WHITE PINE CHLOROSIS IN NORTHERN ILLINOIS: IRON DEFICIENCY OR NOT?

by A. Steven Messenger and Mark W. Stelford

Abstract. Eastern white pine (*Pinus strobus L.*) is a prized ornamental. Its natural habitat includes a wide range of soil texture and moisture conditions, leading to the assumption by many that this species can be planted almost anywhere. Its performance in human-altered landscapes demonstrates otherwise. One malady, symptomized by chlorotic foliage, has been dubbed "white pine decline," and because alkaline soil is often associated with this condition, iron deficiency has been postulated. Our studies, conducted over a wide range of soil textures throughout northern Illinois, confirm the negative role of soil alkalinity but lead us to reject the hypothesis of iron deficiency. On the contrary, our data suggest iron **efficiency** by this species.

Eastern white pine (*Pinus strobus L.*) is a prized ornamental (2, 21), but can be intolerant of many chemical and physical conditions found within human-altered sites. Thousands of dollars are spent annually replacing trees because many of these stress-causing factors are ignored by tree owners, nurserymen, landscape planners and arborists (22). This intolerance may manifest itself as "white pine decline", one symptom being chlorotic foliage (22).

White pine decline has been attributed mainly to physical and some biotic factors including extremes in soil moisture and weather, changes in soil physics and chemistry, and attacks on plant parts by fungi, insects, and nematodes (22). The primary soil chemical factor that is believed to play a role is soil pH, with alkaline conditions reported to induce iron chlorosis (22). Recent research has suggested that a deficiency of iron in the foliage does not necessarily exist in chlorotic trees growing in alkaline soils in northern Illinois (11). Instead, the data suggest that soil pH may play a role in inducing a nutrient imbalance; i.e., excesses of one or more macronutrients and deficiencies of one or more micronutrients, especially manganese (11).

This paper reports the results of an investigation conducted during February of 1980, 1982, 1989, and 1992 that compared "healthy" and chlorotic eastern white pines throughout northern Illinois to determine if any significant differences in foliar nutrient concentrations and soil pH existed between the two groups.

Eastern white pine has an extensive geographic range and environmental tolerance. An aggressively reproducing species, it is present on many different sites, including such extremes as glacial outwash sands, lacustrine clays, dry rocky ridges, and wet sphagnum bogs (5), illustrating its tolerance of a wide range of soil texture and moisture regimes. These sites encompass almost all of the soil orders within its geographic range, these being the Inceptisols, Ultisols, Spodosols, Entisols, and Alfisols with parent materials including glacial drift, granites, sand dunes, gneisses, schists, and sandstones, as well as phyllites, slates, shales, and limestones (23). Eastern white pine competes well on drier, sandy sites but can also be found on clayey and poorly drained soils (5, 23, 24).

The extensive natural range of eastern white pine has led to the premature conclusion that "it will grow in almost any area" (10). However, reports of white pine exhibiting signs of environmental stress have been documented in association with "human-altered" sites (22). Soil properties altered by human activity have been designated as the primary sources which lead to stress in eastern white pines. Soil strata at human-altered sites may have a more alkaline pH, contain more clay and have a higher degree of compaction than natural sites (22). Though substantial differences in soil physical properties may exist between sites with healthy and chlorotic eastern white pine specimens, these properties, *per se*, are unlikely to be responsible for the stress since eastern white pine, as mentioned earlier, is reported to be very tolerant of soil texture and moisture extremes.

Differences in soil chemistry and the resultant nutrient composition of the foliage may provide a supplemental explanation of tree health differences. Alkaline soil is frequently associated

Table 1. Average soil pH observed to 24 inches (60 cm) and sample size (n).

