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Michigan State University PH.D. 1985

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MANGANESE DEFICIENCY AND NUTRITION OF URBAN *ACER SACCHARUM* AND *ACER RUBRUM*

By

Edgar Thomas Smiley

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
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Department of Forestry

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ABSTRACT

MANGANESE DEFICIENCY AND NUTRITION OF URBAN ACER SACCHARUM AND ACER RUBRUM

By

Edgar Thomas Smiley

Maples are the most commonly planted tree species in the United states. One of the most obvious problems with maples in the Great Lakes states is interveinal chlorosis.

Foliar analysis data from healthy urban trees are required to make diagnosis of deficiencies and fertilizer prescriptions. Two hundred and ninety-eight urban sugar and red maples in the Great Lakes States were sampled and the data presented as guides to diagnosis and fertilization. Healthy urban trees contained lower than expected concentrations of N and Mn, intermediate levels of Al, Cd, Cu, Fe, Mg and Zn; and high levels of B, Ca, Cr, K, Na and P.

Information on the foliar nutrient fluctuation is required to define sampling periods, assuring compatibility of results. The affect of manganese deficiency on fluctuation is not well defined. Patterns in manganese deficient urban sugar and red maples were generally the same as those found in forest trees. In two

cases the patterns were distinctly different. Manganese in deficient red maples lacked the expected increase of concentration during the season. Phosphorus lacked the expected end-of-season decrease. The best time to sample foliage in lower Michigan was August through mid-September. Sampling for manganese in deficient trees may be conducted in June or later.

Manganese deficiency was confirmed as the cause of interveinal chlorosis of urban sugar and red maples. Reduced growth in manganese deficient trees was detected only in severe cases. Three soil factors were found to be related to manganese deficiency of urban sugar and red maples, the most important was soil pH. Sugar maple growing in soils with pH values greater than 6.8 to 7.0 and red maples in soils with pH over 6.1 to 6.6 typically had visual symptoms of manganese deficiency. Organic matter levels between 2 and 5.5% favored manganese uptake in sugar maple, and levels between 3 and 5.5% favored manganese uptake in red maples. Soil redox potential was the third most important factor. Poorly drained sites, having low redox potentials, had more chlorosis.

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INTRODUCTION

This dissertation is a composite of three papers on manganese deficiency and mineral nutrition of urban sugar and red maples. The first paper is a general overview of maple nutrient levels. This information is needed to define deficiencies, excesses and fertilization goals. A revised set of terminology is presented which defines several points relating tree condition to foliar nutrient level. The conclusions presented are meant as a practical guide to urban forestry practitioners in determining nutrient status of maples.

Manganese deficiency is one of the most important problems of maples in the upper midwest. Little is known about the affect this deficiency on fluctuations of manganese or other nutrients in the tree. The second paper examines fluctuations in manganese deficient urban sugar and red maples. These data are necessary to determine optimum sampling periods to achieve comparable results in nutrient diagnosis, both with this research project and for field practitioners.

In order to quantitatively define the factor responsible for manganese deficiency and the impact which the deficiency has upon the tree, the final paper studies manganese deficiency in urban sugar and red maples.

Literature Review

Maples are the most widely occuring and most often planted trees in urban areas of the United States (Giedraitis and Kielbaso, 1982). One common problem of maples in the Great Lakes states is an interveinal chlorosis which is attributed to a lack of manganese (Kielbaso and Ottman, 1976).

Manganese

Manganese is a ubiquitous element widely distributed in rocks, soil, plants and animals. It is second only to iron in abundance in the earth's crust (Chapman, 1973, Hodgson, 1962). Manganese (Mn) exists in three naturally occuring valences, +2,+3,+4 (Ehrlich, 1981). The trivalent ion is unstable in solution and the quadrivalent ion appears only at extremely low pH. In reducing environments, compounds are mainly Mn^{+2} and in oxidizing environments the most stable compound is β-MnO2, pyrolusite (Dion and Mann, 1946, Mortvedt et al., 1972). In a basic media, oxidation of Mn^{+2} by oxygen can occur. This reaction is catalyzed by the presence of fine particles (Fujimoto and Sherman, 1948). At intermediate oxidation-reduction (redox) potentials many compounds may be formed with Mn in any of its three valences (Bohn, 1970) .

In soil, Mn in the divalent state is quite soluble and therefore subject to leaching. Much soil Mn is

organically complexed, thus not readily available to plants (Heintze and Mann, 1947, Page, 1962). A study of soils across the United States found that between 84 and 99% of the total solution Mn in the A horizon was complexed (Geering et al., 1969). Most of this was in the +2 oxidation state. Manganese is also fixed by clay minerals in the soil (Reddy and Perkins, 1976). A proposed cycle for Mn in soil was presented by Fujimoto and Sherman (1948). This cycle shows changes from +2 to +4 via redox reactions and related to hydration/dehydration.

Absorption of Mn by plant roots is by the typical two phase process characteristic of most plant nutrients (Maas et al., 1968). The initial phase of absorption is rapid, thought to be passive. This is followed at higher tissue concentrations by a slower, sustained, metabolically controlled phase, moving the element farther into the root.

Manganese fits well into Viets' (1962) theory of nutrient pools in the soil (Curtin et al., 1950, Salcedo and Ellis, 1979). Roots may easily absorb divalent Mn in aqueous solution. With more energy, or a weak extractant, Mn can be removed from cation exchange sites. However, it is most difficult to remove Mn which is: adsorbed, chelated or complexed; within secondary clay minerals and insoluble oxides; or Mn in primary minerals. With the

majority of the Mn in the A horizon complexed, the amount available to most plants is minimal.

Manganese in leaves nonspecifically activates several enzyme systems. In the chloroplasts it is essential for the operation of photosystem II (Cheniae, 1970). Generally, symptoms of deficiency include interveinal chlorosis of the youngest leaves due to a disruption of chloroplasts (Possingham et al., 1964). If mild, the symptom will disappear as the leaf matures (Chapman, 1973). In more severe cases, chlorosis will persist and may be followed by interveinal necrosis. Growth losses are noticed with most crops.

In the United States, manganese deficiencies have been reported in at least 25 states (Berger, 1962). This includes all of the Great Lakes states: Michigan, Wisconsin, Minnesota, Illinois, Indiana, Ohio, Pennsylvania, and New York. Some of the more sensitive crops are: apple, cherry, citrus, oats, raspberry, and sugar beet (Chapman, 1973).

Manganese excess is also a common problem. This is due to high levels of soil Mn or low pH (Watson, 1960). Mild symptoms are not well described except for a reduction in growth and uneven distribution of chlorophyll (Chapman, 1973). More severe symptoms consist mainly of interveinal chlorosis/necrosis, necrotic spotting, reduced growth and a distortion in growth.

The level of Mn in foliage associated with deficiency

symptoms varies greatly with the crop. Chapman (1973) summarized data from 34 crops. The point at which symptoms appear ranges from 2 ppm to over 100 ppm. Due to this variability, standard values must be determined for individual crops.

Manganese Deficiency of Trees

Manganese deficiency of trees has an extensive history. Early deficiency work was on high value citrus trees (Chapman, 1973), walnut trees (Braucher and Southwick, 1941, Vanselaw, 1945), and maple trees (Kreag, 1939 and 1940). Most early research concentrated on defining and finding short term solutions to the problem. Applications of manganese sulfate as sprays, soil treatments or trunk implants gave temporary remission of symptoms and were widely used.

A resurgence in interest in manganese deficiency of maples occured in the 1970's. Many similar steps were taken to define the problem and to advise short term solutions (Kielbaso, 1979, Kielbaso and Ottman, 1976, Smith and Mitchell, 1977). Injections of manganese sulfate again proved to be the preferred method of treatment. However, the method of packing holes in the tree's bark and wood with $MnSO_4$ had been changed. $MnSO_4$, sometimes mixed with other nutrients, was put into trees in an encapsulated form (Medicaps). Sprays and soil pH adjustments were recommended if financially acceptable.

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CHAPTER 1

FOLIAR NUTRIENT DIAGNOSIS OF URBAN SUGAR AND RED MAPLES IN THE GREAT LAKES REGION *

E. THOMAS SMILEY, JAMES B. HART, Jr. AND J. JAMES KIELBASO

Introduction

With the growth of the tree nutrition sector of the arboriculture industry, use of foliar analysis for diagnosis of nutrient deficiencies will be of increasing importance. However, information on healthy trees required to make diagnoses and prescriptions is very difficult to locate, or completely unavailable.

There have been numerous studies of foliar nutrient levels of forest and nursery grown maples (Boyce and Sydnor, 1983, Chapman, 1973, Ellis, 1975, Gerloff et al., 1964, Guha and Mitchell, 1966, Hanna and Grant, 1962, Mitchell and Fretz, 1977, Smith, 1978). These studies provide only part of the information required for diagnosis since environmental conditions in the forest or nursery can be quite different from those conditions in which street trees grow.

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A review of the literature finds conflicting and inadequate terminology associated with nutrient analysis (Smith, 1962). The confusion is compounded by the problems associated with defining quality standards of ornamental plants (Dirr, 1975).

The relationship between foliar nutrient level and tree condition may be divided into five zones separated by four concentration points (Figure 1). Trees with nutrient levels in the severe deficiency zone have visually obvious symptoms of deficiency. The upper boundry of this zone is defined by the symptomatic deficiency point (SDP). Between the SDP and the optimum or critical concentration, is the zone of mild deficiency or hidden hunger. In this zone there is an insufficient level of the nutrient, but the tree does not have obvious deficiency symptoms. Trees in either of these two zones should exhibit growth responses to additions of the nutrient. Trees in the luxury comsumption zone will not respond to additions of the nutrient since they already contain adequate amounts. Above the point of excess concentration is the zone of mild toxicity. This zone is analogous to the mild deficiency zone in that trees appear healthy but are not. The point at which toxicity symptoms become apparent is the symptomatic toxicity point (STP). With nutrient concentrations above this, the tree will be in the severe toxicity zone. Visually healthy trees have

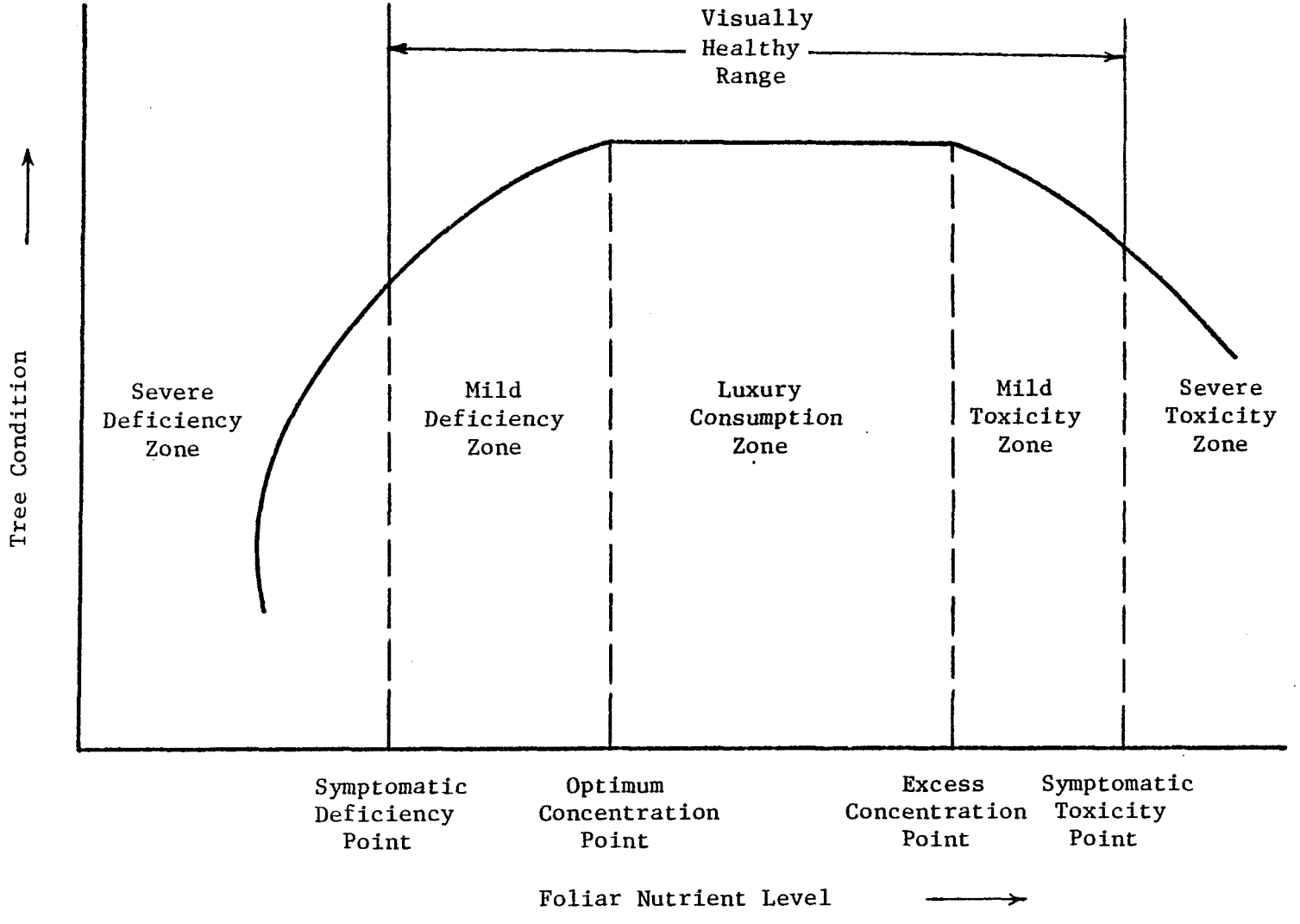

Figure 1. Idealized relationship between foliar nutrient level and tree condition, adapted from Smith (1962).

nutrient concentrations in the zones of mild deficiency, luxury comsumption or mild toxicity.

The curve presented (Figure 1) is an idealized relation between one essential nutrient and tree condition. Plants have between 16 and 19 essential nutrients (Mengel and Kirby, 1982), all of which have response curves. The response to added nutrients is affected by other nutrients, system pH, and environmental conditions. This makes the identification of cardinal points difficult.

The purposes of this study were to review the literature on nutrient levels and to determine diagnostic levels of nutrients in healthy urban sugar maples (Acer saccharum Marsh.) and red maples (Acer rubrum L.).

Materials and Methods

Foliage from 131 red maples and 167 sugar maples were collected during July, August and early-September of 1982 and 1983. Samples were collected from street and park trees in the cities of Stevens Point, Wisconsin; Highland Park, Lake Forest, and Rockford, Illinois; Ann Arbor, Birmingham, East Lansing, Flint, Grand Rapids, Lansing, Michigan State University campus East Lansing, and Saginaw, Michigan. Red maple samples were also collected from the street tree collection at the Ohio Agriculture Research and Development Center, Wooster. All trees had a diameter of 5 to 31 cm (2 to 12 in.) at 1.5 m (4.5 ft.) above ground level (DBH). Five lateral branches, which included all of the current year's growth, were removed from the middle one third of the crown facing south. Length of current year's branch growth was measured. Chlorosis was rated by visually dividing the tree into thirds horizontally, randomly selecting five terminals in each third, and rating the worst leaf on each terminal. Healthy, green leaves were given a rating of zero, terminals with leaves having slight, indistinct chlorosis were rated at one. More chlorotic leaves were given proportionally higher ratings up to five for necrotic. All fifteen values were averaged to provide a rating for the tree. Trees with small, sparse, uniformly chlorotic foliage were not sampled. The cultivar of red maple was

identified when possible, although data were pooled for statistical analyses. The majority of the red maples sampled were 'Red Sunset' and 'October Glory'.

Sugar and red maples in the visually healthy range were defined as those with a chlorosis rating of less than 0.5 and an average current season's growth of 25 cm (9.8 inches) or more.

Leaves were removed from the lateral branch sample, petioles discarded, leaves counted, then rinsed in distilled water and oven-dried at 70 degrees C (158 degrees F). They were subsequently weighed and ground in a Wiley mill with a 20 mesh screen. Total Kjeldahl nitrogen and total phosphorus were colorimetrically determined on a Technicon Auto-Analyzer II following digestion with sulfuric acid (Bremner, 1965, Technicon, 1977). Determination of total metals (Al, B, Ca, Cd, Cu, Fe, K, Mg, Mn, Ni, Na, Zn) followed digestion with nitric and perchloric acids using a Spectrametrics SMI III DC - argon plasma emission spectrometer (Blanchar et al., 1965, Ellis et al., 1976). Quality was monitored by analyzing duplicate samples at a rate of 15% and each batch of 35 samples was referenced to a National Bureau of Standards' specimen. Data were on a dry weight basis.

Results and Discussion

The mean sugar maple nitrogen level (Table 1) was within the range of values previously reported (Table 2). The lowest N value reported for a healthy tree (.62%) was found in an urban tree. The red maple mean was less than the majority of reported values although all values were within the range.

The mean phosphorus (P) levels were close to the median reported value. The highest value for sugar maple (.33%) was from this study. Slightly higher concentrations in urban trees may relate to higher soil temperatures, lawn fertilizers or other environmental factors. The highest reported concentration of P (.42%) was the average of Ohio nursery 'Schlesinger' red maples (Smith, 1962).

The mean potassium (K) levels found in urban sugar maple (2.5%) was over twice the highest documented level in nonurban sugar maples (1.09%) (Mader and Thompson, 1969). The red maple mean was high (1.8%), but not as high as one greenhouse experiment (3.7%) (Boyce and Sydnor, 1983).

Calcium (Ca) in sugar maple averaged 2% in this study. This was higher than most nonurban trees. The cause of these high foliar concentrations is probably the high levels of Ca, especially $CaCO_3$, located within the rooting zone. High levels of $CaCO_3$ are typical in the subsoils of this region. Removal or burial of surface horizons in urban soils due to housing and street construction results

Table 1. Average foliar nutrient levels of healthy sugar and red maples in selected cities of the Great Lakes region sampled during mid and late summer 1982 and 1983.

SUGAR MAPLES

NUTRIENT	CONCENTRATION MEAN	RANGE	NO. OF SAMPLE	STD. DEV.
	%			
NITROGEN	2.0	.62-2.7	28	.40
PHOSPHORUS	.19	.11-.33	28	.06
POTASSIUM	2.5	1.1-3.3	13	.36
CALCIUM	2.0	1.4-2.5	13	.29
MAGNESIUM	.39	.21-.86	14	.04
	ppm			
ALUMINUM	70	22-138	16	32
BORON	120	14-336	16	96
CADMIUM	.81	.23-2.0	13	.58
COPPER	7.0	.9-14	16	3.2
IRON	146	75-311	27	54
MANGANESE	175	23-396	27	117
NICKEL	.84	.04-1.8	12	.55
SODIUM	259	82-452	13	101
ZINC	21	7.4-132	27	23

Table 1 continued

RED MAPLES

NUTRIENT	CONCENTRATION MEAN	RANGE	NO. OF SAMPLE	STD DEV
	%			
NITROGEN	1.7	1.3-2.6	25	.36
PHOSPHORUS	.23	.12-.38	25	.06
POTASSIUM	1.8	.97-2.4	11	.10
CALCIUM	1.4	.90-1.5	11	.05
MAGNESIUM	.42	.25-.89	21	.03
	ppm			
ALUMINUM	30	6-56	16	13
BORON	97	3.8-522	22	107
CADMIUM	.83	.05-5.5	19	1.2
COPPER	11	5.7-32	20	6.6
IRON	109	32-478	25	89
MANGANESE	138	32-385	25	95
NICKEL	1.1	.25-1.9	16	.50
SODIUM	130	69-311	16	54
ZINC	28	14-55	23	12

Table 2. Nutrient levels in leaves of healthy tree by other authors.

NUTRIENT	SPECIES		SITE	SOURCE
	SUGAR MAPLE	RED MAPLE		
	%			
NITROGEN	.73	.90	Forest	9
	1.12-3.09	-	Forest,SB*	15
	1.66-1.75	-	Forest	7
	1.9	-	Urban	14
	2.15	2.60	Nursery	18
	2.77-2.85	2.55-2.68	Forest	4
PHOSPHORUS	.06-.17	-	Forest, SB	15
	.10-.12	-	Forest	7
	.12	.07	Forest	9
	-	.22	Greenhouse	2
	.23	.42	Nursery	18
	.24	-	Urban	14
	.24	.22-.33	Expt.Sta.	11
POTASSIUM	.39	.35	Forest	9
	.52-.58	-	Forest	7
	.60	.88-1.6	Expt.Sta.	11
	.66-1.09	-	Forest, SB	15
	.70	-	Urban	14
	-	2.5-3.7	Greenhouse	2
	.90	1.23	Nursery	18
CALCIUM	.59-2.12	-	Forest, SB	15
	1.01	.94	Forest	9
	-	.99-1.1	Greenhouse	2
	1.45-1.72	-	Forest	7
	1.81	1.39	Nursery	18
	1.92	-	Urban	14
	2.0	1.1-1.6	Expt.Sta.	11
MAGNESIUM	.09-.20	-	Forest, SB	15
	.14	.12-.17	Expt.Sta.	11
	.18	-	Urban	14
	.26-.29	-	Forest	7
	-	.39-.48	Greenhouse	2
	.30	.57	Nursery	18
	.45	.33	Forest	9
SULFUR	.05	.08	Forest	9

Table 2 continued

	ppm			
ALUMINUM	57	-	Urban	14
	92	53-64	Expt.Sta.	11
	489	600	Nursery	18
BARIUM	.05	.05	Forest	4
BORON	38	-	Urban	14
	52	31	Nursery	18
	62	57	Forest	9
	174	87-141	Expt.Sta.	11
CADMIUM	.21	1.5-2.8	Expt.Sta.	11
	-	2.2-12.8	Greenhouse	17
CHLORINE	299	2487	Forest	9
CHROMIUM	.38	.36-.38	Expt.Sta.	11
COPPER	6	-	Urban	14
	9.8	3.6	Forest	9
	10	18	Nursery	18
	10.6	8.5-11	Expt.Sta.	11
IRON	37	-	Urban	14
	-	45-56	Greenhouse	2
	156	102-140	Expt.Sta.	11
	157	181	Forest	9
	226	683	Nursery	18
LEAD	17	9.2-17	Expt.Sta.	11
MANGANESE	30	-	Urban	14
	30	20	Nursery	18
	-	35-94	Greenhouse	2
	89-212	-	Forest	7
	533	478-758	Expt.Sta.	11
	805	444	Forest	9
MOLYBDENUM	.05	.05	Forest	9
	.06	.02-.15	Expt.Sta.	11
SODIUM	78	-	Urban	14
	120	100-490	Expt.Sta.	11
STRONTIUM	58	21	Forest	9
	63	21-31	Expt.Sta.	11

Table 2 continued

ZINC	13	-	Urban	14
	24	75-96	Expt.Sta.	11
	26	45	Nursery	18
	42.3	22.5	Forest	9
	-	49.3-147.5	Greenhouse	17

* Sugarbush trees included in study.
\# Potted trees grown at pH 5.5 in sand culture.

in more calcareous subsoil contacting roots, thus more Ca uptake (Craul, 1982).

Boron (B) levels in urban trees were higher than typically reported. Boron concentrations were very high in trees with marginal scorch. Severe toxicity is expected above 400 ppm in sugar maple and above 500 ppm in red maple. High levels have been related to boron soil contamination (Mader and Thompson, 1969).

Cadmium (Cd) levels greater than 1 ppm are generally considered undesirable (Mengel and Kirby, 1982). Levels as great as 5.5 ppm in this survey of healthy trees may be due to Cd deposition on streetside soils from vehicle tires and lubricating oil. Red maples with concentrations as high as 12.8 ppm have not exhibited severe toxicity symptoms (Mitchell and Fretz, 1977).

Manganese (Mn) levels are known to be highly variable in foliage (Chapman, 1973). Typically, the urban tree levels were less than those of the forest trees. Healthy

trees were found with Mn concentrations as low as 23 and 32 ppm for sugar and red maples, respectively. However, regression analyses predict that sugar maples with less than 106 ppm, or red maples with less than 69 ppm will typically be deficient (Chapter 3). Low Mn levels are related mainly to high soil pH and high organic matter levels.

Sodium levels, notably in sugar maples, averaged twice the level of nonurban trees. This may be attributed to the large amounts of deicing salts used in this region. Levels of aluminum, copper, iron, magnesium, and zinc were not greatly different from previously reported values.

