G. A., D. L. Mader, and T. A. Tatter. 1982. *A composite sampling technique to assess urban soils under roadside trees.* J. Arboric. 8:96-99.
29. Schwab, A. P., and W. L. Lindsay. 1983. *The effect of redox on the solubility of manganese in a calcareous soil.* Soil Sci. Soc. Am. J. 47:217-220.
30. Shuman, L. M. 1979. *Zinc, manganese, and copper in soil fractions.* Soil Sci. 127:10-17.
31. Smiley, E. T., J. B. Hart, and J. J. Kielbaso. 1985. *Foliar nutrient diagnosis of urban sugar and red maples in the Great Lakes region.* J. Environ. Hort. 3:104-107.
32. Smith, E. M. 1976. *Manganese deficiency—common in maples.* Amer. Nurserym. 11, 131.
33. Teuscher, H. 1956. *The red maple—a neglected tree.* Am. Nurserym. 104:9, 58, 59.
34. Trocme, S., G. Barbier, and Chabannes. 1950. *Recherches sur la chlorose par carence de manganese des cultures irriguees a l'ean d'egout.* Ann. Agron. 1:663-685.

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