Healthy			Chlorotic		
Identifier	Avg. pH	n	Identifier	Avg. pH	n
H-1980-1	7.7	4	C-1980-1	7.7	3
H-1980-2	7.9	4	C-1980-2	8.1	3
H-1980-3	7.2	4	C-1980-3	7.2	3
H-1982-1a*	4.7	3	C-1982-1	7.5	3
H-1982-6b	5.5	3			
H-1982-11c	6.8	3			
H-1982-16d	6.6	3			
H-1989-1	5.8	4	C-1989-1	7.6	4
H-1989-2	5.5	4	C-1989-2	7.9	4
H-1989-3	5.7	4	C-1989-3	7.8	4
H-1989-4	5.5	4	C-1989-4	7.9	4
H-1989-5	5.4	4	C-1989-5	7.8	4
H-1992-1	5.8	3	C-1992-1	7.5	3
H-1992-2	5.8	3	C-1992-2	7.7	3
H-1992-3	5.9	3	C-1992-3	7.6	3
H-1992-4	5.6	3	C-1992-4	7.6	3
H-1992-5	5.5	3	C-1992-5	7.5	3
			C-1992-6	7.5	3

Note that the sample numbers indicate replicates (sample numbers which correspond between healthy and chlorotic trees are not side-by-side comparisons).

with chlorosis in a wide variety of plants, especially those naturally associated with acid soils (4). Eastern white pine has been observed in natural settings with an average soil pH of 4.4 to 4.6 in the root zone (1). The suggested optimal soil pH range for eastern white pine growing on minimally and moderately weathered soils is 4.5 to 6.0 (3). The onset of chlorosis has been observed in white pines grown in soils with a pH above 6.5 (8).

Recent work has raised skepticism concerning the hypothesis that chlorosis in trees associated with alkaline soil is exclusively a function of an iron deficiency in tree foliage (7, 11). Iron-induced chlorosis may be unlikely in eastern white pine since it tends to accumulate relatively high concentrations of foliar iron (15). Manganese, a micronutrient which can have an antagonistic relationship with iron, has been identified as deficient in the foliage of chlorotic maples and oaks (11, 18). Maximum availability to plants of these two nutrients is at soil pH of approximately 4.5 to 6.0; and both iron and manganese become generally less available with higher pH values (3, 17). The exchangeable fraction of soil manganese (Mn^{2+}) is the dominant pool of plant available Mn (17). Consistently high correlations have been identified between Mn uptake, soil pH, and exchangeable Mn (17). This relationship offers an explanation for the concentrations of manganese in the needles of potted eastern white pine seedlings being significantly increased as a result of acid rain treatments (16).

Needle litter at the base of each tree can acidify the soil (16). This litter layer may be replaced by turf grass in a human-altered setting (22), thus eliminating any acidifying benefits provided by it.

Materials and Methods

To identify significant differences in foliar nutrient concentrations and soil pH between healthy and chlorotic eastern white pine specimens, soil and needle samples were collected during February of 1980, 1982, 1989, and 1992. The sampling sites were in lawns, parks, and plantations located in the northern Illinois counties of DeKalb, DuPage, and Ogle (sites subjected to wind-blown road de-icing salts were avoided). Soils at these sites range from very sandy Udipsamments through very silty Hapludalfs to clayey Hapludalfs and have undergone human-induced alterations prior to tree planting, primarily structure and horizon disruption, and erosion. All of the trees were dominant or co-dominant and exceeded 35 cm (14 inches) in diameter at breast height (135 cm or 54 inches above ground level). Needle samples of the most recent year's growth were utilized for standardization purposes since chemical composition varies with needle age (15). Samples of the most recent needles were taken each year. These were oven-dried at 70°C (158°F) for 48 hours, ground in a Wiley Mill fitted with a 20-mesh screen, digested in a nitric-perchloric acid mixture, and analyzed for elemental concentrations of P, K, Ca, Mg, S, Zn, B, Mn, Fe, Cu, and Al by inductively coupled plasma emission spectroscopy (ARL Model 35000) and of N by thermal conductance (Leco FP 428). Soil pH determinations on fresh samples were made with a glass electrode in a soil-water volume ratio of 1:1. In all four sets of samples the foliar nutrient concentrations and the corresponding soil pH measurements were assigned to one of two categories, healthy or chlorotic. Difference in mean concentration of each element in foliage and the pH of soil extracted from several, but variable, depths within the upper 24 inches (60 cm) were determined using t-tests.