To determine the optimum concentration of each nutrient for maples would require extensive fertilizer trials in numerous locations. Once optimums are determined, it could be stated that trees with nutrient levels less than the optimum will respond to fertilizaton and those with greater levels will not. Thus, the optimum may be used as a target level in fertilization programs. Owing to the lack of this information, we have compiled a table of preliminary foliar goals for fertilization (Table 3). These levels were derived by selecting the mean of healthy urban trees (Table 1) as a minimum and the mean plus one standard deviation as the maximum. Exceptions were made if half or more of the values in Table 2 were greater than the mean plus the standard deviation from

Table 3. Preliminary foliar goals for fertilization of urban sugar and red maples sampled in late summer in the Great Lakes region.

NUTRIENT	SPECIES	
	SUGAR MAPLE	RED MAPLE
	%	
Nitrogen	2.0 - 2.4	1.7 - 2.1
Phosphorus	.19 - .25	.23 - .37
Magnesium	.39 - .43	.42 - .45
	ppm	
Copper	7.0 - 10	11 - 18
Iron	146 - 200	109 - 198
Manganese	175 - 292	138 - 233
Zinc	21 - 44	28 - 96

Table 1. In those cases, the higher values from Table 2 were averaged and entered as the maximum.

The preliminary guide to the diagnosis of severe toxicity and severe deficiency (Table 4) was a compilation of the extreme values from Tables 1 and 2. The major assumptions made in the formulation of Table 4 were that data of Tables 1 and 2 included a range of nutrient concentrations approaching the points of symptomatic deficiency and symptomatic toxicity, and that the methods of sample selection and analysis were compatible. Table 4 is meant as an aid to the diagnosis of severe nutrient problems. If a tree has symptoms and a nutrient concentration near the SDP, a deficiency problem should be suspected. If a tree has symptoms and a level near the

Table 4. Preliminary guide for foliar nutrient diagnosis of sugar and red maples *.

NUTRIENT	SUGAR MAPLE SDP	STP		RED MAPLE SDP	STP
			%		
NITROGEN	.62	3.1		.90	2.7
PHOSPHORUS	.06	.33		.07	.38
POTASSIUM	.39	3.3		.35	3.7
CALCIUM	.59	2.5		.90	1.6
MAGNESIUM	.09	.86		.12	.89
			ppm		
BORON	14	336		3.8	522
IRON	37	311		32	478
MANGANESE	23	805		32	758
ZINC	7.4	132		14	96

* If a tree has symptoms and nutrient concentration near the symptomatic deficiency point (SDP) deficiency problem should be suspected. If a tree has symptoms and concentration near the the symptomatic toxicity point (STP), a toxicity problem should be suspected. Data based on samples from thirteen locations and previously published literature. Concentrations may vary depending on site, other nutrients, and environmental factors.

STP, a toxicity problem should be suspected. As was mentioned with the manganese data, extreme values for healthy trees were used to define the SDP, thus, trees may show deficiency symptoms at higher concentrations.

Additional research is required to more accurately define the SDP, STP and optimum nutrient concentraitons for maples and other urban trees.

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CHAPTER 2

SEASONAL VARIATION OF FOLIAR NUTRIENTS IN MANGANESE DEFICIENT URBAN SUGAR AND RED MAPLES

Introduction

In the diagnosis of nutrient problems, knowledge of seasonal fluctuations is important. Typically, only samples collected during a specific time period from a designated position on a tree may accurately be compared to a nutrient standard (Tamm, 1951).

Seasonal patterns of nutrient fluctuation have been categorized into three groups (Ellis, 1975, Guha and Mitchell, 1966). They are:

A) An initial decrease in nutrient level with leaf expansion followed by a steady increase over the growing season;
B) A continual increase during the growing season, occasionally with a decrease at the end of the season;
C) An initial decrease as leaves expand, followed by a period of relative constancy, or slight decrease, often with a substantial decrease at the end of the season.

Nitrogen (N), phosphorus (P), and potassium (K) tend to have a type C pattern. Iron (Fe) usually exhibits a type A or B pattern. Calcium (Ca) and manganese (Mn) typically

exhibit a type B pattern (McHargue and Roy, 1932, Guha and Mitchell, 1966, Lea et al., 1979A and 1979B).

Tamm (1951), working with birch in Sweden, found that N and P levels were fairly constant from July to September. Trees sampled during this period, irrespective of site or developmental stage, would be directly comparable. Potassium and Ca levels did change during the July to September period. Therefore, samples to be used for K and Ca comparisons should be collected within a shorter period of time near the end of the season. Periods of constant nutrient levels are most common when physiological changes are at a minimum (Lea et al., 1979A, White, 1954). The usual time that minimum nutrient fluctuation occurs is August to mid-September in temperate climates (Ellis, 1975, Lea et al., 1979A and 1979B).

Location in the crown where samples are collected also affects results (Guha and Mitchell, 1966, White 1954, Ellis, 1975). Guha and Mitchell (1966) found that concentrations of Fe varied from the top to bottom of a tree. Ellis (1975) reported Mn and Ca had lower concentrations at the top than at the base. In hardwood tree species, the outer-crown foliage, (sun-leaves) differ from shaded foliage (shade-leaves) in anatomy and morphology. It has been suggested that only sun-leaves be sampled for diagnostic purposes (Leaf, 1973). Sampling during the period of minimum fluctuation and from the proper location on the tree should result in samples

reflecting the overall nutrient status of the tree.

Manganese deficient maples have been reported in numerous cities in the Great Lakes region (Kielbaso and Ottman, 1976, Smith and Mitchell, 1977). The seasonal changes of manganese in deficient maples are not known, nor are the effects which the deficiency has on changes of other nutrients.

The goal of this study was to determine seasonal nutrient fluctuations in manganese deficient sugar and red maples, and to define appropriate sampling periods.

Materials and Methods

In 1982, 12 sugar maples (Acer saccharum Marsh.) and 22 red maples (Acer rubrum L.) were selected on the Michigan State University campus for foliar sampling. Most trees exhibited manganese deficiency symptoms. Chlorosis was rated by visually dividing the tree into thirds horizontally, randomly selecting five terminals in each third, and rating the worst leaf on each terminal. 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 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, with no more than occasional necrotic spots, a rating of four was made. Necrotic (dead) or partially necrotic leaves were rated five. The mode of the fifteen chlorosis ratings was used to group trees. A mode of zero was defined as healthy, one was slight chlorosis, two was slight to moderate, three was moderate, and four was moderate to severe.

Three lateral branches were pruned from the south-facing middle 1/3 of the tree on 5/12, 6/2, 6/23, 7/14, 8/5, 8/30, 9/28/1982. The first sample date was two weeks

after leaf bud break of sugar maples. The last sample was collected as close to the time of leaf fall as possible. The 9/28/82 sample was from the two sugar maples which retained foliage. In 1983, nine of the same sugar maples were similarly sampled on 7/29, 8/26, 9/9, 9/15, and 9/30. Seven of the same red maples were sampled on 9/15.

Leaves were removed from the current year's growth, petioles discarded, then rinsed in distilled water, oven-dried at 70 degrees C, ground in a Wiley mill with a 20 mesh screen, re-dried and weighed prior to analysis. Analyses were conducted on four plant nutrients (N,P,Mn,Fe) in the 1982 study and six nutrients (N,P,Mn,Fe,K,Ca) in the 1983 study. Total Kjeldahl nitrogen and total phosphorus were colorimetrically determined on a Technicon Auto-Analyzer II following digestion with sulfuric acid (Black et al., 1965, Technicon, 1977). Determination of total metals (Ca, Fe, K, Mn) followed digestion with nitric and perchloric acids using a Spectrametrics SMI III DC - argon plasma emission spectrometer (Blanchar, et al., 1965, Ellis et al., 1976). Duplicate samples were run at a rate of 15% and all analyses were referenced to a National Bureau of Standards' specimen run with every 39 samples. Data are presented on a dry weight basis.

The variety of red maple was identified when possible, although data were pooled for statistical analyses. The

majority of the red maples sampled were 'Red Sunset' and 'October Glory'.

Statistical analyses were by means of paired T-Test using temporal differences to separate pairs. Tables showing the differences were prepared, zones containing areas of nonsignificant differences were identified. These areas were compared to the graphs of foliar nutrient level. Time periods with fewest significant differences judged to be periods of minimum fluctuation.

Results

The average chlorosis ratings for sugar maple and red maple were 0.8 and 3.0, respectively.

Nitrogen levels in sugar maple varied from 5.68% to .67%. Concentrations were high in the early season and decreased through the summer (Figure 2). The 5-12-82 sample was significantly greater than all other samples. The late September 1983 N levels was significantly lower than most other summer readings.

Nitrogen levels in the red maples varied from 6.52% to .88%. Concentrations were highest at the beginning of the season and decreased gradually to September (Figure 3). There were few significant differences among the mean N concentrations in late June through early August.

In sugar maple, phosphorus concentrations were high early in the season and then decreased in early June to remain relatively constant in July, August and September with the exception of the 9/30/83 mean (.33%) which was significantly higher than earlier levels (Figure 4). In the period from June through mid-August there were no highly significant differences among P means.

Concentrations of phosphorus in red maples varied from .75% to .12%. Levels began high, decreased in June, and remained fairly constant to September 28 (Figure 5). There were no statistically different means after June 2. The 1983 sample was not significantly different from 1982 means.

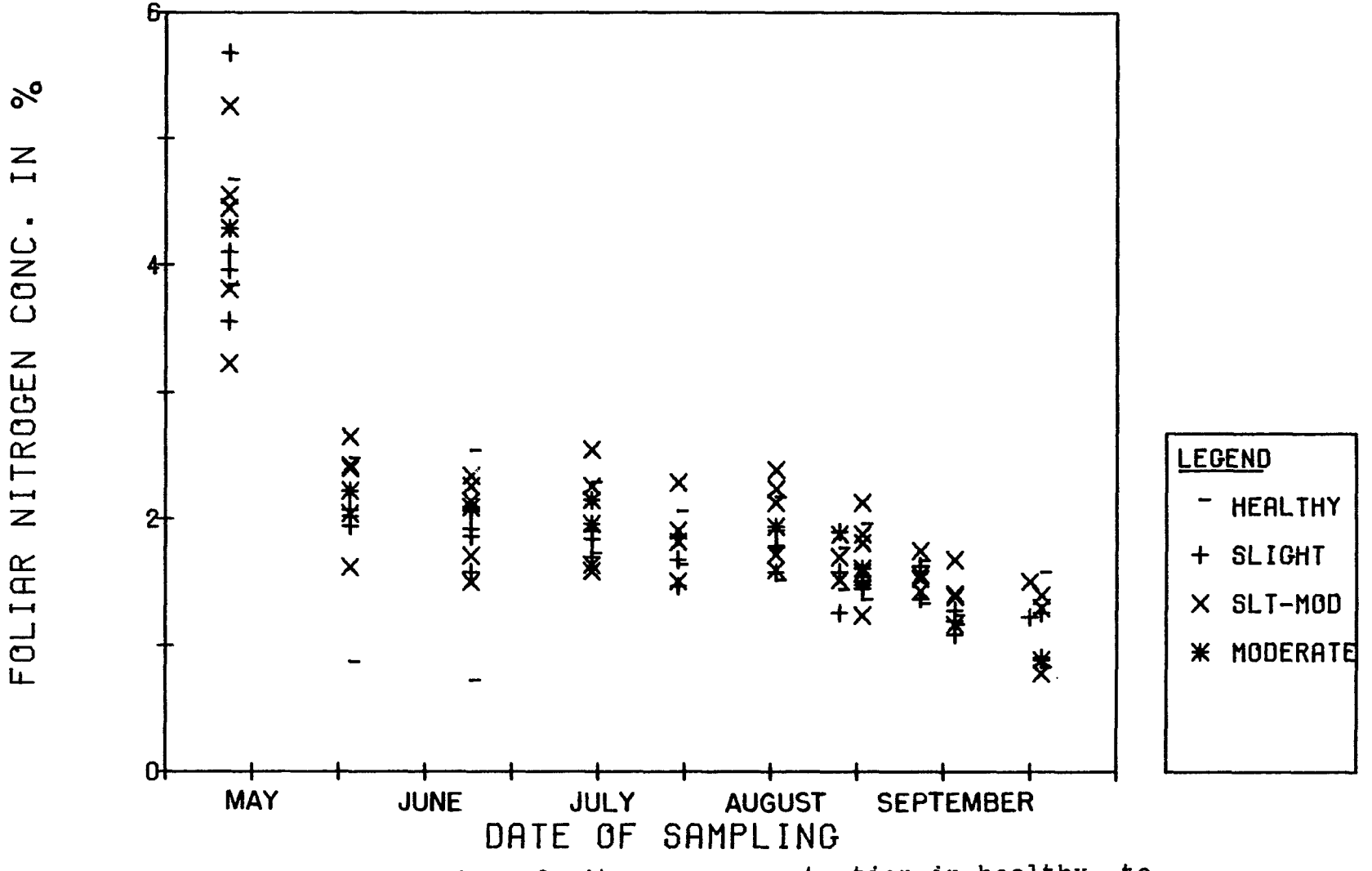

Figure 2. Fluctuation of nitrogen concentration in healthy to moderately chlorotic sugar maples during 1982 and 1983.

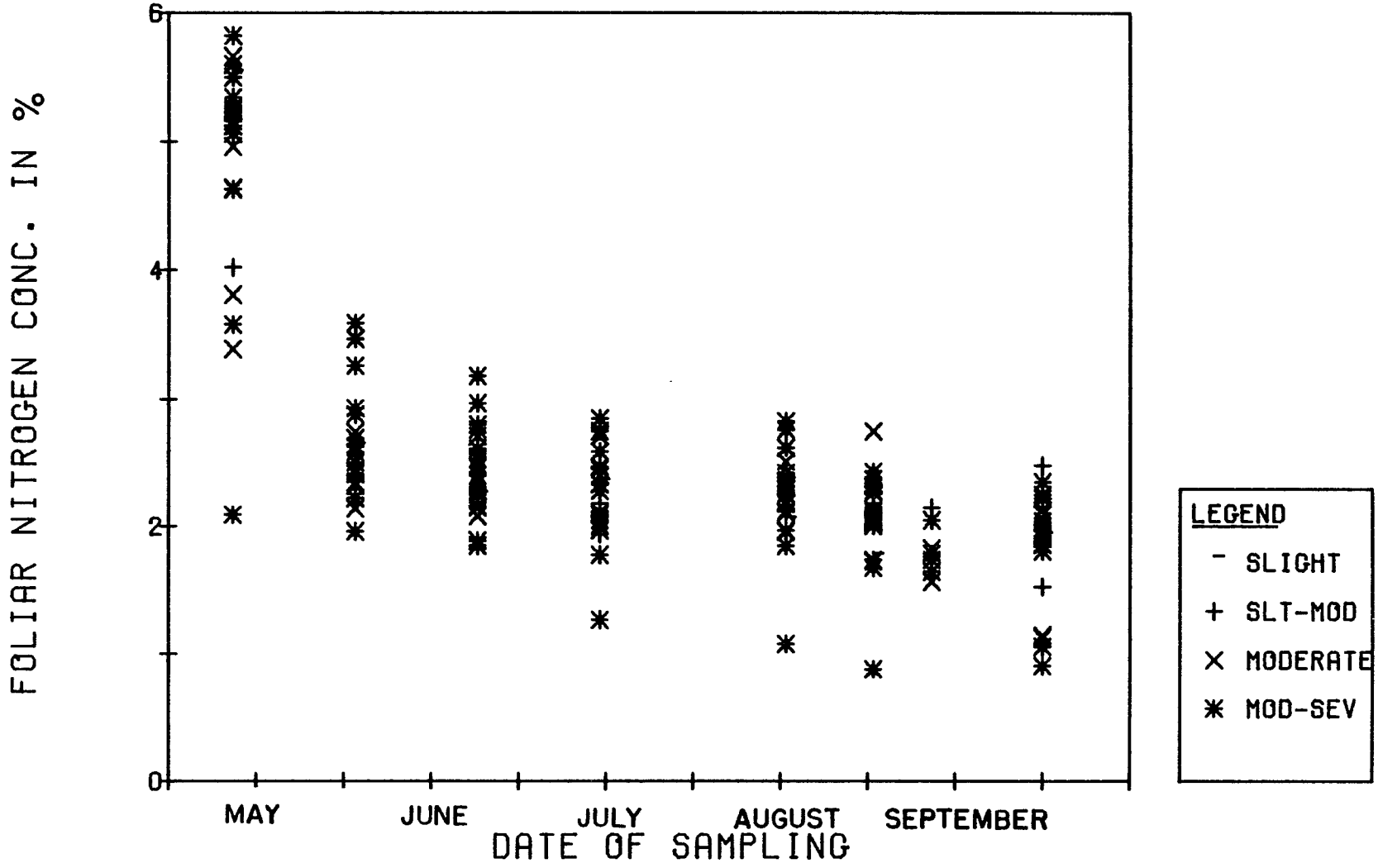

Figure 3. Fluctuation of nitrogen concentration in slight to moderately - severe chlorotic red maples during 1982 and 1983.

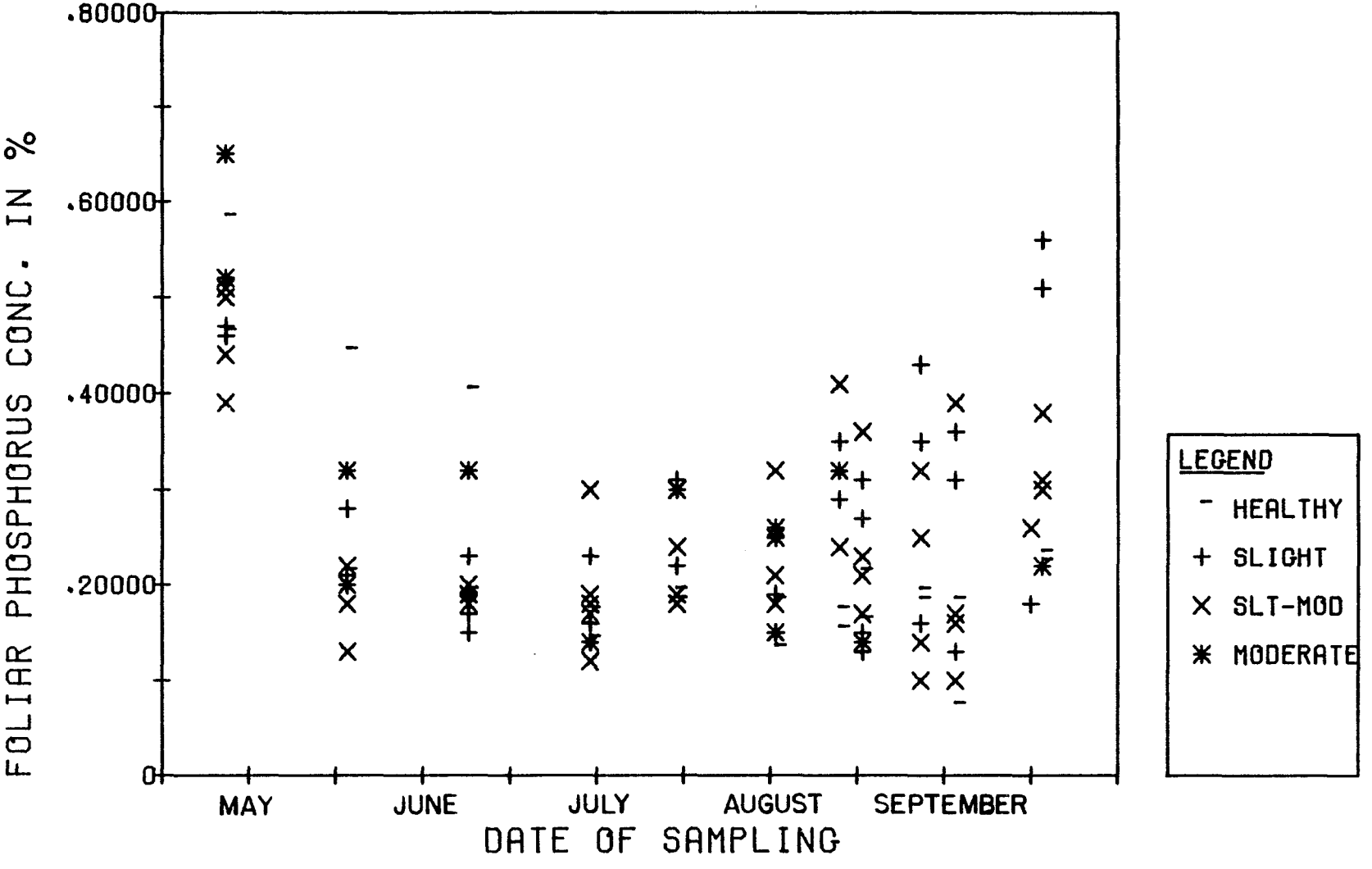

Figure 4. Fluctuation of phosphorus concentration in healthy to moderately chlorotic sugar maples during 1982 and 1983.

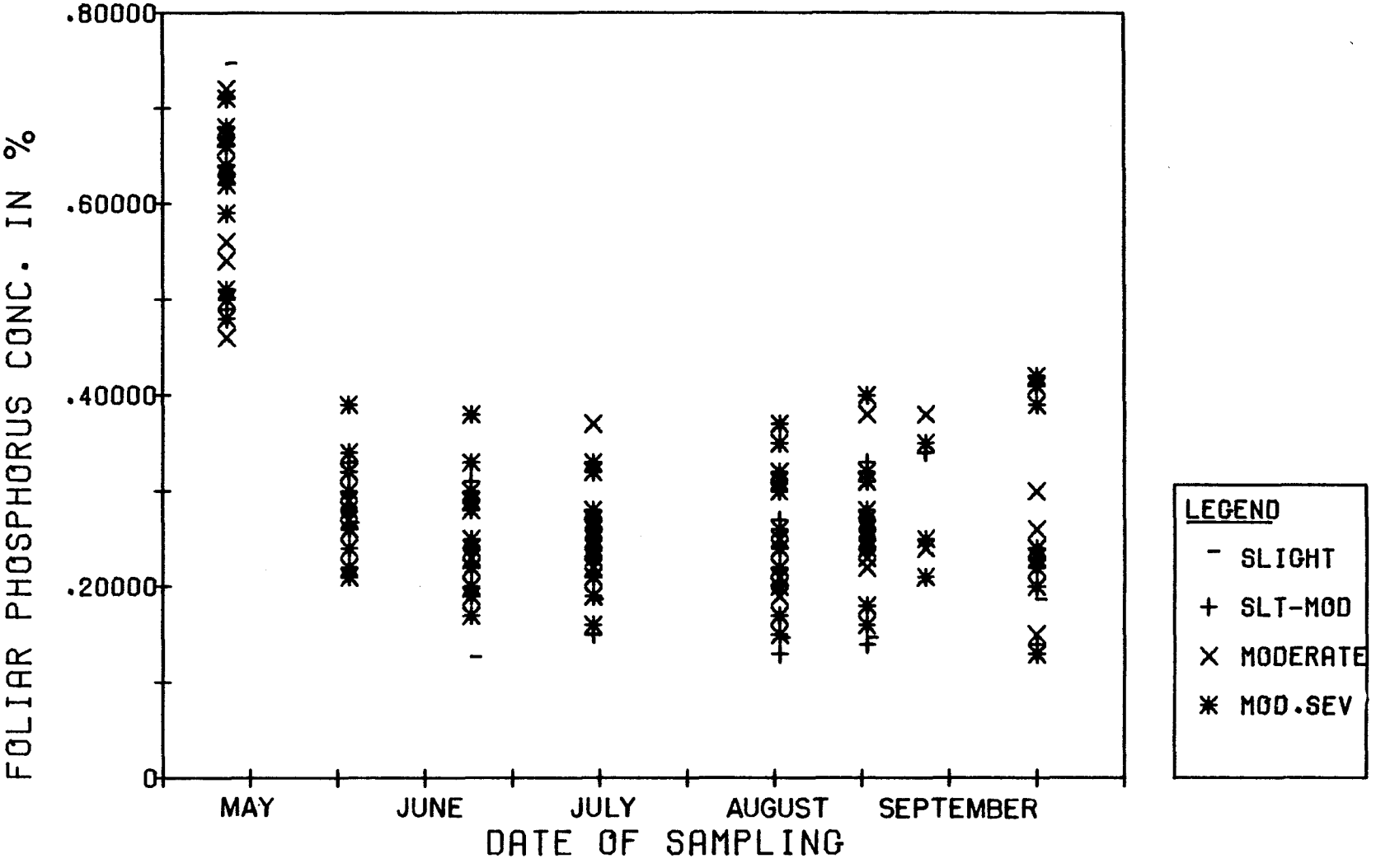

Figure 5. Fluctuation of phosphorus concentration in slight to moderately - severe chlorotic red maples during 1982 and 1983.

Sugar maple data for one year show a relatively constant level of potassium in the later part of the summer (Figure 6). There were no highly significant differences between the means.

Data from 1983 on calcium in sugar maple show a relatively constant level from July through September (Figure 7). None of the means were significantly different.

Iron in sugar maple showed a large degree of variability with concentrations ranging from 60 to 393 ppm (Figure 8). The trend was a moderate level at the start of the season, falling off significantly in June, and then increasing significantly in July and August to a level greater than the initial concentration. Iron means were relatively constant in mid-August through mid-September.

Red maple exhibited less variability of iron concentration than did sugar maples. Values ranged from 32 to above 300 ppm, with the majority of values less than 220 ppm (Figure 9). Values were high in May, decreased in June and remained low until August, when there was a slight increase. The August and September means were similar.

Manganese variability in sugar maple was second only to iron. Concentrations varied from over 300 to less

than 30 ppm. Manganese means increased from June to August. August to mid-September means were relatively constant even though individual values varied greatly (Figure 10). Differences between the two years were not significant.

Manganese levels in red maples were not as variable as in sugar maples. Values ranged from 3 to over 60 ppm with most values less than 30 ppm (Figure 11). Concentrations were significantly higher at the start of the season, decreased in June and remained fairly constant through September.

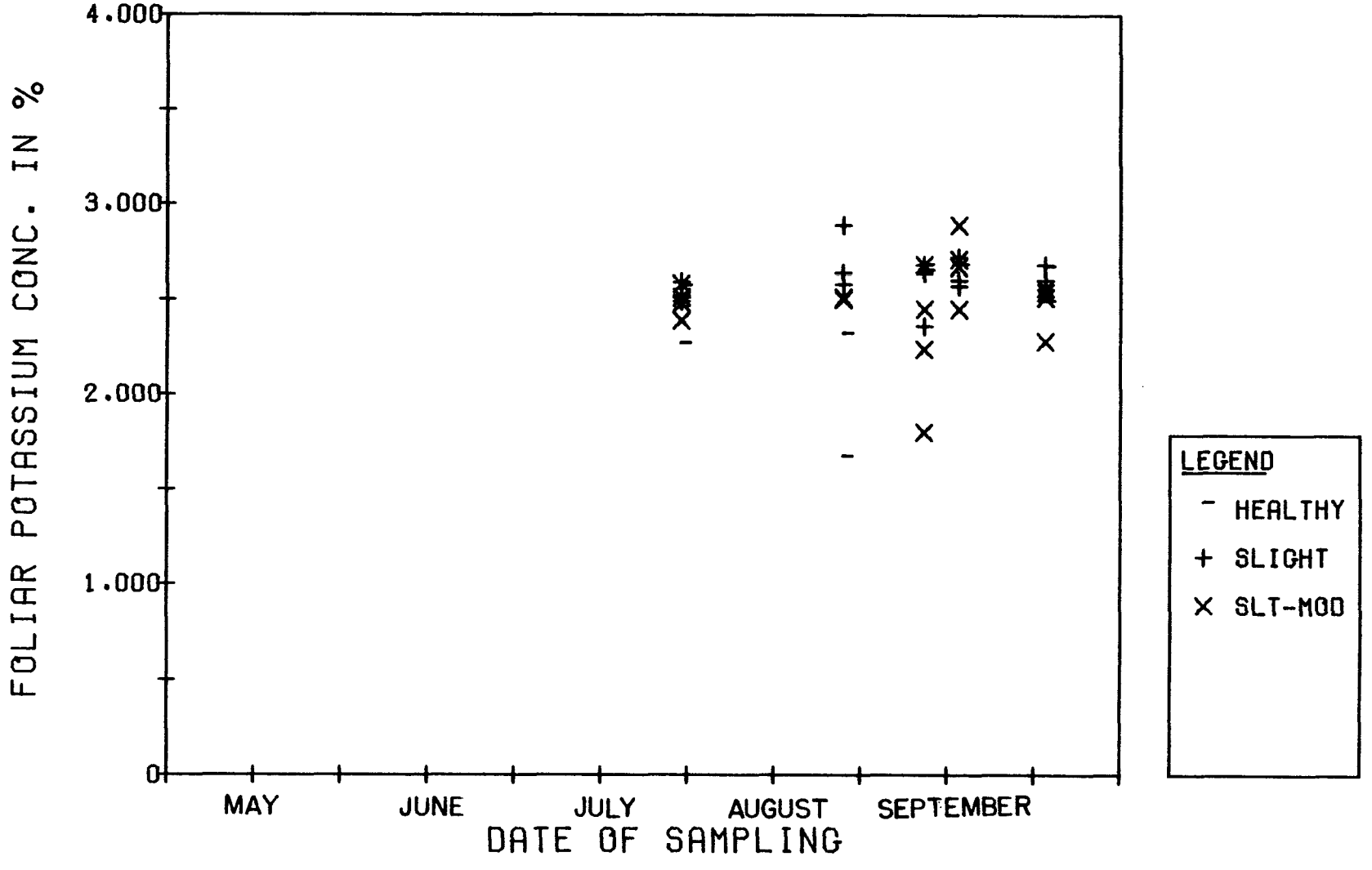

Figure 6. Fluctuation of potassium concentration in healthy to slight - moderately chlorotic sugar maples during 1982 and 1983.

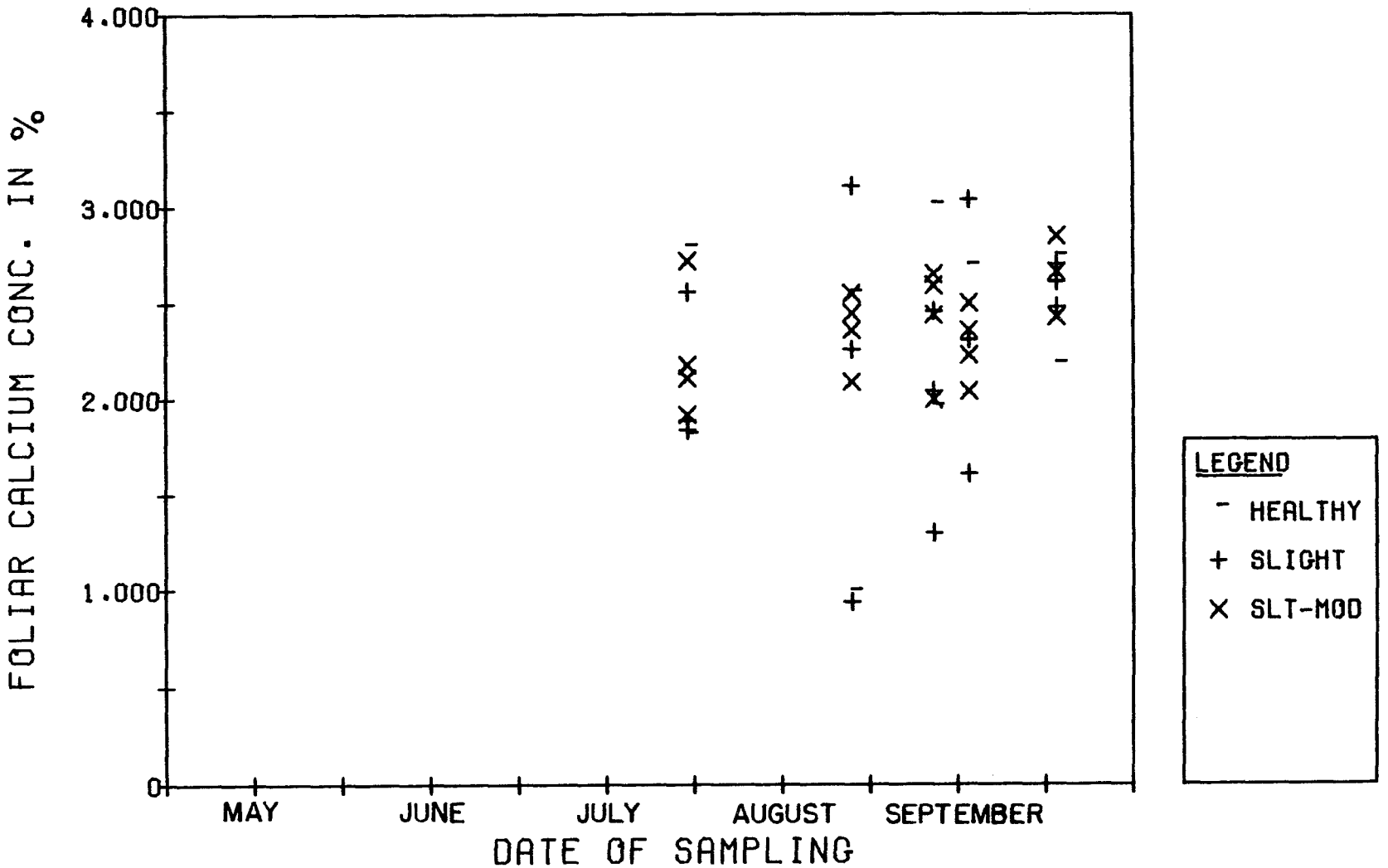

Figure 7. Fluctuation of calcium concentration in healthy to moderately chlorotic sugar maples during 1982 and 1983.

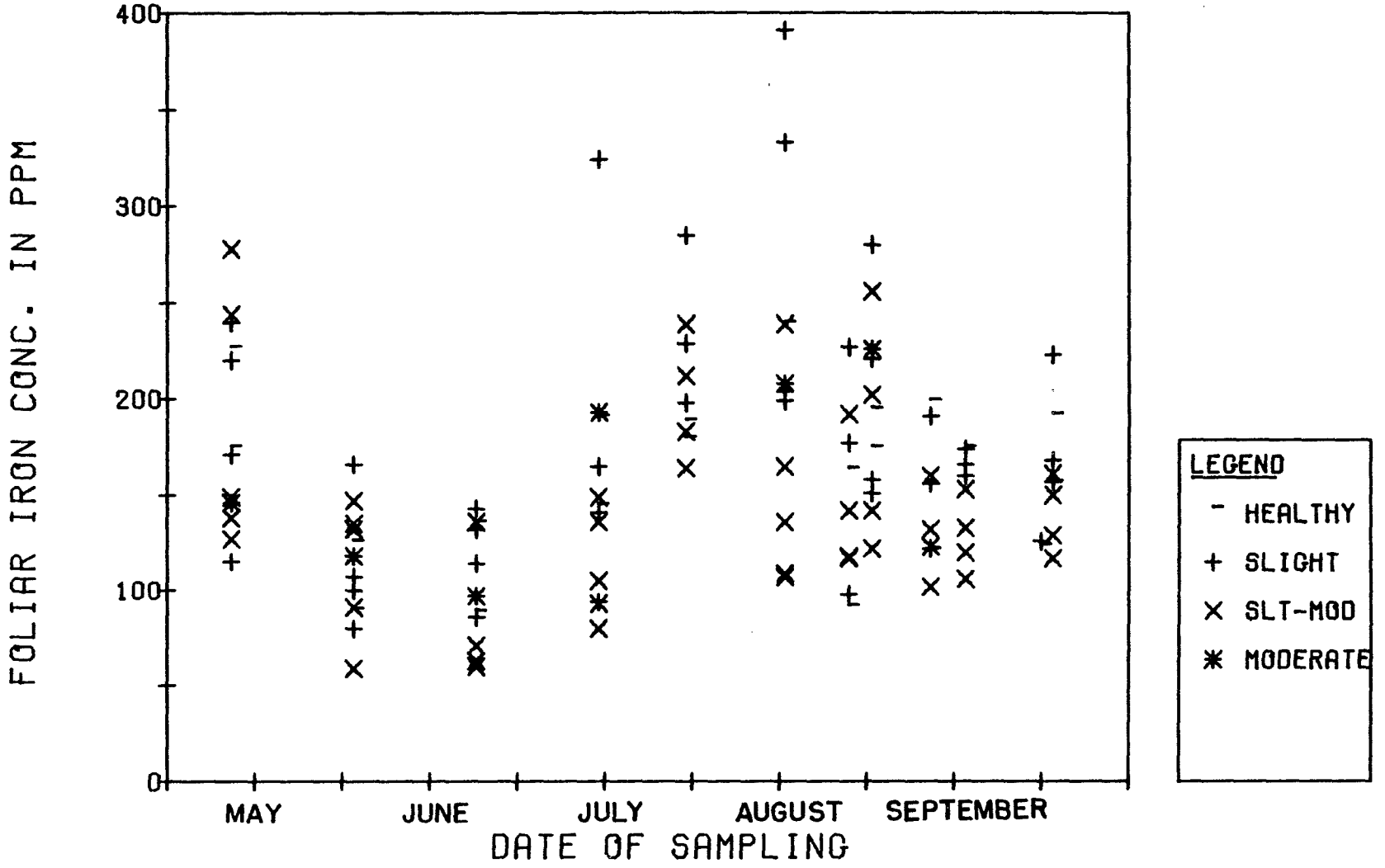

Figure 8. Fluctuation of iron concentration in healthy to moderately chlorotic sugar maples during 1982 and 1983.

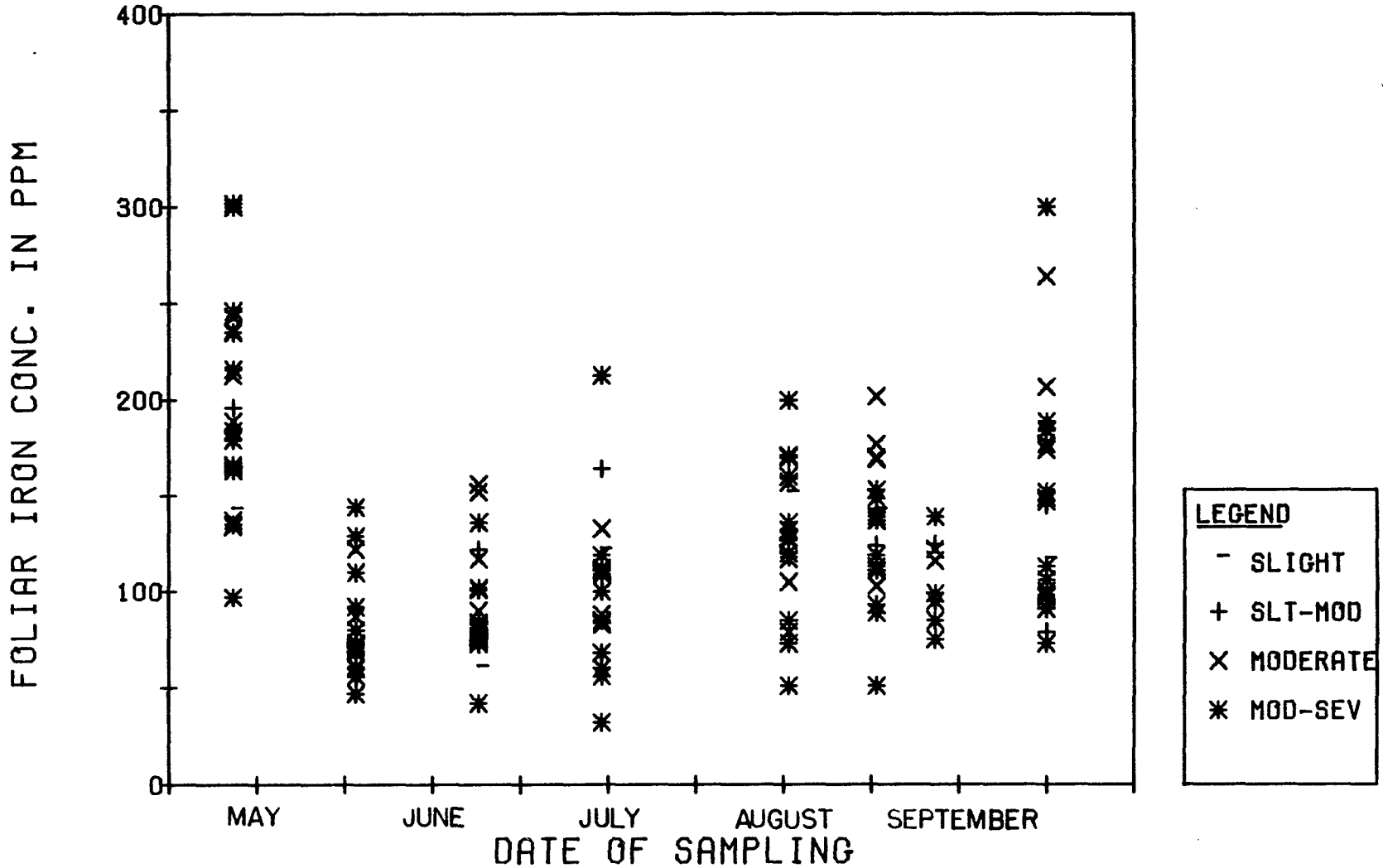

Figure 9. Fluctuation of iron concentration in slight to moderately - severe chlorotic red maples during 1982 and 1983.

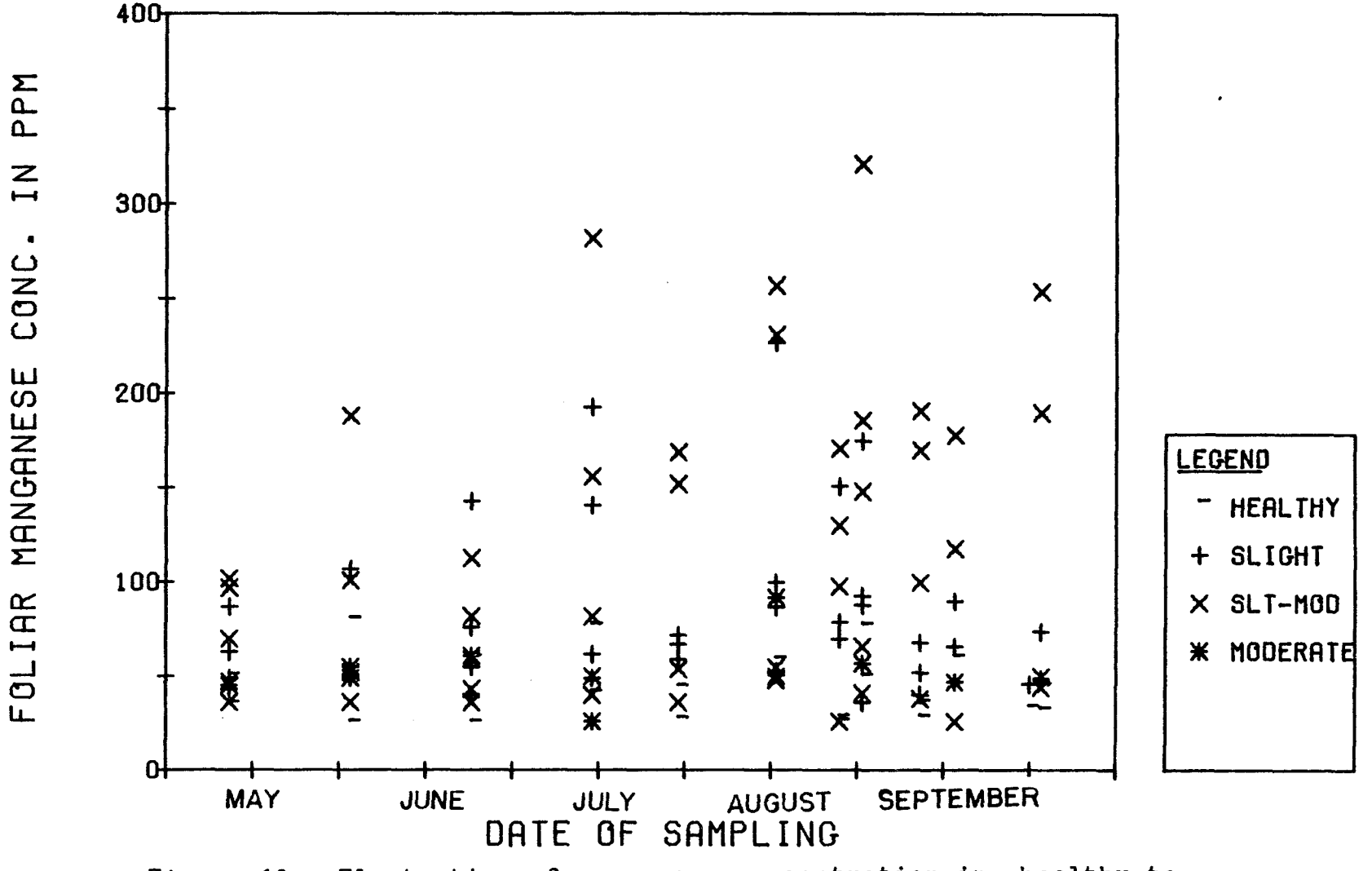

Figure 10. Fluctuation of manganese concentration in healthy to moderately chlorotic sugar maples during 1982 and 1983.

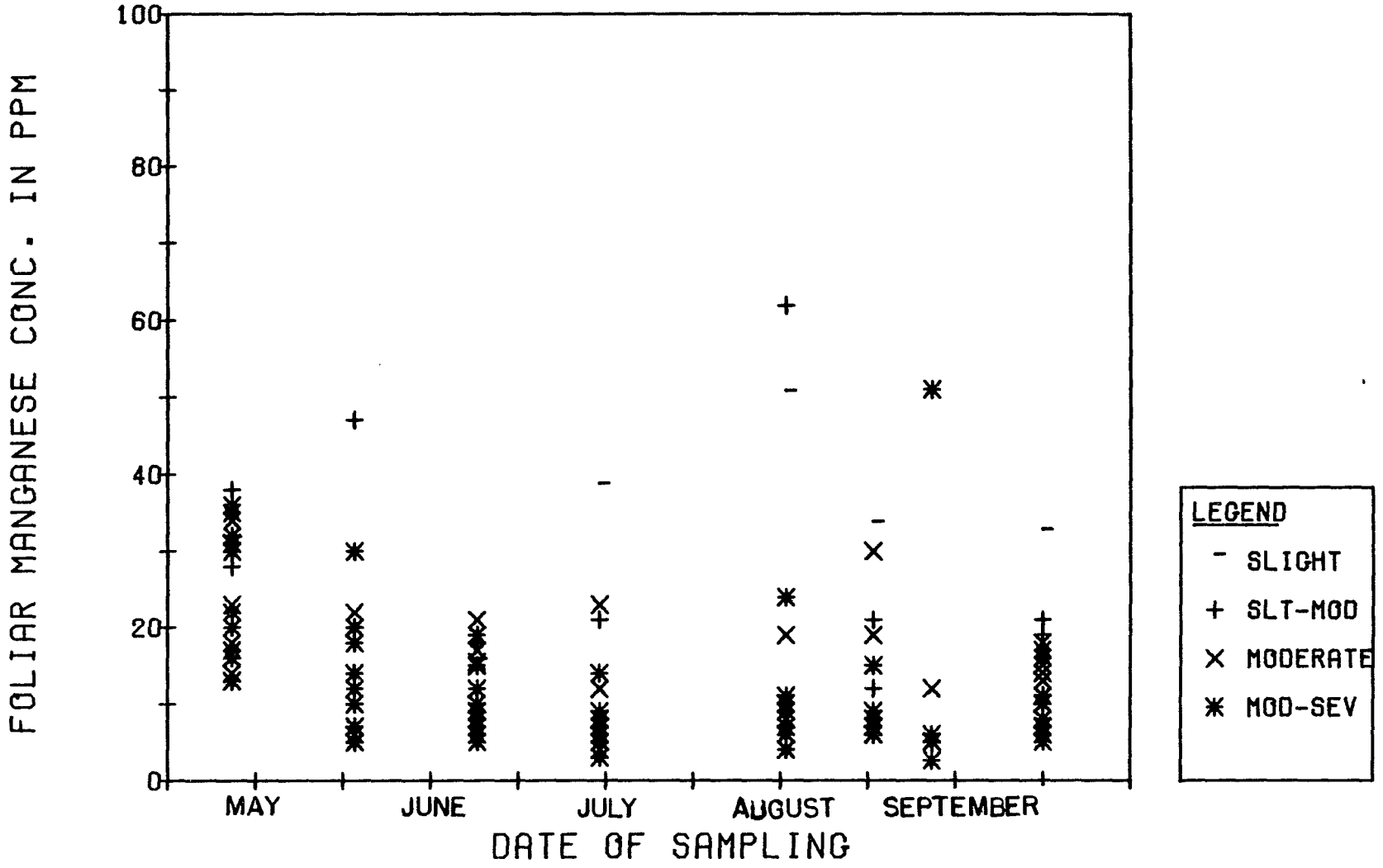

Figure 11. Fluctuation of manganese concentration in slight to moderately - severe clorotic red maples during 1982 and 1983.