Results and Discussion

Average foliar nutrient concentrations for 33 healthy and 19 chlorotic samples are illustrated in Figures 1A and 1B. Three of the twelve nutrients analyzed were present in significantly different concentrations between healthy and chlorotic foliage. Of the macro-nutrients, significantly more calcium (0.47%) was found in the foliage of chlorotic trees. This value is also higher than the survey average for healthy eastern white pines of 0.32% (6). The significantly higher soil pH (Table 1) associated with the chlorotic trees may provide an explanation for the excessive calcium. The calcium present in a given soil is more available to plants where the soil solution is alkaline (3); the soil samples from the chlorotic tree sites had an average pH of 7.7 compared to an average of 6.1 for the sites with healthy trees and they contained sufficient calcium carbonate within 1.5 feet (45 cm) of the soil surface to effervesce strongly when treated with dilute sulfuric acid. The principal form of available nitrogen in an alkaline soil environment is nitrate (NO_3^-), which is absorbed by roots with cations, calcium (Ca^{2+}) usually being the most abundant, especially in calcareous soils. Thus, excesses of foliar calcium might be expected. Excesses of foliar magnesium, a macronutrient that possesses a similar soil pH/availability relationship as calcium, have been documented in chlorotic white oaks, pin oaks, and red maples (11, 12, 13). The lack of excessive magnesium with a corresponding calcium excess in the chlorotic

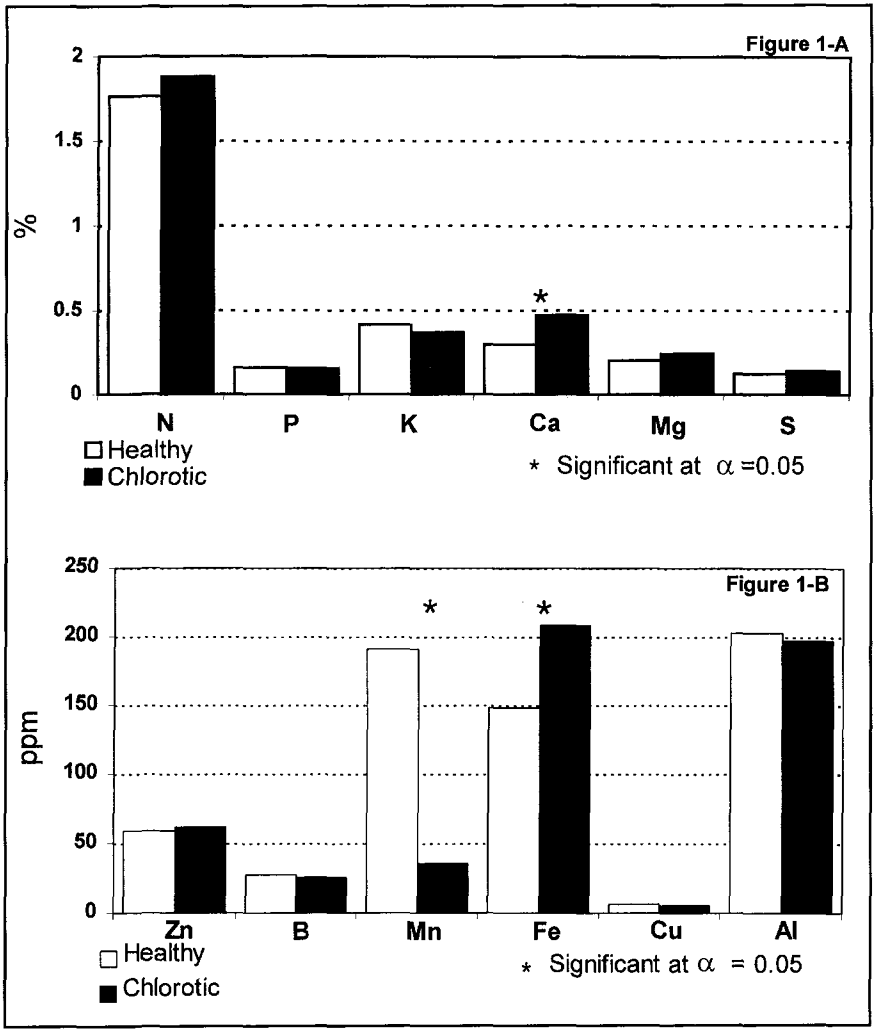

Figure 1. Foliar nutrient comparisons between chlorotic and healthy eastern white pine trees. A. Macronutrients; B. Micronutrients. Macronutrient concentrations are expressed as %, and micronutrients as ppm, based on a dry tissue weight basis.

foliage of white pine may be a result of high exchangeable Ca-Mg ratios or Mg fixation in the rooting zone (19) or Mg exclusion by aluminum at the root-soil interface (9). Eastern white pine's status as an aluminum-accumulating species points to the importance of the exclusion mechanism since the oaks and maples show no tendency to accumulate aluminum (14).