Discussion

Nitrogen concentrations in both red and sugar maples showed a decreasing trend (Type C) over the growing season as is typical in other crops and trees (Ellis, 1975, Guha and Mitchell, 1966, Mengel and Kirby, 1982, McHargue and Roy, 1932, Oland, 1963, Smith, 1962). The time of year which maples exhibited the least N changes, thus the best time of year to sample was during June, July, August or early September. Manganese deficiency had little effect on the seasonal pattern.

Phosphorus fluctuation was similar in both sugar and red maples. Concentrations started high, decreased in June, then leveled off through the end of the sampling period (Type C). This was the expected pattern for P, until the end of the season, when a significant decrease was expected (Guha and Mitchell, 1966, Oland, 1963). Since the majority of the P loss observed by Oland (1963) was after mid-October, the lack of sampling past September may account for the lack of a decrease. Early leaf drop in these maples, was probably due to low levels of manganese. Data may be compared during the June through September period.

With limited data for potassium and calcium it was difficult to make accurate comparisons. Relatively constant levels of potassium have been reported during the summer for sugar maple (Leaf et al., 1979A) and other

species (Tamm, 1951, Guha and Mitchell, 1966). A significant decrease in K should be expected at the end of the season (Moore, 1966, Oland, 1963). Again, manganese deficiency may be interfering with the normal withdrawal of K. Samples for K should be comparable when collected during August and mid-September.

Calcium concentrations did not exhibit the expected Type B increase which has been observed in forest trees (Guha and Mitchell, 1966, McHargue and Roy, 1932, Lea et al., 1979A). This may be due to initially high Ca levels inhibiting continued uptake. The period from August through mid-September, which showed a plateau, should be the best period for sampling. High Ca levels are related to high soil pH, which, in part, is responsible for the chlorosis.

Studies by Guha and Mitchell (1966) show a Type A accumulation of iron from June to September in horsechestnut, beech and sycamore. During September Fe concentration decreased or remained constant (Guha and Mitchell, 1966). Other studies refer to Fe concentrations as continually increasing in a Type B pattern (Smith, 1962). The pattern in both red and sugar maples was Type A. The high degree of variability makes the drawing of a smooth curve difficult. Year-to-year differences were often significant, reducing the validity of comparisons. The best period for sampling was in August or early September.

Manganese in forest sugar maple has shown a Type B pattern (Lea et al., 1979B). This pattern was evident in urban sugar maples. Red maples exhibited a strikingly different pattern. Concentrations decreased from May to July and never achieved a level as high as the original May level. Variability in the red maple data was much less than sugar maple data. This trend was due to the severe manganese deficiency of the red maples. Manganese levels were at a high point early in the season due to a preferential translocation of Mn to meristematic tissue and probable release of stored Mn (Mengel and Kirby, 1982). Concentrations decreased as foliage expanded, competing for a limited supply of Mn. Mid-July through mid-September is the optimum period for sampling. Data from severely deficient trees should be comparable after June. Four sugar maples had Mn levels greater than 100 ppm and exhibited chlorosis symptoms. This may have been due to the effects of repeated sampling, removing the young leaves which normally function as Mn sinks, allowing higher concentrations to accumulate in other leaves.

With several exceptions, seasonal variation patterns in manganese deficient sugar and red maples were very similar to the patterns of forest trees. The greatest differences were with phosphorus and manganese. Since the manganese availability was low, the pattern lacked the

expected increase during the season. Sampling for Mn in severely deficient trees may be conducted at any time during the growing season with a reliable degree of comparability. Phosphorus fluctuation patterns did not exhibit the expected decrease in concentration at the end of the season due to premature leaf drop or physiological disruption related to manganese deficiency.

Accepting the criterion of minimum fluctuation as optimum, the best time of the year to sample foliage from urban sugar and red maples in lower Michigan is August through mid-September. To define severe deficiency symptoms, samples may be collected as early as June.

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CHAPTER 3

MANGANESE DEFICIENCY OF URBAN SUGAR AND RED MAPLES: A DEFINITION OF THE PROBLEM AND SOIL FACTORS INVOLVED

Introduction

Soil Factors Associated With Manganese Deficiencies

High soil pH is the factor most frequently associated with manganese (Mn) deficiencies. Lucas and Davis (1961) state that, "the availability of Mn is influenced more by soil reaction than any other plant nutrient." Manganese availability is greatly decreased at pH greater than 5.5, and severe deficiency symptoms occur above 6.5 on mineral soils (Leeper, 1947). On organic soils the pH at which symptoms occur is lower (Lucas and Davis, 1961). In most soils, the availability of Mn^{+2} decreased 100 fold for each pH unit increase (Mortvedt et al., 1972).

Maas et al. (1968), experimenting with excised barley roots, found that within the physiological range where Mn is soluble (pH<7) absorption peaked at pH=6. This is higher than the 5.5 which is generally accepted as the maximum pH for adequate Mn uptake.

In an attempt to predict Mn deficiencies, total soil Mn had almost no significant correlation (Steckel et al., 1948). This is largely due to the different oxidation

states and complexes of Mn in the soil.

Oxidation-reduction (redox) potentials are often cited as contributing factors in Mn deficiencies. The amount of manganese which is extractable from soil has been shown to be inversely related to redox (Copeland, 1957). This is usually credited to the change of valence from +4 to +2. The Mn^{+2} ion is more mobile in the soil and thus is more easily extracted, taken up by roots, or leached from the soil. Soil redox may be decreased by limiting oxygen through flooding or compaction (Pal et al., 1979, Fujimoto and Sherman, 1948).

Soil organic matter (OM) is thought to be essential for development of Mn deficiency (Mulder and Gerretsen, 1952). There are several hypotheses which explain this. Microorganisms associated with OM may alter the redox potential, thus precipitating Mn due to valence changes (Geering et al., 1969), or Mn may become organically bound (McBride, 1982).

Soil moisture affects the availability of Mn. The reasons for this may be numerous and not all are clearly defined (Mortvedt et al., 1972). One important factor is the transportation of the Mn to roots for subsequent uptake. Depression of redox potential is also associated with excessive soil water (Fujimoto and Sherman, 1948). Without speculation as to reasons, or experiments to quantify observations, several authors have mentioned that deficiencies tend to be associated with low soil moisture

levels (Kreag, 1940, Mortvedt et al., 1972, Mulder and Gerrestsen, 1952, Rich 1956). Others have suggested that symptoms are more severe in moist conditions (Smith, 1976). Moisture variability may account for year to year variations of symptoms.

Soil microorganisms are known to affect micronutrient availabilities in at least two ways. The first is through direct involvement in redox reactions of the nutrient. Microorganisms can oxidize Mn^{+2} to the relatively insoluble MnO2 thus creating deficiencies while not changing the total amount of Mn present (Geering et al., 1969, Ehrlich, 1981). They may also have the opposite effect on Mn availability through their consumption of O2 and release of CO_2, affecting both the pH and redox potential. The composition and activity of microbial populations are dependent on many factors, including OM, moisture content and oxygen levels. Mycorrhizae are known to promote iron uptake in high lime soils. Dale et al. (1955) found that iron chlorosis of pines seldom occurred in natural sites. Trees with normal mycorrhizae, even on high lime locations (pH=7.8) did not exhibit symptoms. When normal mycorrhizae were lacking, symptoms developed no matter what iron/fertilizer combinations were applied to the soil. Mycorrhizae have not been studied as they relate to Mn deficiency.

Competing cations may worsen existing Mn deficiency problems. In extensive experiments with barley roots,

Maas et al. (1969) found that magnesium (Mg) significantly depressed the rate of Mn absorption. Calcium (Ca) increased absorption of Mn. When both Ca and Mg were present, Mn absorbtion was decreased further than with Mg alone. Iron is also known to reduce uptake of Mn (Mortvedt et al., 1972, Olson and Carlson, 1949).

Low light intensities and low soil temperatures have been associated with an increase in deficiency symptoms due to changes in photosynthetic rates and the movement of Mn in and to roots (Mortvedt et al., 1972).

Manganese deficiencies are seldom observed in trees on soils in their natural state (Kielbaso and Ottman, 1976, Sherman and Harmer, 1942).

Manganese deficiency of maples

High soil pH due to profile disruption is the major factor which has been associated with Mn deficiencies of maples (Kielbaso and Ottman 1976, Kreag, 1940). Calcium levels are also not normally as high in nondisturbed surface soils as has been observed with symptomatic trees. There were two reasons given for this high Ca level. The first is that subsoils high in Ca have been exposed or brought to the surface (Craul, 1983). The second explanation for high Ca levels is improper drainage, leaving calcium compounds near the surface instead of leaching. In urban situations, excessive water may collect

due to run-off from sidewalks, streets, and houses (Kreag, 1940). Without proper drainage, water would evaporate leaving Ca behind. Calcium could make soil Mn less available due to pH changes or cation competition.

Urban soils are thought to have very low levels of organic matter (Antheunis et al., 1982). This has been associated with manganese deficiency (Kielbaso and Ottman, 1976). Although Mn deficiency is usually associated with high OM levels, low OM levels may reduce root growth and nutrient uptake. Organic compounds are also known to assist in the maintenance of Mn in an available form (Heintze and Mann, 1947, Shuman, 1979).

Selection of root stocks for horticultural varieties may explain the variation in symptoms between native and varietal maples (Brown et al., 1958). A root stock genetically unable to absorb sufficient amounts of nutrients will result in deficiency symptoms (Berrang and Steiner, 1980). Selection of root stocks to compensate for nutrient problems has shown some success with red maples (Teuscher, 1956).

In summary, there are generally seven factors which have been associated with Mn deficiencies and Mn availability. They are: 1) soil pH, 2) oxidation-reduction potential, 3) organic matter, 4) moisture levels, 5) plant genetics, 6) microorganisms, and 7) competing cations. Soil pH, and to some extent, competing cations have been studied in the case of maple trees.

This study had three objectives: 1) Confirmation of the diagnosis of manganese deficiency, 2) Quantification of the growth impact of manganese deficiency, 3) Definition of the site factors related to manganese deficiency.

Materials and Methods

Sampling Design

Managers of thirty two urban forestry programs in Minnesota, Wisconsin, Illinois, Michigan, Ohio, and Ontario, Canada were contacted in the winter of 1981-1982 and invited to participate in this research project. Managers who responded favorably were again contacted to determine numbers of young sugar maple (Acer saccharum Marsh.) and red maples (Acer rubrum L.) in their areas. There were 13 respondents who were interested and had sufficient numbers of trees. All of their cities were visited. The sites sampled in 1982 were Stevens Point, Wisconsin; Highland Park, and Rockford, Illinois; Ohio Agriculture Research and Development Center, Wooster; and in Michigan, Grand Rapids, Ann Arbor, Lansing, Flint, and Michigan State University campus, East Lansing. Sites sampled in 1983 were, Stevens Point, Wisconsin; Lake Forest, Illinois; Michigan State University campus, Saginaw, and the city of East Lansing, Michigan.

Sampling Methods

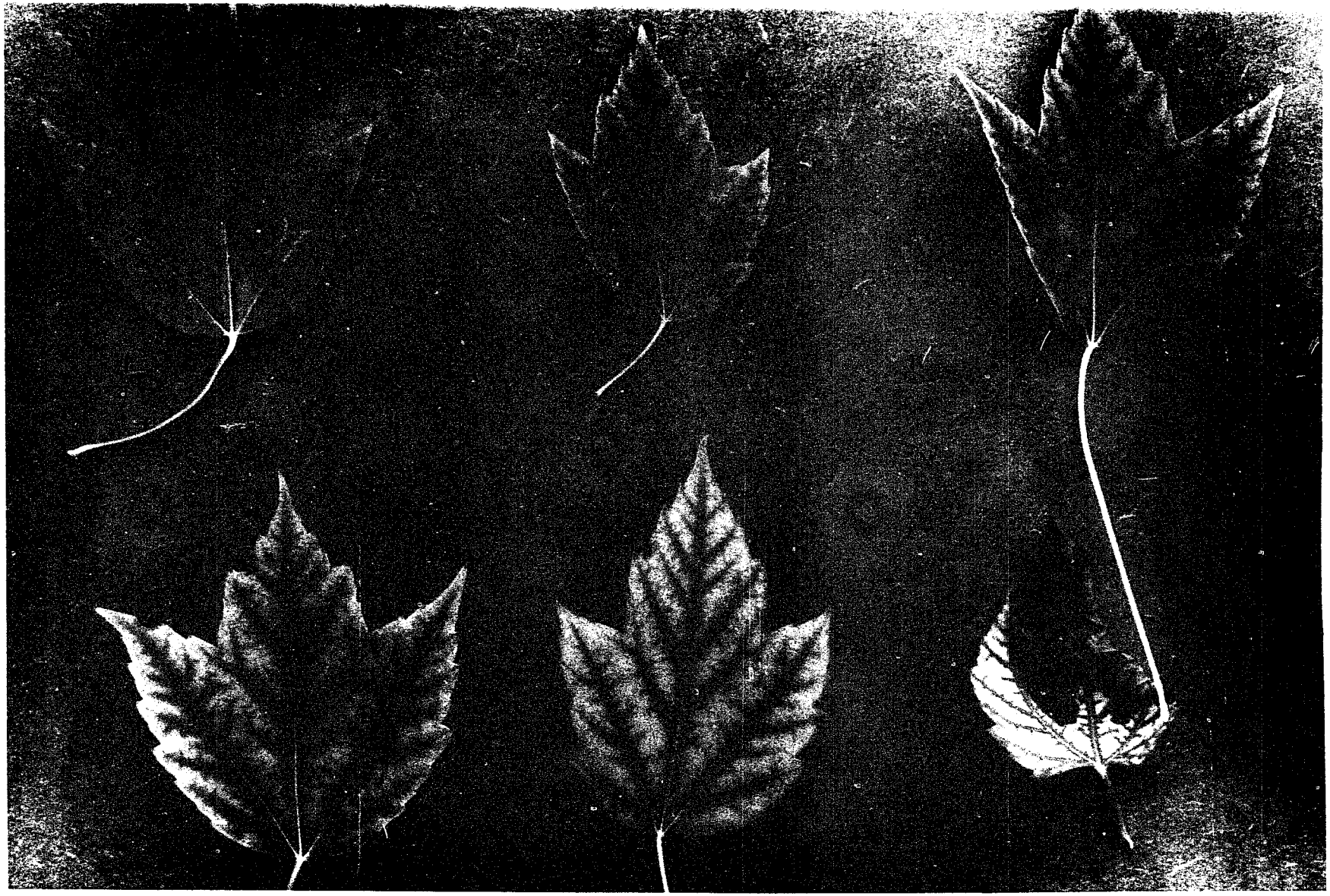
Tree managers were asked to locate one area of healthy sugar and red maples and a second area in which trees exhibited interveinal chlorosis symptoms. Trees with small, uniformly chlorotic leaves, and columnar varieties were not sampled.

Data collected on-site in 1982 were: species and variety, years since transplant, method of transplanting, history of fertilization, location, diameter, crown shape, chlorosis rating, terminal length, and soil profile characteristics. In 1983 the data collected on-site were species, location, diameter, chlorosis rating, terminal length, terminal diameter, and redox potential. Samples collected for laboratory analysis were foliage, surface soil and, in 1982 only, subsoil.

Tree diameter was measured with a Biltmore stick at 1.5 meters above the soil surface (DBH). 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 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 (dead) or partially necrotic leaves were rated five (Figure 12). An overall chlorosis rating was determined

Figure 12

Photograph of red maple 'October Glory' leaves with series of chlorosis symptom. Upper left to right, Rating group 0, Group 1, Group 2. Lower left to right, Group 3, Group 4, Group 5.



by averaging all 15 ratings (Messenger, 1984). 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. This distinction was used for group separations in the statistical procedures.

Five branches were pruned from the middle one third of the crown facing south. Length of current year's growth was measured from the terminal bud to last year's terminal bud scale scars. In 1983, the diameter of the terminal was also measured at the proximal end, but not over swollen areas.

Surface soil was sampled with ten 2.5 cm dia. x 15 cm deep cores from around the tree using a Hoffer Soil Sampler (Elano Corp, Xenia, Ohio). Cores were taken between the dripline and approximately half the distance to the trunk of the tree in a random pattern, with an equal number of samples from each side of the tree (Ruark et al., 1982, SCS, 1972).

Soil profile and subsoil samples were collected in 1982 using a bucket auger (AMS, American Falls, ID 83211). Descriptions were made at 15 cm intervals to a depth of 90 cm unless a layer obstructive to root growth was encountered. At each interval the following soil characteristics were noted: soil color including value and chroma using Munsell color charts (Soiltest, Evanston, IL, 60202); soil texture - determined by hand using method described by Thien (1979); gravel - noted if it made up

more than 15% of soil volume; effervescence - detected by addition of one drop 10% HCl; roots - if tree roots were present in sample; structure - present, massive or single grained; mottles - if present in sample; films - if clay films were present on stones or soil aggregates (USDA, 1975). A soil sample was collected for laboratory analysis from the deepest interval in which tree roots were present. In 1983, surface soil samples were analyzed following the same procedures for texture, effervescence and gravel.

Soil oxidation-reduction (redox) potential was classified into one of two groups at each soil depth in 1982. Soils with a value > 4 and chroma < 2 were classified as reduced, all others were oxidized (USDA, 1975). In 1983, surface soil redox measurements were made using three platinum micro electrodes (3.95 x .644 mm), an Ag/AgCl reference electrode (Jensen Instruments, Tacoma, Washington 98444), and an Orion Research Ion-analyzer Specific Ion Meter Model 407 (Quispel 1947, McKenzie and Erickson 1954). Electrodes were acid-cleaned before use.

Soil redox potential was calculated using the equation:

Eh = 242 mv + corrected meter reading

where Eh is equal to the soil redox potential in mv (Puri and Sarup, 1938). Empirical pe values were determined using the formula:

pe = Eh/59.2

where pe is equal to the negative log of the electron concentraiton. Values for pe + pH were the simple addition of pe and pH for each sample tree.

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.

Laboratory Procedures

Foliage samples were rinsed in distilled water, petioles discarded, leaves counted and oven dried at 70 degrees C the same day they were removed from the tree. Subsequently, leaves were ground in a Wiley mill with a 20 mesh screen and stored in sealed 60 ml plastic souffle cups or acid-washed glass vials. Samples were re-dried and weighed prior to analysis. Soil samples were air dried, passed through a 1 mm screen, and stored in paper bags prior to analysis.

Total Kjeldahl nitrogen and total phosphorus of plant tissue and soils was colorimetrically determined on a Technicon Autoanalyzer II following digestion with sulfuric acid (Black, 1965, Technicon, 1977). Determination of total metals (Al, B, Cd, Cr, Cu, Fe, Mn, Na, Zn) followed digestion of subsamples with nitric and perchloric acids (Blanchar et al., 1965, Ellis et al., 1976, Sommers and Nelson, 1972). Concentrations were

determined using a Spectrametrics SMI III DC-argon plasma emission spectrometer (Dahlquist and Knoll, 1978).

Soil samples were extracted with 0.1N H_3PO_4 1:10 (w:v), shaken at 150 rpm for 20 minutes, and then filtered through Whatman #1 filter paper (Salcedo and Warncke, 1979, Salcedo et al., 1979, Whitney, 1980).

Soil organic matter was colorimetrically determined using a method developed by Sims and Haby (1971) based on wet combustion of organic matter with dichromate in sulfuric acid (Black, 1965, Graham, 1948, Walkeley, 1947). The colorimetric readings were converted to percent organic matter using a regression equation generated by a comparison of forty samples which were wet-combusted. The regression produced was $Y = -.315 + 12.29\ x$ where Y is equal to predicted percent organic matter from wet combustion and x is equal to actual colorimetric absorbance reading.

Soil pH was measured using an Orion Model 901 Ion-analyzer equipped with a combination electrode. Soil was mixed one-to-one with deionized water and continuously shaken at 150 rpm for 20 minutes (Ederbach Corp, Ann Arbor, MI). The particles were allowed to settle for 10 minutes and the supernatant slurry was measured (Black, 1965).

In 1982 root samples were collected, cleaned and stained using the method described by Kormanik and McGraw (1982). Mycorrhizal infections were then evaluated and

classified according to a slightly modified USDA Forest Service scheme where Class 1 is 0-5% of root length infected, Class 2: 6-25%, Class 3: 26-50%, Class 4: 51-75%, Class 5:76-100% (Kormanik and McGraw, 1982).

The 1983 samples were collected from 0 to 15 cm depth. Roots were washed, cleaned and stained using the methods described by Phillips and Hayman (1970). Root measurements and percentage of root length infected were determined using the grid method (Schenck, 1982).

Statistical Analyses

Trees were rejected from analyses if one or more of the following conditions were found:

1) greater than 25% of bark missing from trunk
2) tree in the shade of adjoining trees
3) tree missing primary leader or a major portion of the crown.

Analysis of data was conducted on the CDC Cyber 750 computer located in the MSU Computer Laboratory. Statistical procedures and data manipulations were performed using the Statistical Package for the Social Sciences version 8.3 (MSU, 1981, Nie et al. 1975,). Results of statistical analysis were judged significant when probability levels were less than, or equal to, five percent (.05) unless indicated otherwise. Results were

judged highly significant if probability levels were less than, or equal to, one percent (.01).

Statistical tests used were: 1) Student's T-Test for comparison of two group means; 2) Analysis of variance for categorical, ordinal, and interval data with separation of means using Scheffe's procedure;3) Analysis of covariance to differentiate the covariate from the main effects; 4) Simple correlation coefficients for interval and ratio using regression techniques; 5) Multiple linear regression for interval and ratio data; 6) Discriminant analysis for separation of groups by interval and ratio values (Nie et al., 1975, White and Mead, 1971). Seventy-five percent of the data were used to define the discriminant function and the remaining 25% were used to test the function.

Results

Description of study trees

Two hundred and ninety-eight trees were sampled in the summers of 1982 and 1983 (Table 5). Tree diameters ranged from 5 cm to 31 cm DBH, with a mean of 14 cm. Red maples were mainly 'Red Sunset' and 'October Glory', they were combined for analysis.

Data on date of transplanting, method of transplanting, and history of fertilization were not available from most tree managers.

Nutrients related to chlorosis

Chlorotic sugar maples had a significantly lower concentration of Mn, and higher concentration of N, Ca and Cu than healthy trees (Table 6). Chlorotic red maples had significantly lower concentrations of Mn, higher concentrations of N and Al as compared to healthy red maples (Table 7). Other nutrients (P, K, Mg, Fe, Zn, Na, B, Cd, Cr) showed no significant differences.

Table 5. Summary of tree species sampled.

City and State	Red maples	Sugar maples
1982		
Stevens Point WI	1	13
Highland Park IL	4	12
Rockford IL	4	10
OARDC Wooster OH	30	0
Grand Rapids MI	5	12
Lansing MI	0	12
Flint MI	0	15
MSU E. Lansing MI	22	12
Ann Arbor MI	7	10
1983		
Stevens Point WI	10	10
Lake Forest IL	10	10
Saginaw MI	9	10
E. Lansing MI	10	10
MSU E. Lansing MI	8	23
Birmingham MI	11	8
Total	131	167

Table 6. Foliar element concentration of urban sugar maples sampled in the Great Lakes states during late summer 1982 and 1983.

	Healthy #			Chlorotic		
Element	mean	S.D.	n	mean	S.D.	n
	%			%		
N *	1.81	.46	55	1.97	.37	80
P	.21	.08	55	.21	.09	80
K	2.74	.32	19	3.03	83	31
Mg	.43	.16	28	.39	.15	44
Ca *	2.08	.33	19	2.69	1.4	33
	ppm			ppm		
Mn**	211	156	53	62	81	79
Fe	152	56	53	151	54	79
Zn	17	17	51	20	10	79
Cu**	6.7	3.2	32	9.9	5.3	45
Na	268	116	27	298	110	45
Al	65	31	32	82	55	46
B	122	90	32	207	360	45
Cd	.70	.52	28	.65	.63	44
Cr	1.1	0.8	30	2.1	3.8	44

S.D. = Standard deviation, n = number of trees included in analysis.

* Significant difference (p=.05) between means of healthy and chlorotic trees.

** Highly significant difference (p=.01) between means of healthy and chlorotic trees.

Table 7. Foliar element concentration of urban red maples sampled in the Great Lakes States during late summer 1982 and 1983.

	Healthy #			Chlorotic		
Element	mean	S.D.	n	mean	S.D.	n
	%			%		
N *	1.76	.36	40	1.95	.49	76
P	.24	.08	40	.26	.11	76
K	2.69	.39	14	5.30	18	43
Mg	.42	.16	26	.42	.15	34
Ca	1.42	.32	14	1.57	.31	43
	ppm			ppm		
Mn**	132	82	41	26	51	79
Fe	114	82	41	143	81	79
Zn	34	16	39	36	17	77
Cu	11	6.4	25	9.7	4.3	34
Na	131	57	25	241	344	34
Al**	34	22	25	56	39	34
B	82	97	27	118	61	36
Cd	.81	1.1	22	.57	.61	36
Cr	1.3	0.9	21	1.2	0.6	30

S.D. = Standard deviation, n = number of trees included in analysis.

* Significant difference ($p<.05$) between means of healthy and chlorotic trees.

** Highly significant difference ($p<.01$) between means of healthy and chlorotic trees.

Chlorosis ratings

The correlation between foliar manganese concentrations and the mean chlorosis rating (CR) for sugar maples was r =-.52. For red maples the correlation was r =-.70. When the logarithm of the foliar Mn concentration (MNL) was compared to the mean chlorosis rating, the correlation increased to r = -.72 for sugar maple and r = -.86 for red maple (Figures 13 and 14). The regressions which relate these variables are CR = -3.7 MNL + 8.0, CR = -3.1 MNL + 6.25 for sugar and red maples, respectively.

There were 14 red maples (11%) which had over 32 ppm Mn and were chlorotic. Seven trees had more than 75 ppm Mn and were chlorotic.

Fifty-four (32%) sugar maples were chlorotic and had more than 23 ppm Mn. Thirty trees were chlorotic with over 45 ppm Mn and 14 were chlorotic with over 100 ppm Mn.

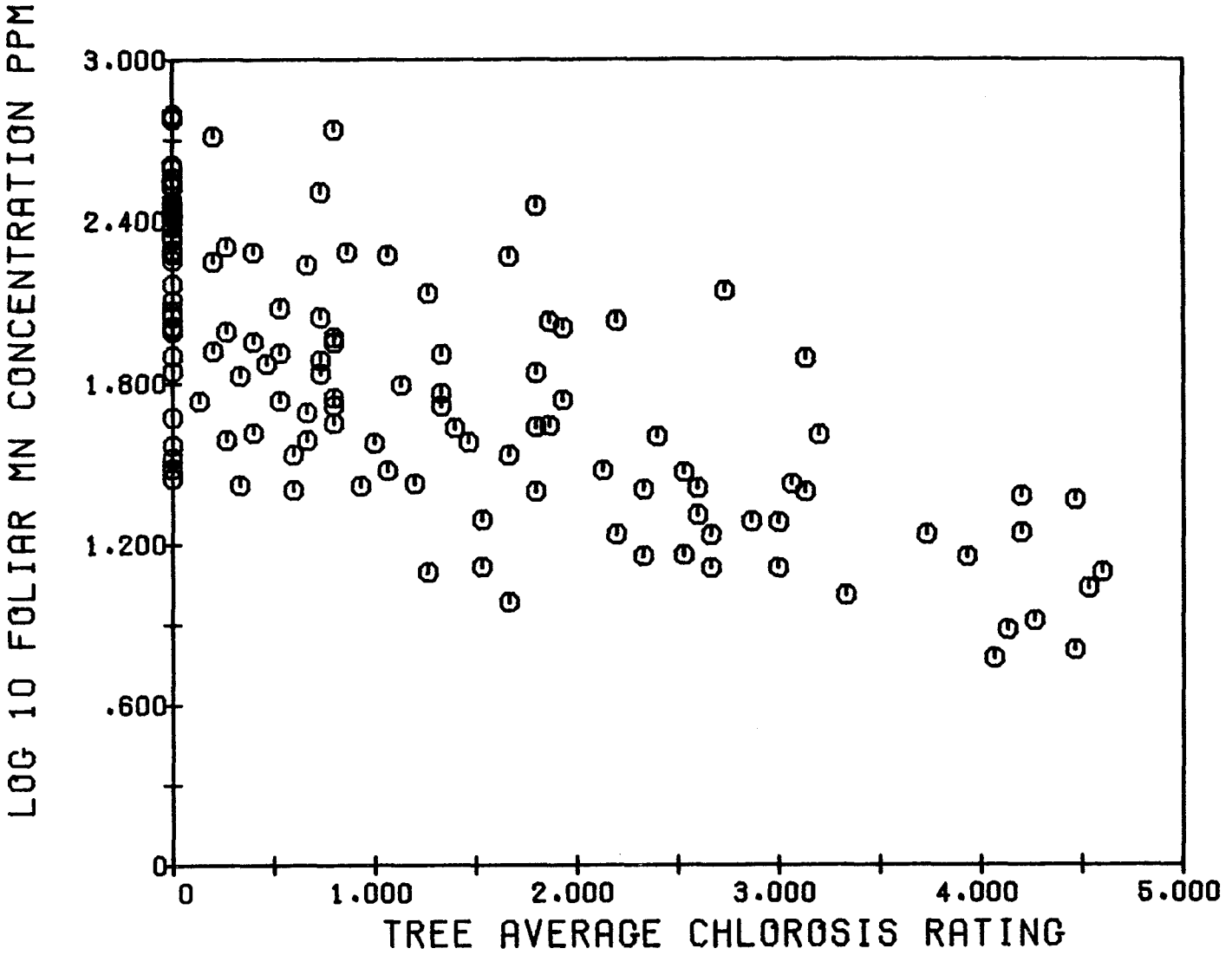


Figure 13. Relation of foliar manganese concentration and chlorosis ratings for urban sugar maple sampled in the Great Lakes region during late summer 1982 and 1983.

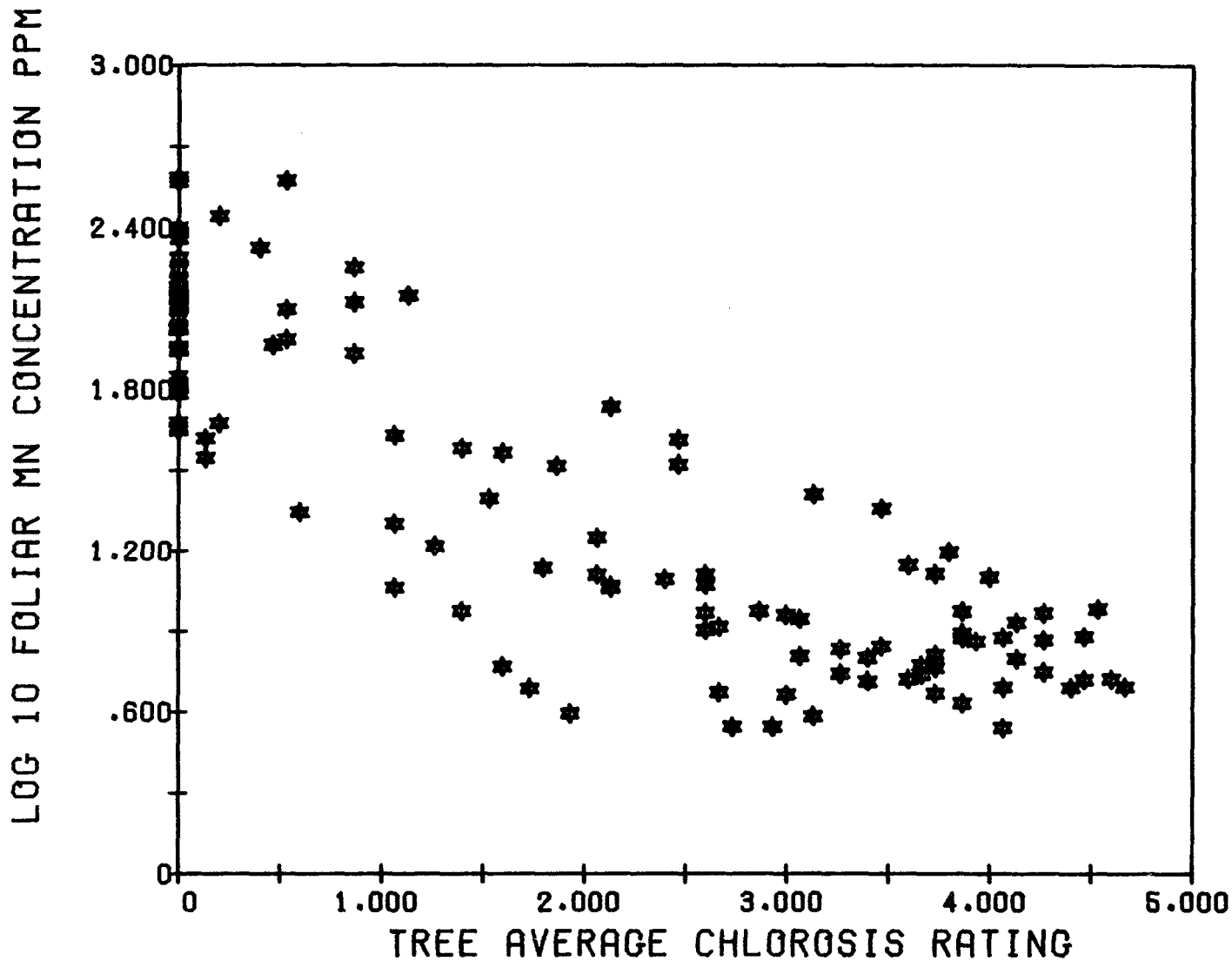


Figure 14. Relation of foliar manganese concentration and chlorosis ratings for urban red maple sampled in the Great Lakes region during late summer 1982 and 1983.

Growth impacts

Growth differences were observed in four different forms. Necrotic leaves on upper branches were always related to lower Mn levels in samples fron the middle of the crown. The mean Mn concentration in sugar maples with necrotic leaves was 25 ppm; necrotic red maples had a mean of 7 ppm.

Healthy red maples had a significantly longer terminals than chlorotic trees (Table 8). Sugar maples had the opposite relation, with healthy trees having less growth than chlorotic trees. A significant negative linear relation existed between length and foliar Mn in sugar maple (Figure 15). Red maples exhibited a weak positive relation (Figure 16).

Healthy sugar maple terminals had smaller diameters (mean = 4.8 mm) than chlorotic trees (mean = 5.5 mm). Red maples had similar diameter means of 3.7 mm for healthy and 4.0 mm for chlorotic (Table 8). The majority of the healthy red maples had diameters between 3 and 5 mm, with numerous chlorotic trees having both more growth and less growth (Figure 17). Sugar maples exhibit the same pattern with the majority of healthy trees having diameters between 3.5 and 6.5 mm (Figure 18). Sugar maple twig diameter was not correlated with Mn concentration. In red maple there was a significant inverse relation (r=-.25).

Table 8. Growth differences between healthy and chlorotic trees sampled in selected cities of the Great Lakes region during late summer 1982 and 1983.

Growth Form	Healthy # mean	S.D.	n.	Chlorotic mean	S.D.	n.
Sugar Maple						
Terminal length (cm)*	24	12	55	31	16	80
Terminal diameter (mm)*	4.8	.93	22	5.5	1.2	33
Leaf weight (g d.w.)	.61	.22	54	.60	.16	78
Red Maple						
Terminal length (cm)*	26	13	40	20	11	79
Terminal diameter (mm)	3.7	.52	14	4.0	.98	43
Leaf weight (g d.w.)*	.33	.10	39	.26	.09	79

S.D. = Standard deviation, n = number of trees included in analysis.

* T-test results indicate a significant difference ($p<.05$) between means of healthy and chlorotic trees.

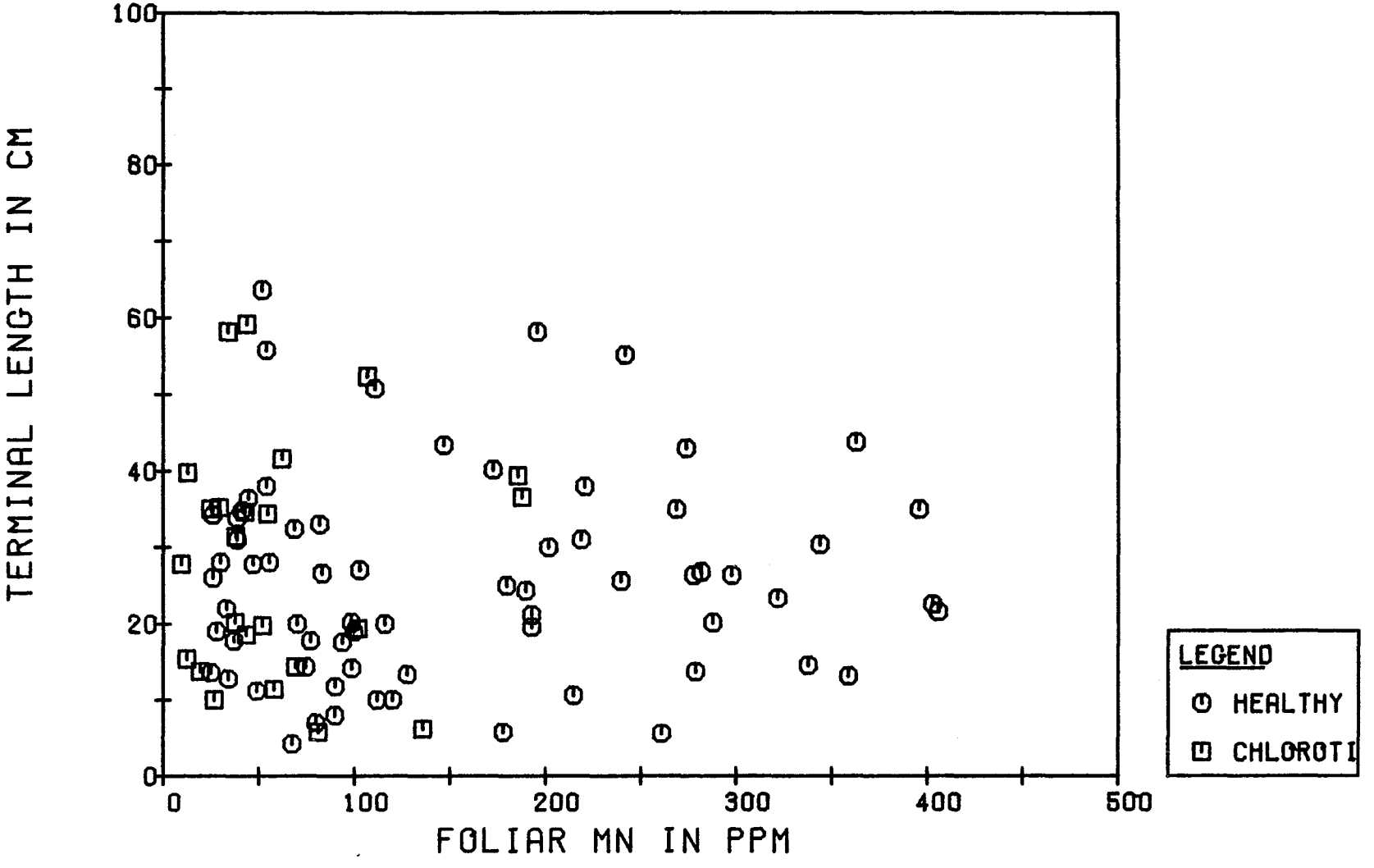


Figure 15. Relation of terminal length and foliar manganese concentration in healthy and chlorotic sugar maples sampled in the Great Lakes region during late summer 1982 and 1983.

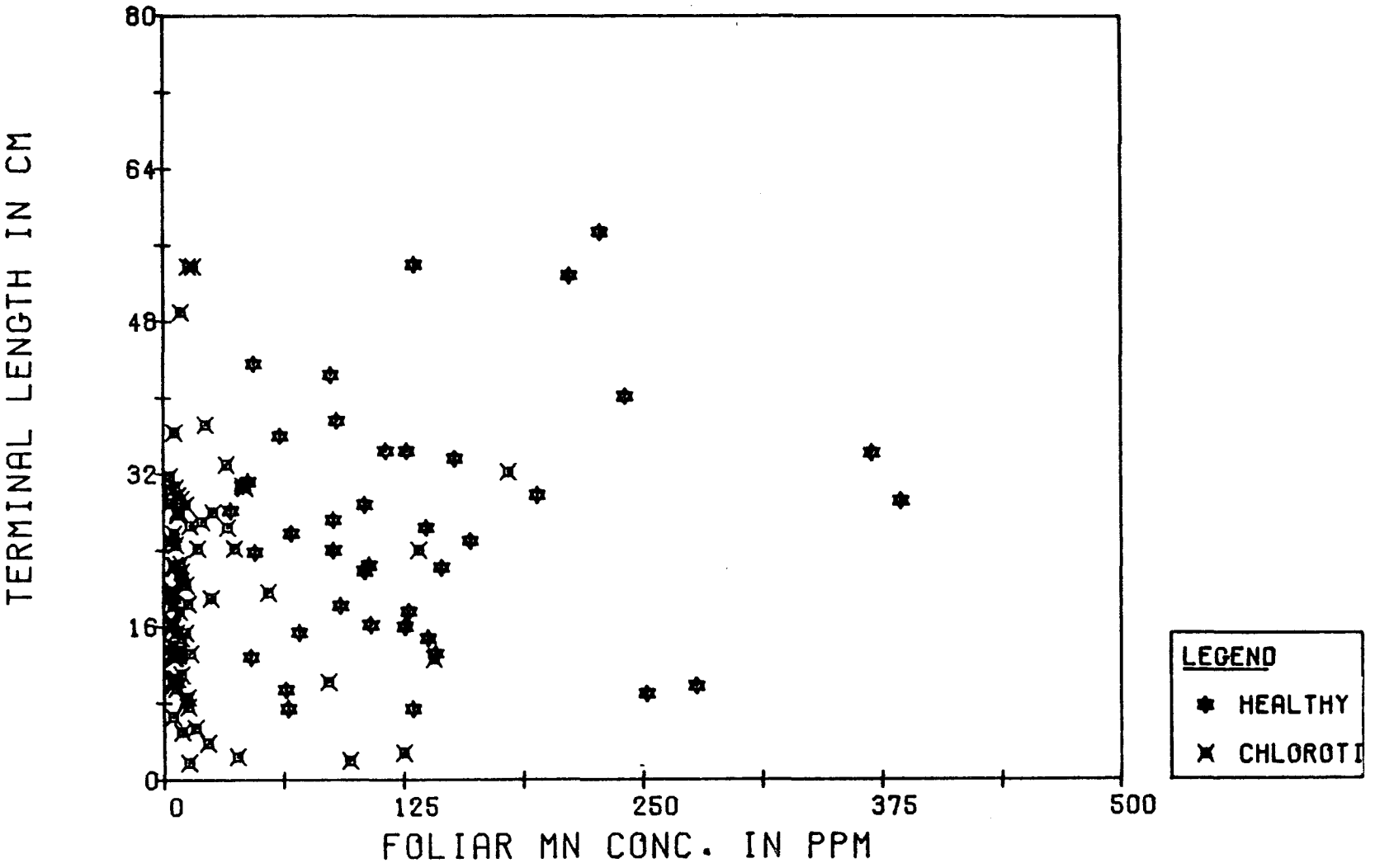


Figure 16. Relation of terminal length and foliar manganese concentration in healthy and chlorotic urban red maples sampled in the Great Lakes region during late summer 1982 and 1983.

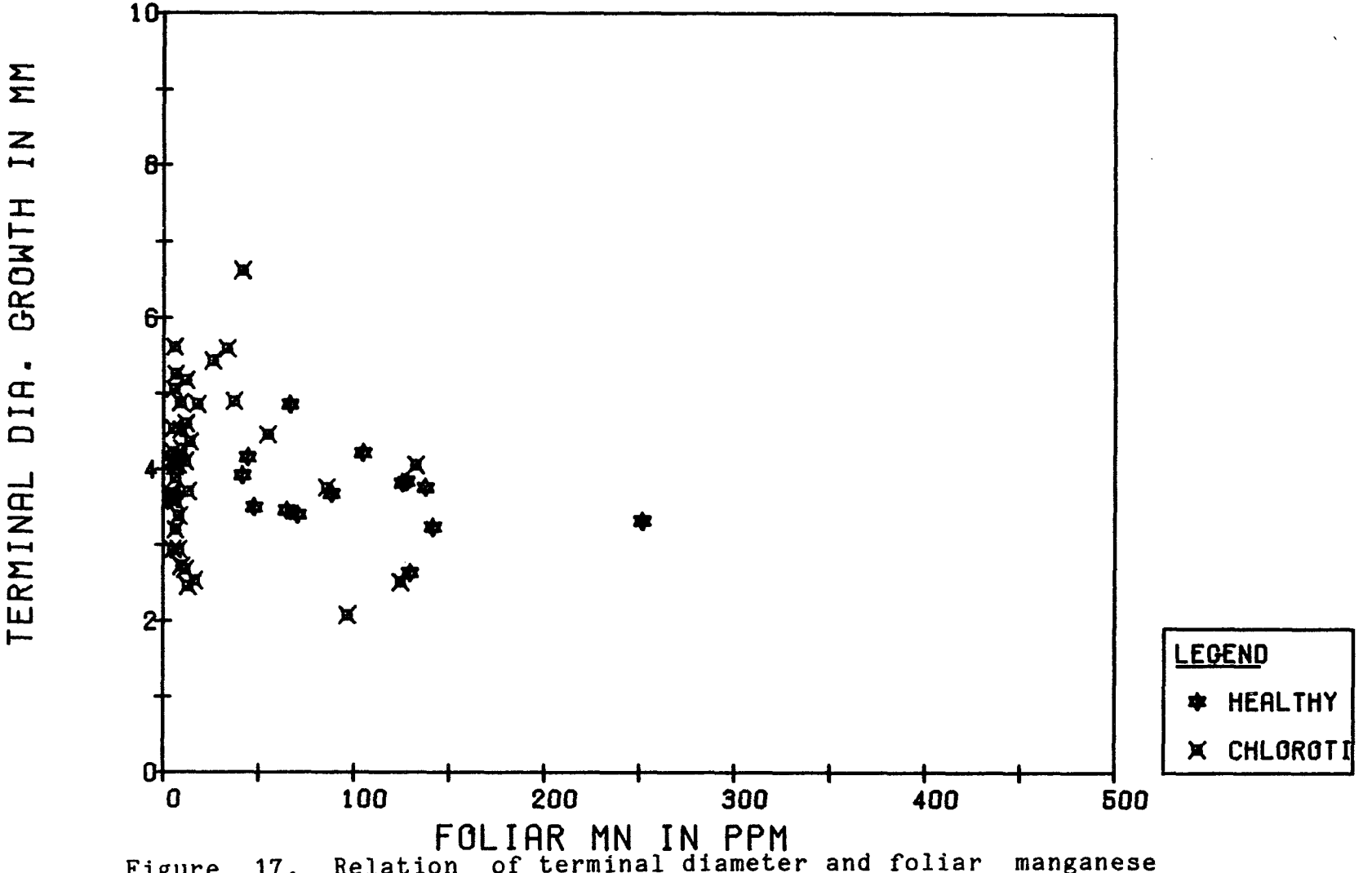


Figure 17. Relation of terminal diameter and foliar manganese concentration in healthy and chlorotic urban red maples sampled in the Great Lakes region during late summer 1982 and 1983.