Iron was also in significantly greater concentrations (208 ppm) in the chlorotic foliage. This result does not support the hypothesis of an iron deficiency-induced chlorosis, especially since low concentrations of manganese (36 ppm) in the chlorotic foliage were significantly different from those in the healthy foliage. Healthy foliage of eastern white pine can have iron concentrations as low as 65 ppm (15) but 36 ppm Mn is a very low value for pines, including eastern white pines (6). The alkaline soil pH of the chlorotic white pines may have significantly reduced the plant available soil manganese (17), thus decreasing the potential for the roots to absorb a sufficient amount of manganese to produce healthy foliage. The plant availability of iron in the soil is also reduced by an alkaline soil condition (3), but two factors may play a role in favoring the uptake of iron by eastern white pine in this pH environment. The first is a reported iron efficiency of this pine species, i.e. its tendency to garner physiologically sufficient iron over a wide range of soil conditions including those considered to be inimical to readily available iron. Side-by-side comparisons have indicated foliar iron concentrations as much as three times higher than those of associated hardwoods (15). The second factor is an antagonistic relationship between iron and manganese (20), which could intensify a deficiency in manganese under conditions of efficient absorption of iron.

Summary and Conclusions

The tolerance of eastern white pine to a wide range of soil texture and moisture conditions has probably influenced the common belief that this species can be planted "almost anywhere." This paper documents an investigation conducted in northern Illinois that suggests a nutrient imbalance may exist in eastern white pine foliage as a result of alkaline soil conditions. The evidence also indicates that the presence of chlorotic foliage may not be due to an iron deficiency. On the contrary, a significant "surplus" of iron was documented in the chlorotic foliage sampled. The data presented in this paper suggest that the range of suitable sites for eastern white pine may not encompass anthropogenically calcareous soils, and that an understanding of the species' intolerance may improve landscaping and reduce the total number of planted eastern white pine that will need to be replaced.

Literature Cited

1. Brand, D. G. and P. S. Janas. 1988. *Growth and acclimation of planted white pine and white spruce seedlings in response to environmental conditions.* Can.J.For.Res. 18:320-329.
2. Elias, T. S. 1980. The Complete Trees of North America. Van Nostrand Reinhold Co, New York, NY. 948pp.
3. Foth, H. D. 1990. (8th ed.) Fundamentals of Soil Science. John Wiley & Sons, New York, NY. 360pp.
4. Gauch, H. G. 1972. Inorganic Plant Nutrition. Dowden, Hutchinson, and Ross, Inc., Stroudsburg, PA. 488pp.
5. Harlow, W. M., E. S. Harrar, J. W. Hardin, and F. M. White. 1991. (7th ed.) Textbook of Dendrology. Mc-Graw Hill, New York, NY. 501pp.
6. Jones, J. B., B. Wolf, and H. A. Mills. 1991. Plant Analysis Handbook. Micro-Macro Publishing, Inc., Athens, GA. 213pp.
7. Kielbaso, J. J. and K. Ottman. 1976. *Manganese deficiency—contributory to maple decline?* J. Arboric. 2:27-32.
8. Larson, M. M., P. Olah, and J. P. Vimmerstedt. 1993. *Forestation of mined lands: effects of soil types and seeded herbaceous species.* J. of Sustainable Forestry. 1:79-92.
9. Marschner, H. 1995. Mineral Nutrition of Higher Plants. Academic Press, London. 889pp.
10. Martin, S. 1988. *Pinus strobus.* American Nurseryman. 168:138.
11. Messenger, A. S. 1986. *Alkaline runoff, soil pH, and white oak manganese deficiency.* Tree Physiology. 2:317-325.
12. Messenger, A. S. 1984. *Seasonal variations of foliar nutrients in green and chlorotic red maples.* J. Environ. Hort. 2:117-119.
13. Messenger, A. S. 1983. *Soil pH and the foliar macronutrient/micronutrient balance of green and interveinally chlorotic pin oaks.* J. Environ. Hort. 1:99-104.