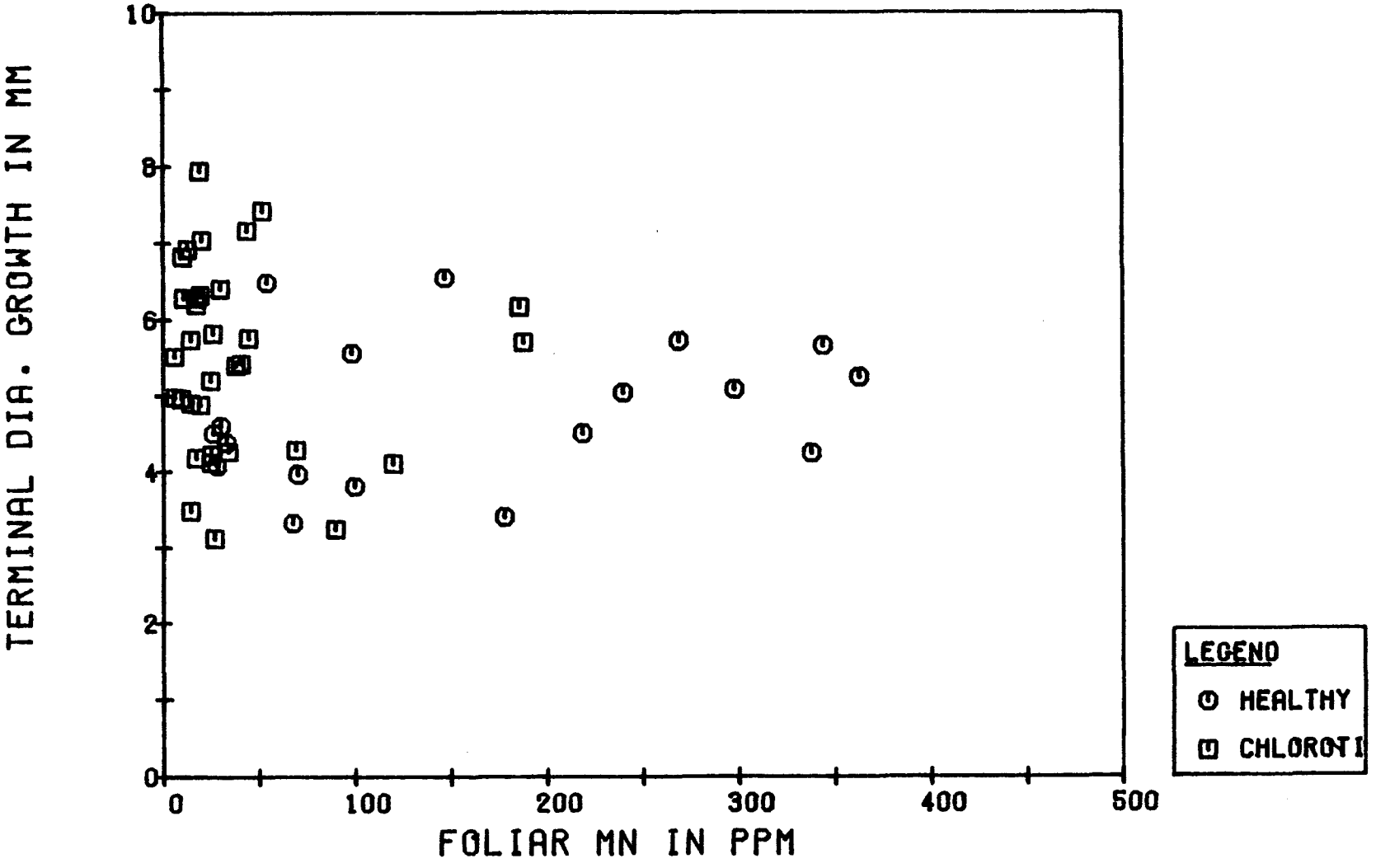


Figure 18. Relation of terminal diameter and foliar manganese concentration in healthy and chlorotic urban sugar maples sampled in the Great Lakes region during late summer 1982 and 1983.

Leaves from chlorotic red maples were significantly lower in weight than from healthy trees (Table 8). There were no statistical differences between leaf weights of healthy and chlorotic sugar maples.

Factors Associated With Chlorosis and Manganese

Soil texture

After accounting for pH differences using an analysis of covarience, texture was not related to foliar Mn concentration in sugar or red maple.

Soil organic matter

Organic matter levels ranged from 0.4% to 9.9% with a mean of 5.6% for 291 samples. The majority of chlorotic sugar maples were on soils with over 5.5% OM with a mean of 5.6% (Figure 19). The mean for healthy sugar maple was 4.8%. Most chlorotic red maples were on soils with over 5.5% OM with a mean of 6.5% (Figure 20). The mean for healthy trees was significantly less at 4.7%. No red maples were found in soils with OM levels lower than 3%. A significant linear relation was found for both species (Table 9).

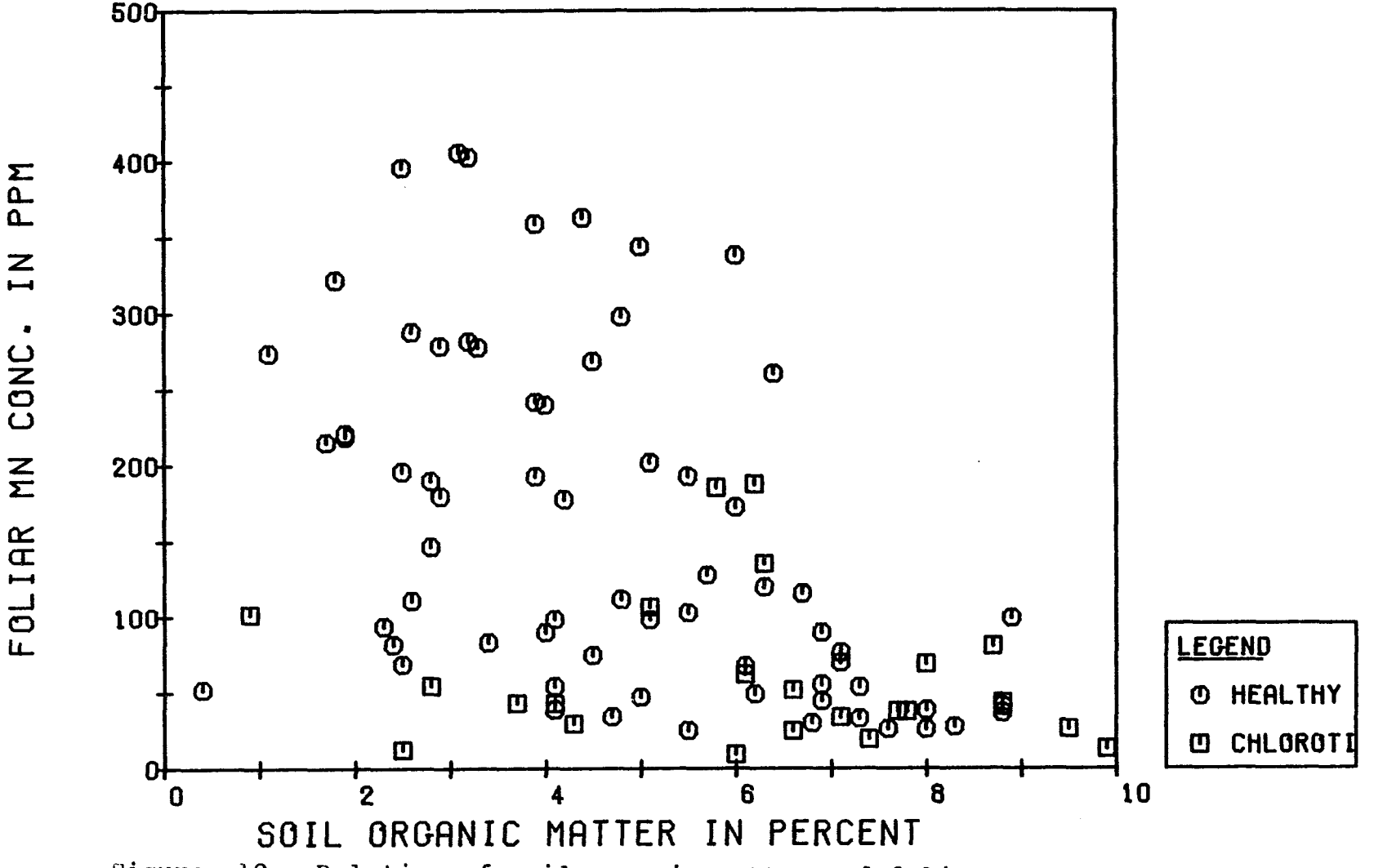


Figure 19. Relation of soil organic matter and foliar manganese in healthy and chlorotic urban sugar maples sampled in the Great Lakes region during late summer 1982 and 1983.

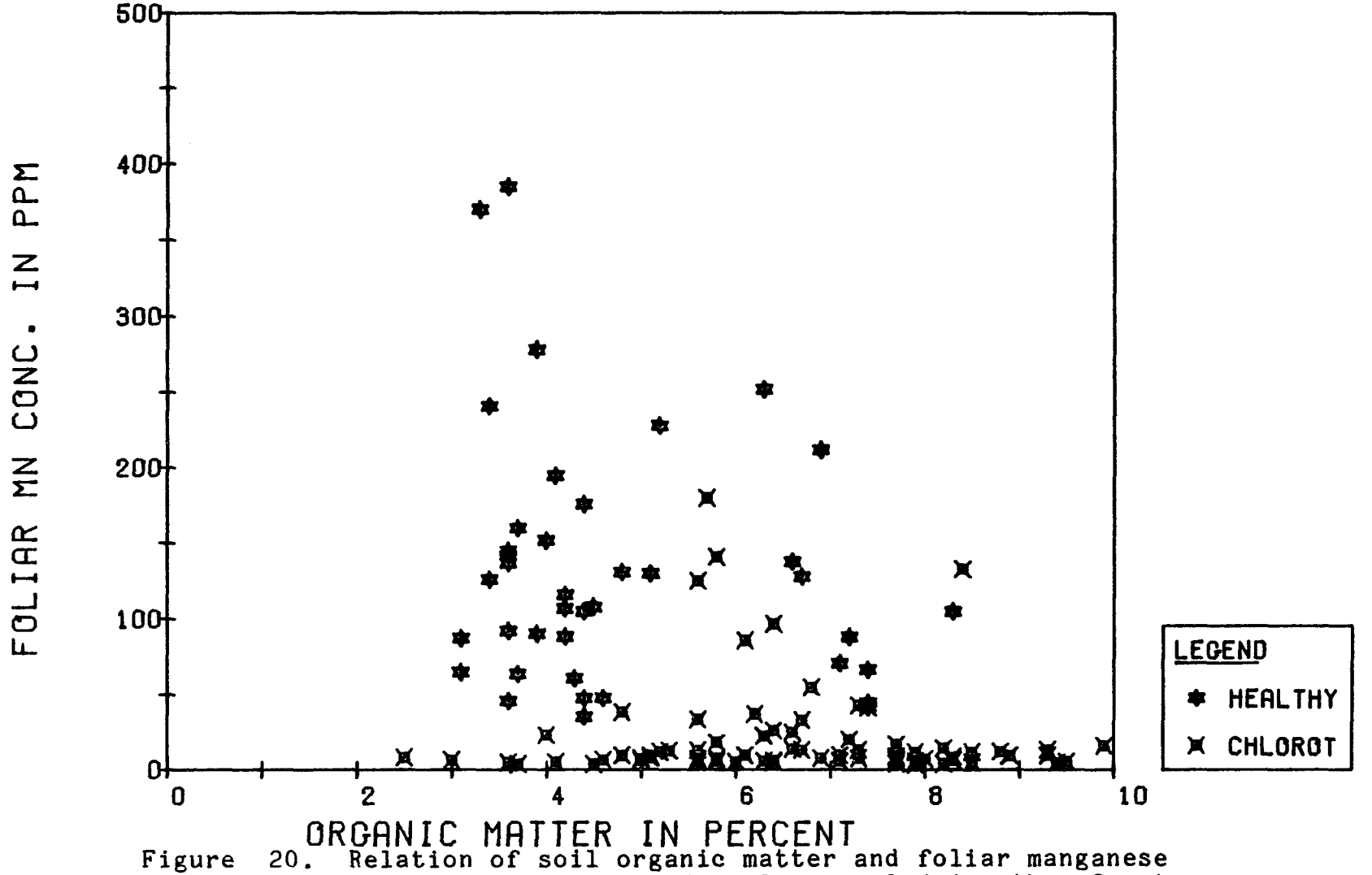


Figure 20. Relation of soil organic matter and foliar manganese in healthy and chlorotic urban red maples sampled in the Great Lakes region during late summer 1982 and 1983.

Table 9. Regressons relating soil factors and foliar manganese in urban sugar and red maples sampled in the Great Lakes region during late summer 1982 and 1983.

Soil Factor	Regression	Sig.*	r^2	n
Sugar maple				
pH	Mn=-248 pH + 1848	HS	.59	129
pH	log Mn=-.863 pH + 78.3	HS	.54	129
pe	Mn=38.2 pe + 12.9	HS	.23	47
Organic Matter	Mn=-26.8 OM + 263	HS	.16	129
Nitrogen	Mn=-.03 N + 197.7	HS	.10	127
Extract. Mn	Mn=-.36 EMN + 140	NS	<.01	122
Red Maple				
pH	log Mn=-.743 pH + 6.4	HS	.48	119
pH	Mn=-89.4 pH + 662	HS	.38	119
Organic Matter	Mn=-15.9 OM + 155	HS	.12	119
pe	Mn=11.4 pe + 28.8	HS	.11	44
Nitrogen	Mn=-.01 N + 100.1	HS	.06	119
Extract. Mn	Mn=.62 EMN + 23	HS	.10	115
Mycorrhizae	Mn= .57 M + 62.2	NS	<.01	24

* Statistical significance, NS = not significant, S = significant at $p<.05$, HS = highly significant at $p<.01$.

Soil manganese

Concentrations of soil manganese ranged from 13 to 234 ppm air dry soil. 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 (Figure 21). On soils with greater than 110 ppm Mn only healthy red maple were found (Figure 22). The linear relation between soil Mn and foliar Mn for sugar maple was not significant while, for red maple it was highly significant (Table 9).

Soil nitrogen

Total soil nitrogen (SN) levels ranged from 101 ppm to over 5000 ppm. There were highly significant negative correlations between total soil nitrogen and foliar manganese for both tree species (Table 9). Generally, as soil N increased, foliar Mn decreased (Figures 23 and 24).

There was also a highly significant correlation between soil organic matter and total soil nitrogen. The regression

$$OM = 349 + .00085\ SN$$

explains 35% of the variability (n=280).

Soil effervescence

Sugar maples on effervescent soils had a mean foliar Mn concentration of 56 ppm (no table). Those on soils

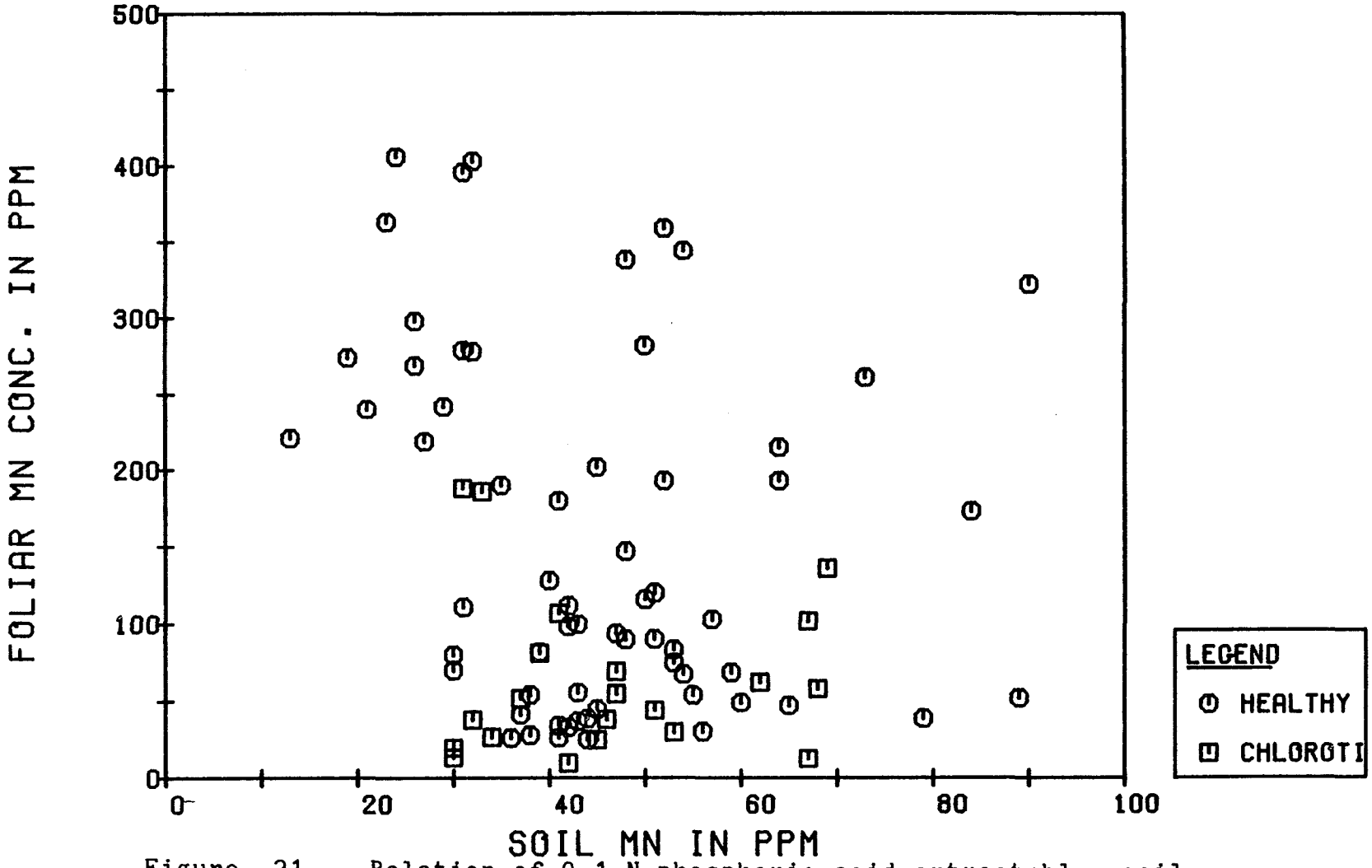


Figure 21. Relation of 0.1 N phosphoric acid extractable soil manganese and foliar manganese in healthy and chlorotic urban sugar maples sampled in the Great Lakes region during late summer 1982 and 1983.

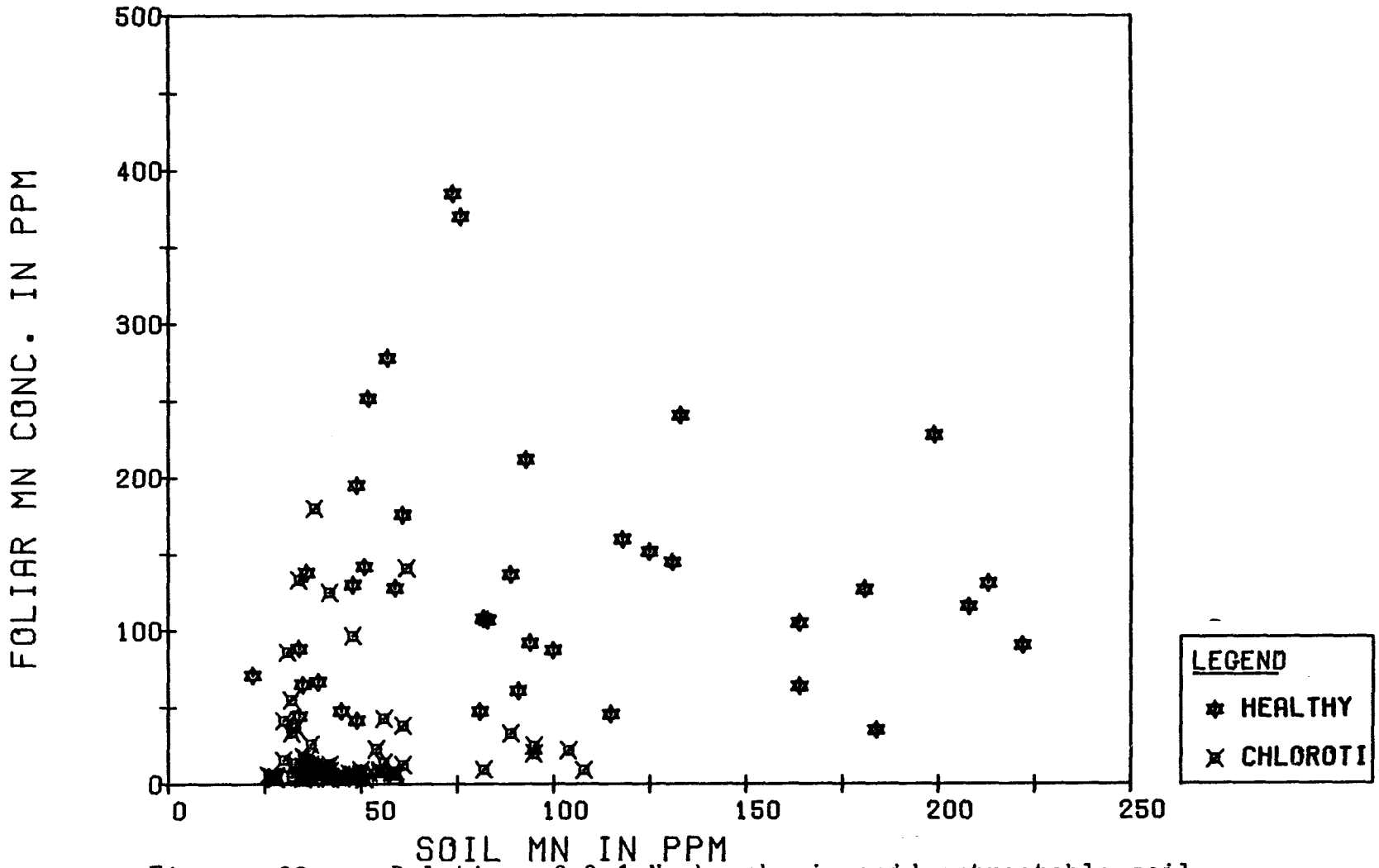


Figure 22. Relation of 0.1 N phosphoric acid extractable soil manganese and foliar manganese in healthy and chlorotic urban red maples sampled in the Great Lakes region during late summer 1982 and 1983.

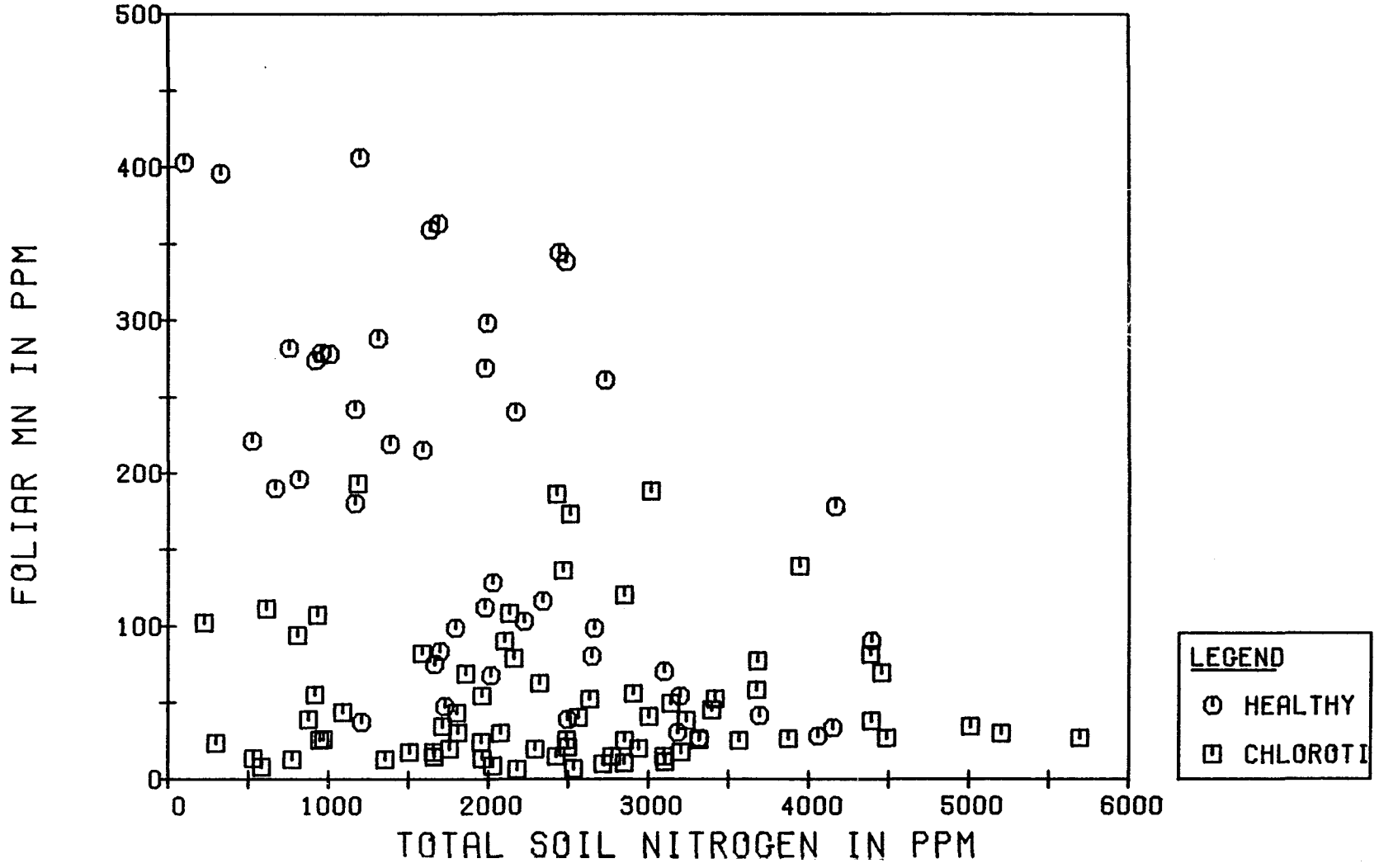


Figure 23. Relation of soil nitrogen and foliar manganese in healthy and chlorotic urban sugar maples sampled in the Great Lakes region during late summer 1982 and 1983.