14. Messenger, A. S., J. R. Kline, and D. Wilderotter. 1978. *Aluminum biocycling as a factor in soil change.* Plant and Soil 49:703-709.
15. Messenger, A. S. 1975. *Climate, time, and organisms in relation to Podzol* development in Michigan sands; II. *relationships between chemical element concentrations in mature tree foliage and upper humic horizons.* Soil Science Society of America Proceedings. 39:698-702.
16. Reich, P. B., A. W. Schoettle, H. F. Stroo, and R. G. Amundson. 1988. *Effects of* ozone and acid rain on white pine (Pinus strobus) seedlings grown in five soils. III. *Nutrient relations.* Can. J. Bot. 66:1517-1531.
17. Sims, J. T. 1986. *Soil pH effects on the distribution and plant availability of manganese, copper, and zinc.* Soil Sci. Soc. Am. J. 50:367-373.
18. Smiley, E. T., J. J. Kielbaso and P. V. Nguyen. 1986. *Foliar nutrient diagnosis of urban sugar and red maples in the Great Lakes Region.* J. Environ. Hort. 3:104-107.
19. Tisdale, S. L., W. L. Nelson, J. D. Beaton, and J. L. Havlin. 1993. Soil Fertility and Fertilizers. Macmillan Publishing Co., New York, NY. 634pp.
20. Troeh, F. R. and L. M. Thompson. 1993. (5th ed.) Soils and Soil Fertility. Oxford University Press, New York, NY. 462pp.
21. Weaver, M. J. and R. J. Stipes. 1990. *The use of seasonal foliar color changes to diagnose stress in eastern white pine.* J. Arboric. 16:137-142.
22. Weaver, M. J. and R. J. Stipes. 1988. *White pine decline: a case study from Virginia landscapes.* J. Arboric. 14:109-120.
23. Wendel, G. W. and H. C. Smith. 1990. *Pinus strobus* L. Eastern White Pine. pp.476-488. **In:** Silvics of North America. Volume 1, Conifers. USDA Agriculture Handbook 654, Washington, DC.
24. Wilde, S. A. and G. K. Voigt. 1967. *The effect of different methods of tree planting on survival of pine plantations on clay soils.* J. Forestry. 65:99-101.

Associate Professor and Graduate Student
Department of Geography and
Department of Geology, respectively
Northern Illinois University
DeKalb, Illinois 60115

Résumé. Le pin blanc de l'Est (*Pinus strobus*) est un arbre ornemental très recherché. Son habitat naturel inclut une vaste catégorie de textures de sol et de degrés d'humidité, ce qui a laissé supposer que cette espèce pouvait être plantée dans n'importe laquelle des situations. Sa performance dans les aménagements paysagers créés par l'homme a plutôt révélé le contraire. Une maladie notamment, manifestée par une chlorose des aiguilles, a été appelée « dépérissement du pin blanc », et parce que cette maladie se produisait généralement dans des sols aux conditions alcalines, alors le postulat de la déficience en fer a été émis. Nos études, menées parmi une vaste gamme de textures de sol dans le Nord de l'Illinois, ont permis de confirmer l'effet négatif des sols alcalins mais nous ont aussi amené à rejeter l'hypothèse de la déficience en fer. Au contraire, nos données suggèrent un « bon fonctionnement » en fer chez cette espèce.

Zussammenfassung. Die östliche Weiße Kiefer (*Pinus Strubus*) ist ein beliebter Zierbaum. Seine natürliche Umgebung umfasst eine Spannbreite von Bodenarten und Wasserbedingungen, was zu der Ansicht führt, dieser Baum würde nahezu überall wachsen. Seine Entwicklung in vom Menschen beeinflußten Landschaften beweist das Gegenteil. Eine Krankheit, deren Symptome chlorotische Nadeln sind, wurde als Absterben der Weißen Kiefer bezeichnet, und weil alkalische Böden oft mit diesen Symptomen assozilert werden, wurde ein Eisenmangel postuliert. Unsere Studien, die über einen weiten Bereich von Bodenstrukturen in Nordillinois durchgeführt wurden, bestätigten die negative Wirkung von alkalischen Böden, aber sie führten uns zu einer Revision die Hypothese des Eisenmangels. Im Gegenteil, unsere Daten zeigten eine Eisenwirksamkeit bei dieser Baumart.