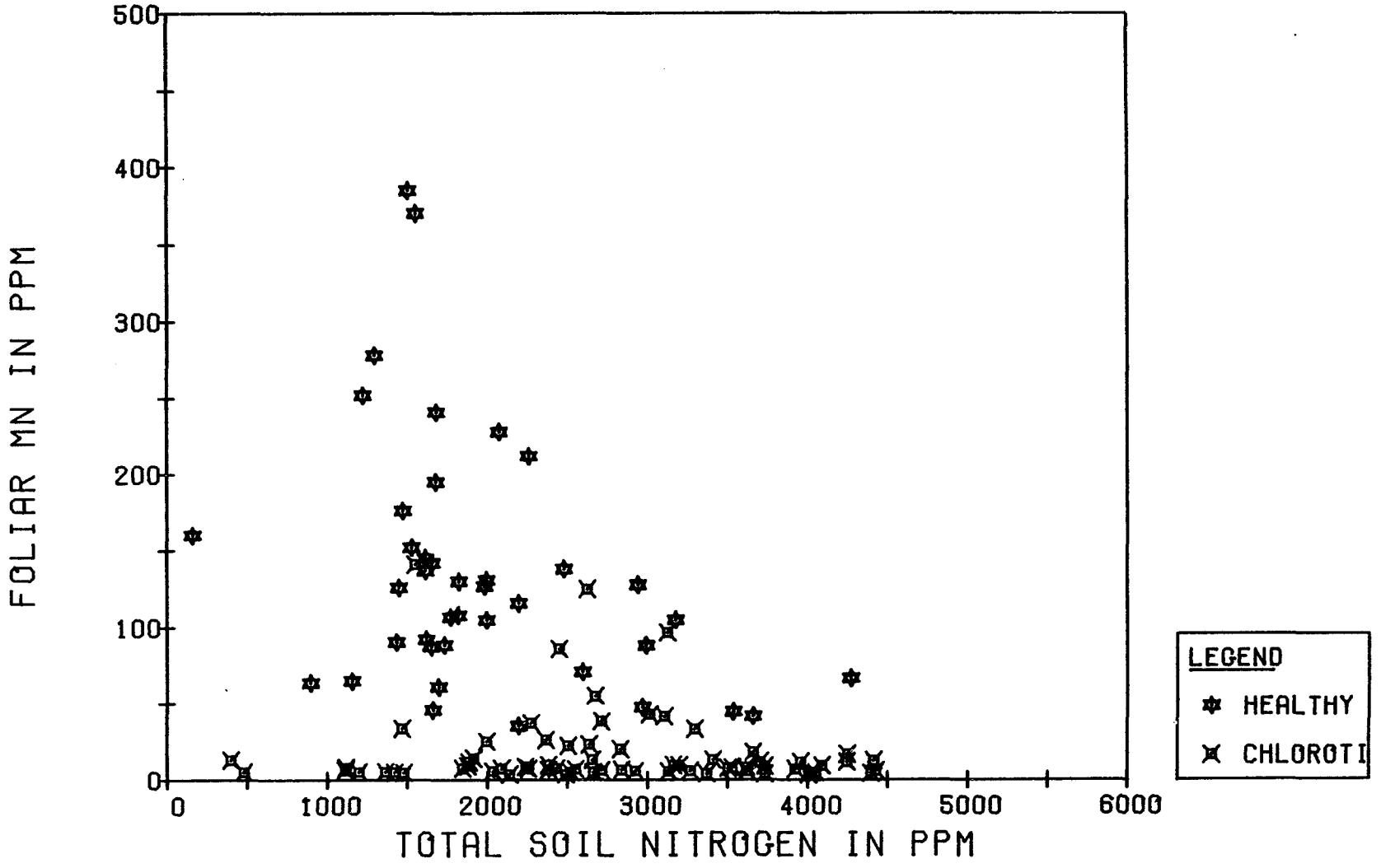


Figure 24. Relation of soil nitrogen and foliar manganese in healthy and chlorotic urban red maples sampled in the Great Lakes region during late summer 1982 and 1983.

without reaction had a significantly higher mean of 169 ppm Mn. Red maple means 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 (n=86) while the mean pH of non-effervescent soils was significantly lower at 6.8 (n=150).

Mycorrhizae

The levels of mycorrhizae present on subsoil roots of sugar maples were all relatively low. Manganese means were similar for all mycorrhizal groups (Table 10).

Red maples had mycorrhizal infection levels from 0 to 45% (n=24). There were no significant correlations between percent of roots infected, or the density of infection, and foliar manganese.

Table 10. Relation of mycorrhizal infection to foliar manganese concentration in urban sugar maples sampled in the Great Lakes region during late summer 1982.

Mycorrhizal group	Ave. Foliar Mn Conc. in ppm	Number of samples
1	67	5
2	165	9
3	108	2
4	193	1

Soil oxidation - reduction potential

In 1982 seven trees were on soils classified as reduced, all these were chlorotic. Redox potentials measured in 1983 ranged from -182 mv to +413 mv (pe = -3.1 to 7.0). Healthy sugar maples were on soils with a mean pe of 3.1 , chlorotic trees had a significantly lower mean of 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 pe in both sugar and red maple (Table 9). Generally, as pe increased so did foliar Mn (Figures 25 and 26).

Precipitation

Precipitation varied from 200 to 302 cm per year for the 15 study areas. Total precipitation was not correlated with foliar Mn levels (Table 11). However, there was a strong correlation was with summer rain. Areas with low rainfall tended to have lower Mn concentrations (Figures 27 and 28).

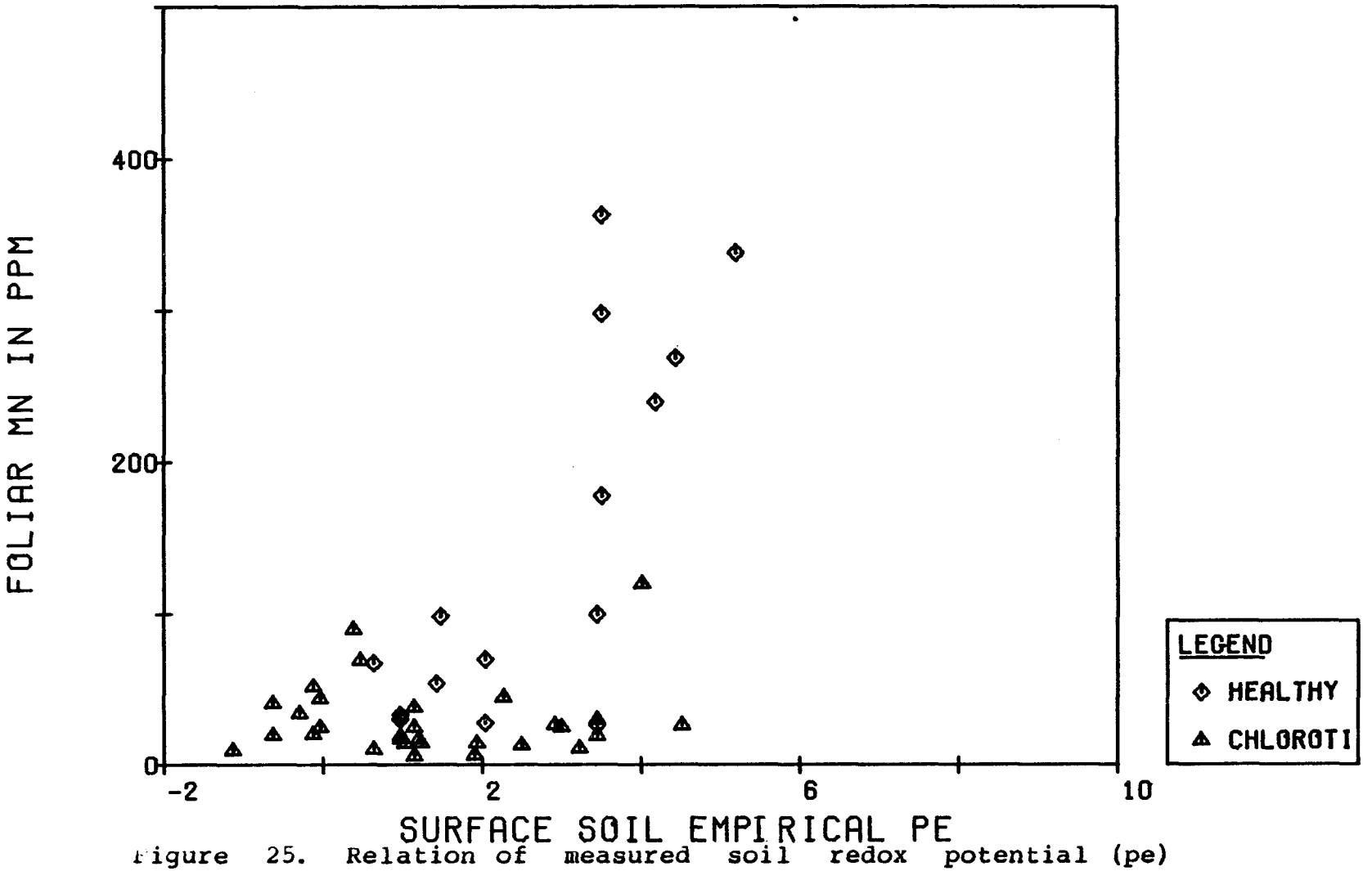


Figure 25. Relation of measured soil redox potential (pe) and foliar manganese in healthy and chlorotic urban sugar maples sampled in the Great Lakes region during late summer 1982 and 1983.

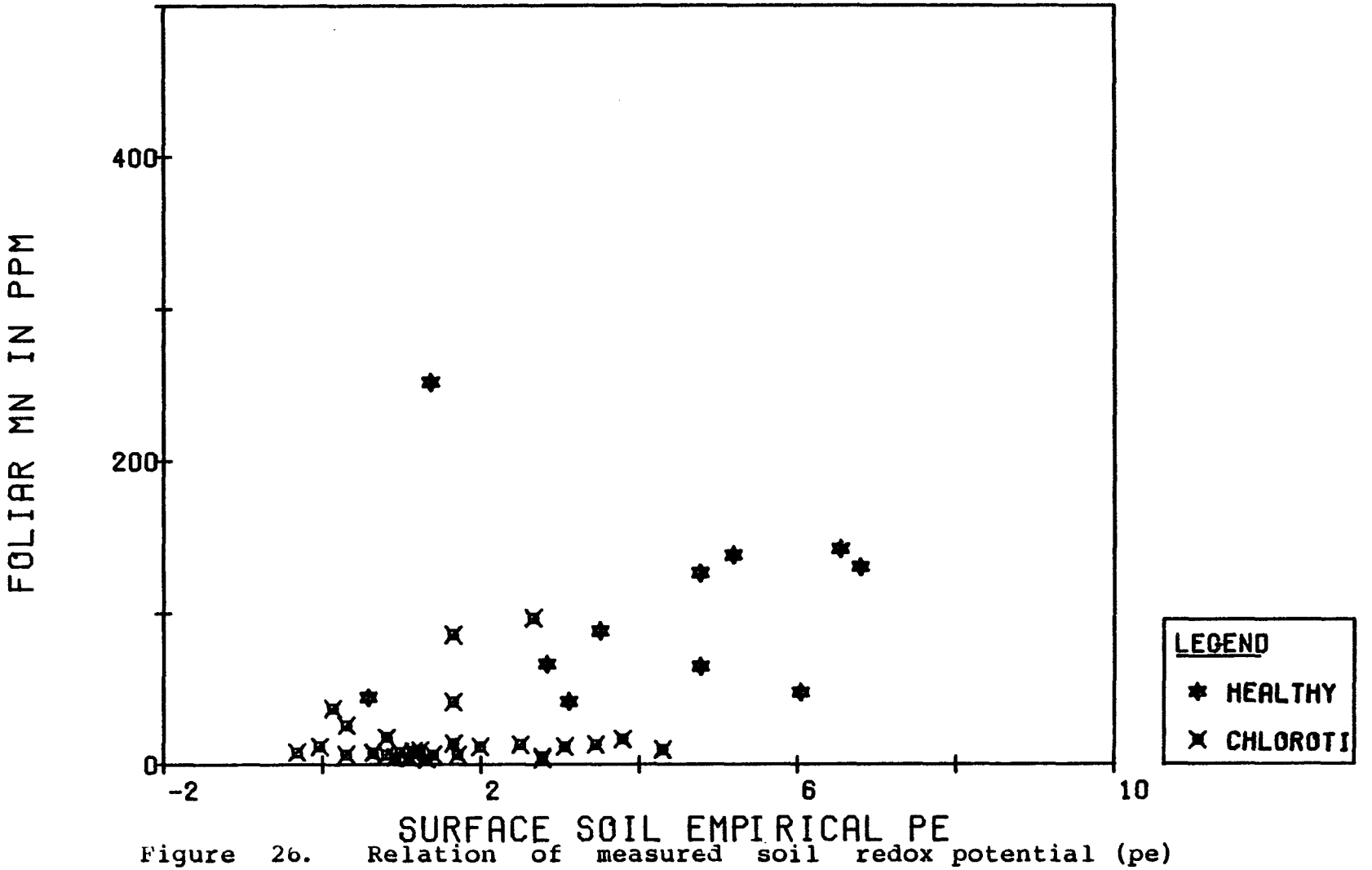


Figure 26. Relation of measured soil redox potential (pe) and foliar manganese in healthy and chlorotic urban red maples sampled in the Great Lakes region during late summer 1982 and 1983.

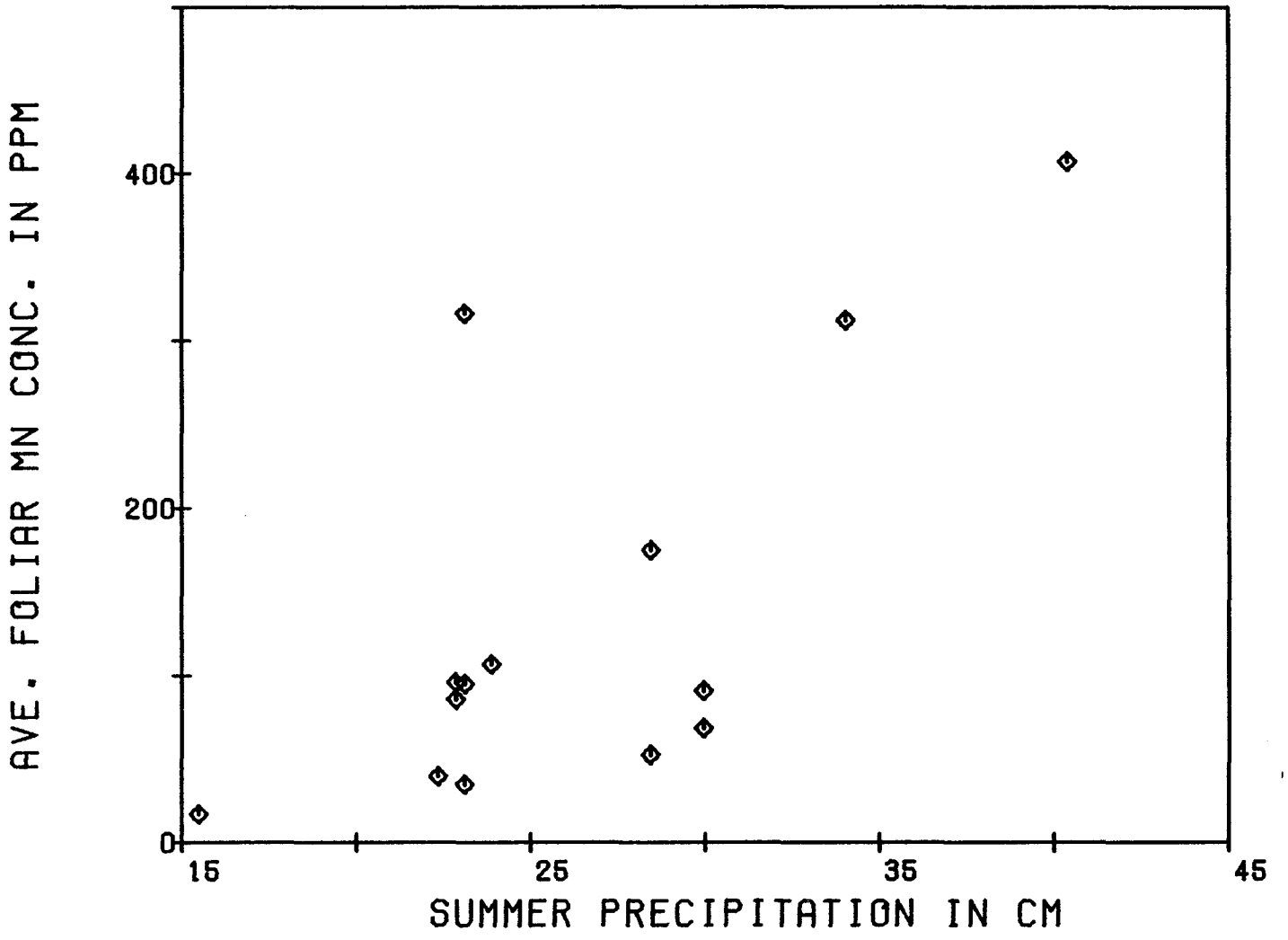


Figure 27. Relation of summer precipitation and average foliar manganese concentration of sugar maples in 12 cities sampled during late summer 1982 and 1983.

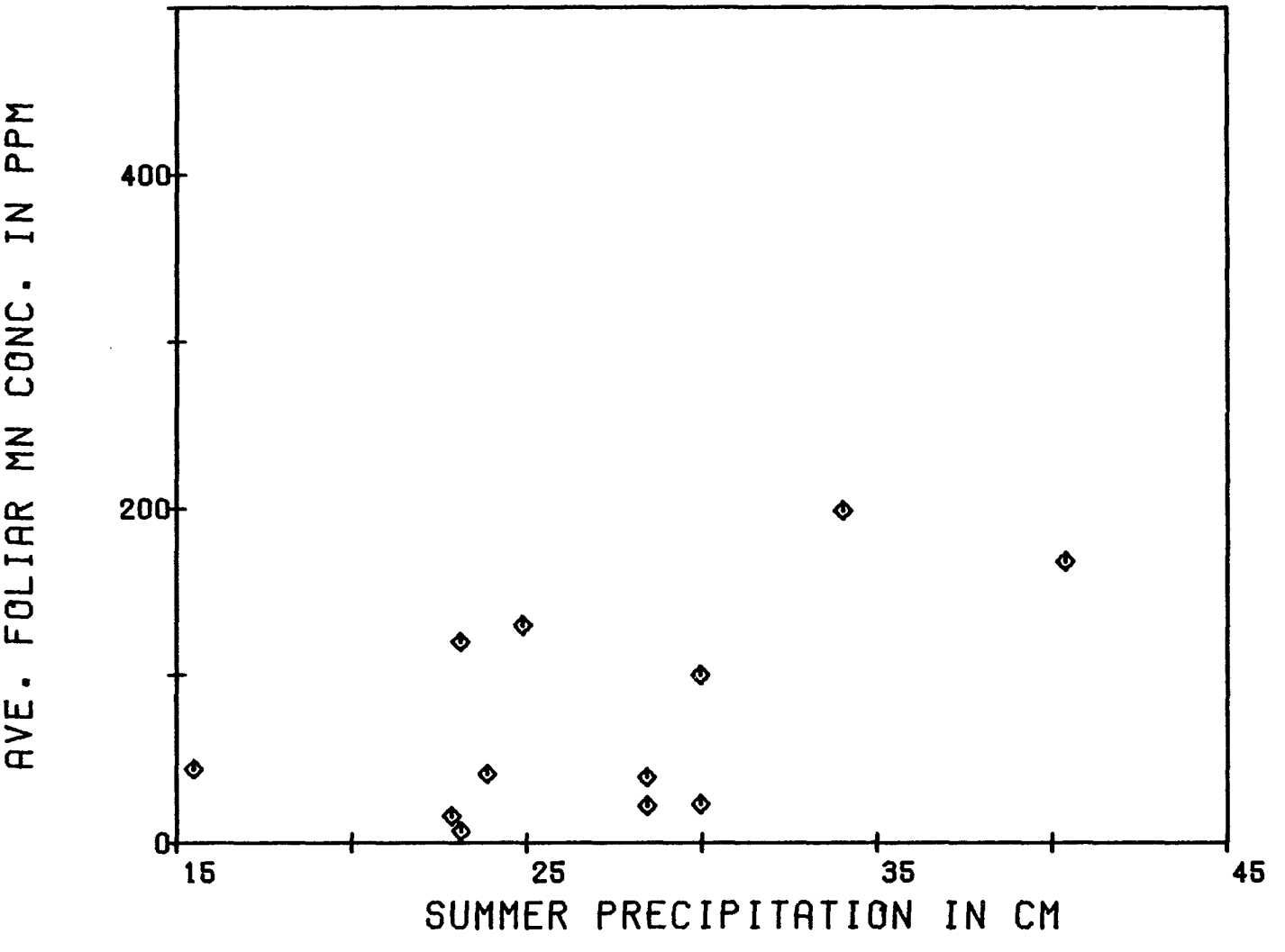


Figure 28. Relation of summer precipitation and average foliar manganese concentration of red maples in 11 cities sampled during late summer 1982 and 1983.

Table 11. Precipitation correlations with average foliar manganese concentrations of sugar and red maple.

Season	Sugar Maple Simple Corr.	r^2	Sig.*	Red Maple Simple corr.	r^2	Sig.
Fall	-.20	.04	NS	-.27	.08	NS
Winter	-.52	.27	S	-.38	.14	NS
Spring	-.22	.05	NS	-.23	.05	NS
Summer	.68	.47	HS	.58	.34	S
Total	.27	.07	NS	.25	.06	NS

* Statistical significance, NS = not significant, S = significant at $p<.05$, HS = highly significant at $p<.01$.

Soil pH

Surface pH was the soil variable most strongly correlated with foliar Mn (Table 9). With increasing pH, foliar Mn decreased. Chlorotic sugar maples had a mean pH of 7.15 (n=79) while healthy trees had a significantly lower mean of 6.66 (n=55). The majority of the chlorotic sugar maples grew on soils with pH greater than 6.8. Few sugar maples were chlorotic below 6.8 while some were healthy above (Figure 29).

Red maples had mean pH values of 7.04 and 6.08 (n=79,40) for chlorotic and healthy trees, respectively. The majority of the chlorotic red maples were on soils of pH 6.6 and above (Figure 30).

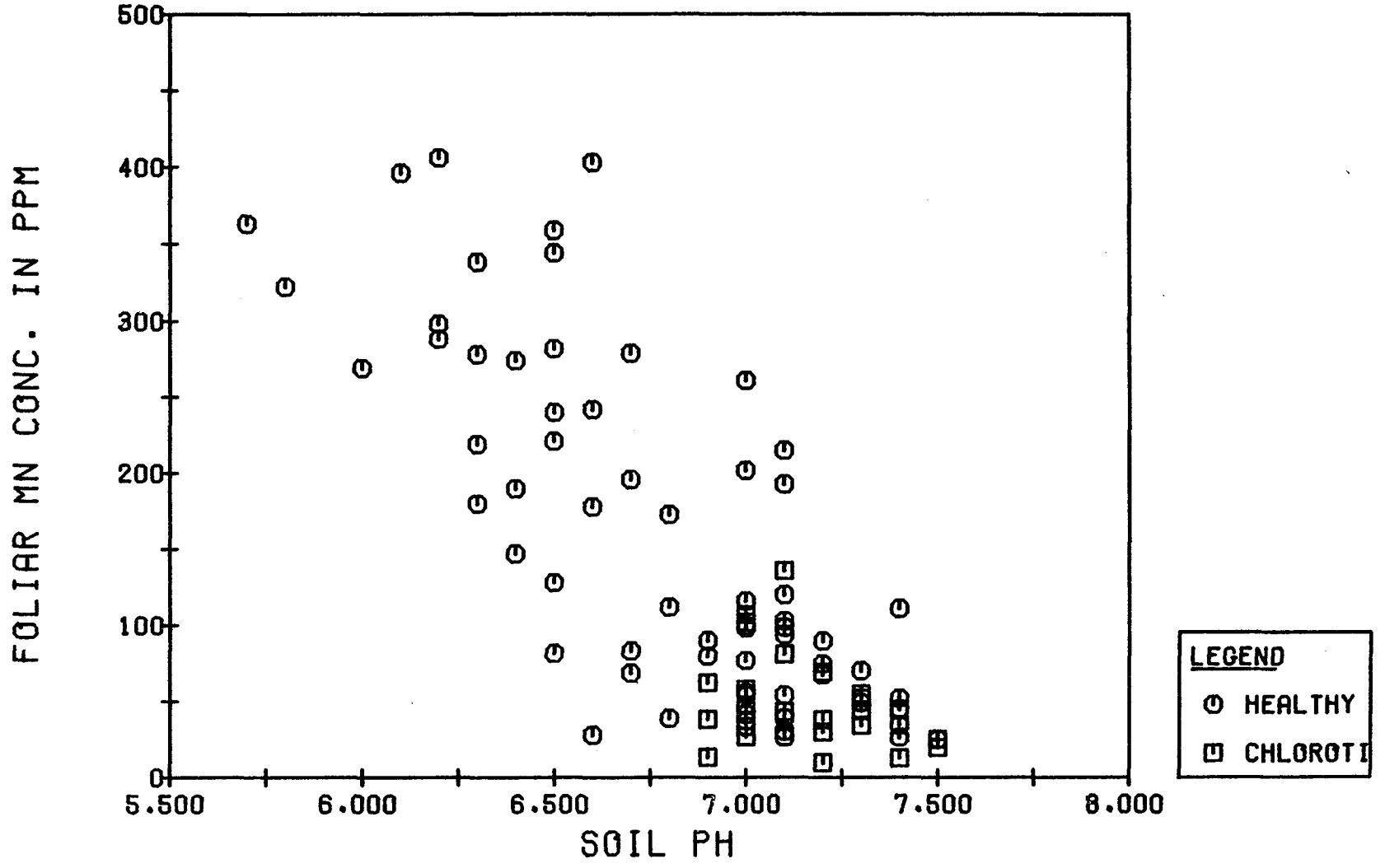


Figure 29. Relation of surface soil pH and foliar manganese concentration in healthy and chlorotic sugar maples sampled in the Great Lakes region during late summer 1982 and 1983.

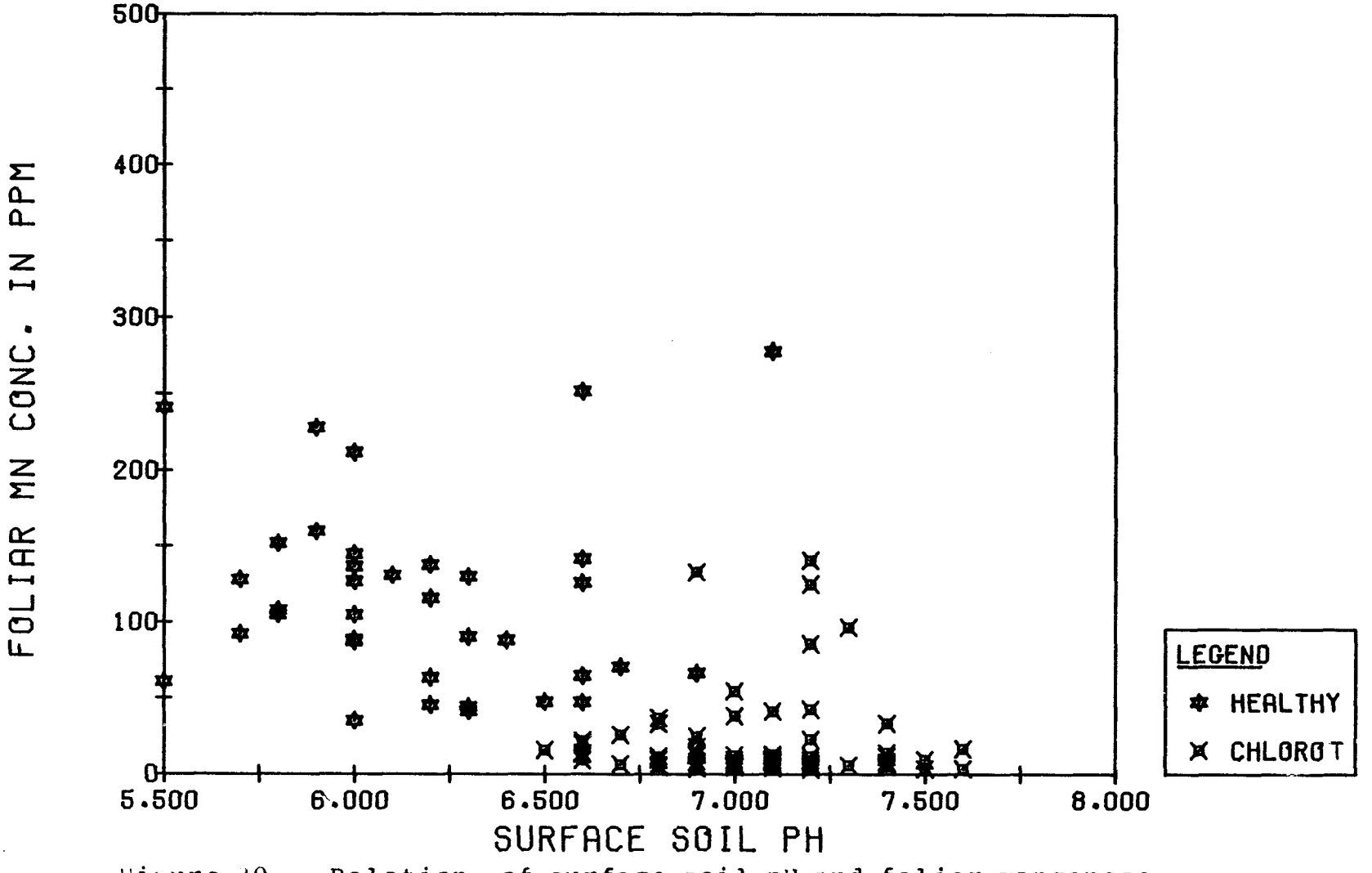


Figure 30. Relation of surface soil pH and foliar manganese concentration in healthy and chlorotic red maples sampled in the Great Lakes region during late summer 1982 and 1983.

Multivariate analyses

Discriminant functions based on soil pH could correctly classify healthy and chlorotic trees at least 74% of the time (Table 12). Accuracy of the separations were improved with the inclusion of redox and OM but not with other soil variables.

Table 12. Unstandardized canonical discriminant functions used to separate healthy and chlorotic urban trees sampled in late summer in the Great Lakes region.

Function*	% Correctly Classified
Sugar Maple	
19.5 = 2.8 pH	74
20.83 = 2.96 pH - .009 pe	80
17.84 = 2.73 pH - .098 pe - .22 OM	84
Red Maple	
19.6 = 2.9 pH	91
22.55 = 3.31 pH - .347 pe	95
24.06 = 3.44 pH - .348 pe + .15 OM	96

* pe equals soil redox potential in mv/59.2,
OM equals soil organic matter in percent air dry weight,
pH equals surface soil pH using 1:2 soil,water ratio

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 (OM2) + .1817 (Eh) - 1111

(n=48, r2=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. A more easily applied regression for sugar maples was:

Mn = -187 (pH) - 1468 (OM) + .19 (Eh) + 1486

(n=48, r2=66%).

For red maple the regression which best predicted foliar manganese was:

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

(n=118, r2=49%).

Discussion

Nutrients responsible for interveinal chlorosis

The nutrient associated with interveinal chlorosis of urban maples in the Great Lakes States has been identified numerous times (Kreag, 1939 and 1940, Kielbaso and Ottman, 1976, Smith and Mitchell, 1977). Uncertainty as to the causal element still exists in other areas of the United States (Morris and Swanson, 1980, Harrell et al., 1984, Hudler, 1984). Foliar analyses in this study showed that the only nutrient consistently in lower concentrations in chlorotic maples was manganese.

Symptoms were also associated with higher levels of nitrogen. This phenomenon has been reported in Ailanthus, Robinia, Fraxinus and other species with iron chlorosis (Iljin, 1951). There are at least two theories to explain the higher N concentration. In this study, chlorotic trees were more often found on high organic matter, high nitrogen soils. High soil N may result in higher foliar N.

Iljin (1951), found that high soluble nitrogen levels interfered with normal physiological activities within leaves, resulting in chlorosis. The concentrating of soluble nitrogen was due to the lack of normal feedback control of nitrate reduction, induced by the iron deficiency (Hewitt, 1970). The form of nitrogen present in maple leaves was not examined in this study. It is

possible that high levels of soluble N are responsible for symptom development.

Chlorotic sugar maples also had higher levels of copper. Copper and Mn are known to be antagonistic in plant systems (Mortvedt et al., 1972). This, coupled with a slight substitutability of Cu for Mn in glycolysis, may explain increased concentration (Mulder and Gerretsen, 1952). With less Mn available, more Cu is preferentially translocated to the leaf.

Calcium levels were higher in chlorotic sugar maples and may contribute to symptom severity. Calcium is known to be antagonistic to soil Mn uptake (Maas et al., 1969). High foliar Ca levels also inhibit Mn absorbtion in leaf cells (Kannan, 1969). High foliar Ca was related to high soil pH and soil effervescence.

The mean aluminum (Al) level in chlorotic red maples was significantly higher than in healthy trees. Typically, plants with Al toxicity also have higher levels of Mn and are on acid soils (Mortvedt et al., 1972, Chapman, 1965). Since these soils were not acidic, it was doubtful that Al toxicity was a primary cause of the chlorosis. Aluminum, like Na, may be less strongly excluded by weak or damaged root systems, thus may secondarily accumulate in weakened trees (Iljin, 1952, Wadleigh and Brown, 1952).

Chlorosis ratings

Chlorosis ratings reflected foliar manganese levels in maples. The logarithmic relation between Mn concentration and symptom intensity has previously been demonstrated (Farley and Draycott, 1973). It indicates that while only small amounts of Mn (<150 ppm) are required for leaf development, higher levels are well tolerated.

The regression which relates foliar Mn to chlorosis rating may be used to determine the point which separates healthy (CR <0.5) from chlorotic (CR >0.5) trees. For sugar maple the point was 106 ppm Mn and for red maples it was 69 ppm Mn. These numbers were substantially higher than the previously defined symptomatic deficiency points (SDP). This was due to the method by which the SDP was defined, using the low end of healthy tree values. While there is only one SDP for a given tree, the range for the population studied was 23 to over 100 ppm. No healthy trees were found with less than 23 ppm Mn and few chlorotic trees were found with above 106 ppm. In between these values, trees were either healthy or chlorotic. All sugar maples with less than 106 ppm Mn may be deficient, even if not symptomatic. The same may be true for red maples with less than 69 ppm Mn. To accurately define the optimum, or critical, concentration of Mn, controlled fertilizer-type experiments would have to be conducted.

Growth impacts

Manganese deficiency in most crops results in significant growth and yield losses (Ahmed and Twyman, 1953, Haas, 1932, Ohki et al., 1977). In maples, necrotic upper terminal leaves were associated with low levels of manganese. Depending on the severity of the deficiency, some or all of the leaves on the upper branches were lost due to the deficiency.

Lateral branches were longer and thicker in chlorotic sugar maples. Chlorotic red maples had shorter and thicker branches than healthy red maples. Chlorotic red maples also had smaller, lighter weight leaves. Increases in indoleacetic acid (IAA) activity (Taylor et al. 1968) coupled with Mn replacement by Fe or Mg in several nonspecific coenzyme reactions (Mulder and Gerretsen, 1952) may be responsible for the higher growth rate in sugar maple. Manganese concentrations were considerably less in red than in sugar maple. Therefore, severely affected trees did have reduced growth, while moderately affected trees had growth increases.

The long term effect on growth needs to be studied over a greater time period with planting and removal data, growth ring analysis, or height measurements. Until these studies are conducted, it is impossible to quantify the impact of varying degrees of deficiency on tree longevity and overall growth rates.

Factors responsible for manganese deficiency

Soil texture

The importance of soil texture in manganese deficiency has been demonstrated by many researchers (Jones, 1983, Rich, 1956, Reddy and Perkins, 1976, Teuscher, 1956). The reason that it was not prominent in this study, was the lack of diversity of texture at a given pH. More extensive sampling of soils of similar pH and differing textures may result in identification of preferred texture groups.

Soil organic matter

Soil organic matter concentrations range from .4 to 10% in temperate region mineral soils (Brady, 1974). The mean in humid, temperate areas is 4%. Urban soils in this study reflected this range with a higher mean of 5.6%.

Chlorotic maples were most often on soils with relatively high levels of OM. The presence of high OM levels have long been associated with Mn deficiency (Christensen et al., 1950, Clark, et al., 1957, Jones and Leeper, 1951, Rumple et al., 1967A and B). The most probable reason for this is the formation of less available organic - Mn complexes (Gerring et al., 1969, Hentze, 1957, McBride, 1982).

The level of soil OM at which Mn solubility was

greatly reduced varies with soil pH (Takkar, 1969). Takkar (1969) found available Mn was lowest at 4% or above for "neutral" (pH 7.5-8.0) and 2% or above for calcareous soils (pH 7.7-8.2). The majority of chlorotic maples in this study were on soils with OM levels over 5.5%. This should be considered prior to mulching. Soils originally of high pH and/or OM should not be mulched with readily available, neutral or basic organic materials since these materials may aggravate or create a chlorosis problem (Clark, et al., 1957). There should be no problem if the soil is acid and/or contains low levels of OM. Wood chip mulches slowly increase OM levels and decrease pH at a rate which tends not to increase chlorosis problems (Watson and Himelick, work in progress, Fraedrich and Ham, 1982).

Chlorosis and low foliar Mn levels were also found on several trees with low OM. Research has demonstrated that organics assist in maintaining Mn in an available form (Heintze and Mann, 1947, Shuman, 1979, Trocme et al., 1950). Organic matter levels may have been too low to provide sufficient Mn on these soils. Organic mulches would be highly recommended in cases of low OM .

The ideal soil organic matter level would provide advantageous amounts of complex formation, cation exchange, moisture retention, and mineralization of nutrients. For sugar maple, acceptable levels of foliar Mn were found in trees on soils with between 2 and 5.5%

OM. The range for red maple was between 3 and 5.5% OM. The higher the OM level, the lower the optimum pH.

Soil manganese

The correlation between soil Mn and foliar Mn was weak. There have been numerous studies on different methods of extracting soil Mn to improve correlation with plant uptake (Boken, 1958, Hammes and Berger, 1960, Hoff and Medersk, 1959, Randall, et al., 1976). The method used in this study was selected due to its success in northcentral soils (Randall et al., 1976, Salcedo and Warncke 1979, Salcedo et al., 1979, Whitney, 1980). Another method which should be tested is the use of a DPTA extractant. DPTA has been used successfully in calcareous, western soils (Curtin et al., 1980, Gough et al., 1980, Shuman et al., 1980, Viets and Lindsay, 1973). With more extensive testing, an appropriate method of predicting deficiency from soil tests should be achievable.

The lack of correlation between soil tests and foliar levels may also lead to the conclusion that the problem is not with the amount of Mn present, but with the availability for uptake (Page et al., 1962).

Soil nitrogen

The mean C:N ratio found in urban soils, 14:1, was somewhat higher than the more typical 10:1 or 12:1 found in agricultural soils (Brady, 1974). This indicates that

typical urban soils do not contain excessive levels of nitrogen. The negative correlation between soil N and foliar Mn may not be an antagonistic nutrient interaction but a reflection of the strong negative correlation between soil organic matter and foliar Mn.

Soil effervescence

Effervescence is an indication of calcium carbonate in the soil (USDA, 1975). Chlorotic trees were more often found on effervescent soils. 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 (Jones, 1957, McBride, 1979). There was not a one-to-one correlation between effervescence and chlorosis due to differences in pH, pe and OM (Christensen et al., 1950).

Mycorrhizae

The relation between mycorrhizae and foliar Mn was not significant. Mycorrhizal levels were low in all samples, probably due to disadvantageous soil conditions. Conditions found in urban soils which have a negative impact on mycorrhizae are high levels of phosphorus, high pH, (Ojala et al., 1983, Slankis, 1974) temperature extremes, high bulk density, and water content extremes (Craul, 1982).

Soil oxidation - reduction potential

Theoretically, redox potential should be one of the most important factors affecting uptake of manganese. This is due to the changes in solubility of Mn with redox changes (Lindsay, 1979).

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. Healthy trees were found in soils with relatively high potential. Evidently, either the measured redox potentials were not controlling the relevant solubility reactions (Quispel, 1947) or since low redox potentials resulted in more mobile Mn^{+2}, the total amount of Mn was lower due to leaching (Tiller, 1963). If total Mn was lower, this should have been obvious in the Mn extraction results, but it was not.

The value of redox potential measurements has long been questioned as they relate to specific oxidation-reduction reactions (Bohn, 1968 and 1969). It is generally accepted that data from redox measurements should be used qualitatively rather than quantitatively. Most research indicates that higher redox potentials are related to lower soil moisture levels (Copeland, 1957, McKeague, 1964, McKenzie et al., 1960, McKenzie and Erickson, 1954). Viewing these results in a soil moisture perspective, it can be seen that healthy trees were more often found on sites which were relatively well drained.

With borderline pH level (6.6-7.0), redox, thus drainage, was of great importance with red maple. The higher the potential, and thus the better the drainage, the greater chances of the tree being healthy. Sugar maple showed the same trend. However, pH was a more dominant factor.

Precipitation

Effects of precipitation on nutrient uptake have been demonstrated (Barrow et al., 1969, Brickelhaupt 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 was 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 high rainfall and well drained soils. For trees suffering from Mn deficiency, higher levels of moisture than normal are required due to

their inefficient utilization of water (Kozakiewicz and Ellis, 1967).

Soil pH

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. This was a stronger relation than that found by Rich (1956) in experiments with peanuts.

The importance of pH was confirmed with multiple linear regressions and discriminant analysis. Numerous soil variables were included in an attempt to find a regression which could predict foliar manganese levels. All of the 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 OM and higher redox.

The regression which related foliar manganese to pH was used to determine symptomatically high pH. Sugar maple on soils above 7.0 should exhibit symptoms and below 7.0 should not. For red maple the value was 6.1. The predicted symptomatic pH for sugar maple was one or two tenths of a pH unit higher than expected from examination of the data (Fig. 29). The red maple symptomatic point is

half a pH unit lower than expected (Fig. 30).

Reasons for the decrease in availability of Mn with increasing pH have been widely researched (Lindsay, 1979, McBride, 1982, Page, 1962 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 rhodocrosite is formed. Since all values of pe + pH in this study were below 15, manganese solubility should be mainly controlled by rhodocrosite and organic complexes (McBride, 1982, Schwab and Lindsay, 1983). With rhodocrosite, 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 rhodocrosite 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.

One practical application of this has been demonstrated by Hacskaylo and Struthers (1959) and Messenger (1984). Acid treatment of soil to reduce the pH did improve color in several treated oaks. Messenger (1984) reports treating red maples but does not present results of the treatment. A significant improvement should occur with acid treatment if soil OM is not reduced below the optimum level and if poor drainage has not caused injury to the roots or prevented nutrient flow to the roots.

Why is manganese deficiency common in urban areas?

There are at least two situations in which red maples prosper (Fowells, 1965, Teuscher, 1956). First, on floodplains where trees are usually in neutral to acid pH soils with strong reducing potentials (low pe values) due to high watertable (DuLaune et al., 1983, Gotoh and Patrick, 1972). Reduced Mn^{+2} is readily available so the tree does not suffer from deficiency despite extreme organic matter levels and neutral pH values.

The second case is moderately well-drained, moist forest sites. Typically, these sites have acidic to slightly acidic surface soils of moderate redox potentials. Surface soil pH values would be low enough that manganese unavailability was not a problem.

Sugar maple evolved, or adapted to, a wide variety of medium textured, high fertility, moist and well drained soils (Fowells, 1965). Optimum pH was reported to be between 5.5 and 7.3 (Fowells, 1965, Spurway, 1941). The naturally preferred soils are therefore, of low to medium pH, high pe, moderate OM.

Manganese deficient urban sites were typified by high pH, moderately low redox and intermediate to high OM levels. Manganese was not readily available since the neutral pH decreased Mn activity, redox was not low enough to reduce Mn, and considerable amounts of Mn were organically complexed.

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 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 growth of other species.

Management recommendations

To manage chlorosis problems, soil pH, OM and moisture should all be considered. The most important of these is soil pH. Sugar maples growing in soils with pH values greater than 6.8 to 7.0 will generally have symptoms. Red maples in soils with pH over 6.1 to 6.6 should also exhibit symptoms.

The simplest means of preventing the problem is to perform soil tests for pH prior to planting. If the pH is above the symptomatic level, maples should not be planted. This would be the most economical evaluation and decision process for the planting of street trees. If the pH is

near the symptomatic level, further testing is advised if maples are highly desired. If the soil has either high (>5.5%) or, very low (<3%) OM, or if the soil is poorly drained, planting should be avoided.

Actions may be taken prior to construction or planting to improve soil quality. Again pH, OM and soil moisture should be considered. If the natural profile and drainage patterns can be maintained, problems should not be severe. If profile is to be altered and soil imported, it should be similar in texture, low pH (<6), and medium OM (3-5.5%). A drainage system should be installed if there will be discontinuities in soil texture, or if the area is poorly drained. Well drained soils in low moisture areas will require irrigation.

If trees are established and exhibiting symptoms, treatments which reduce soil pH should be useful. Levels of soil organic matter should be considered before mulching or other treatments. Organic matter levels between 3 and 5.5% favor manganese uptake in maples. The higher the OM level, the lower the optimum pH. Established trees in soils with low OM levels (0-3%) will be aided by the incorporation of organic matter into the soil. Soils with high levels (>5.5%) should be sparingly mulched with an acidic form of slowly available organic matter, especially if the pH is borderline (6-7). If trees have been planted in a poorly drained soil, runoff from hardened surfaces adjacent to trees should be directed

away and excessive watering should be avoided. Trees in well drained soils or areas of low rainfall may need additional water.

Since it is unlikely that the recommendations on avoidance of the problem will be followed by numerous people who install maples in urban areas, there is a need for more research.

Research needs

Additional applied research is required to find long term, low cost answers to the manganese deficiency problem, which require little or no knowledge of landscape installation or maintenance.

The ideal solution is to identify naturally existing varieties of maples which tolerate adverse soil conditions. These varieties should be marketed in areas with poor urban soils. A project with this goal has been started at the Morton Arboretum. They are attempting to identify varieties of sugar and black maple native to calcareous soils which are not Mn deficient.

If improved varieties cannot be found, current varieties may be improved. This improvement could take the form of improved rootstocks grafted to sugar and red maple scions. Grafting red maple to silver maple roots has shown promise (Teuscher, 1956). Mycorrhizae should also be given more consideration. Although this study failed to reveal significant differences related to

mycorrhizae, there was a slight correlation which may indicate potential for improvement. A search of maples in alkaline soils may result in discovery of mycorrhizal species which could be inoculated on maples prior to leaving the nursery.

Soil treatments which enhance root growth or improve soil chemical factors should also be tested. Efforts may be diredted toward various mulch treatments, mulch followed by fertilization with manganese, or the incorperation of nutrient reservoirs in the soil next to affected trees. Experiments will also be required to define the maximum safe level of OM which can be applied to maples at given pH levels.

At a more basic level, more research is needed to determine the interrelation in leaves between Mn, N, Al, Cu and deficiency symptoms. We need to know if symptoms are due to a shortage of Mn, or toxicity of soluble N or other nutrient. This would help explain why foliar sprays and some implants are not always effective. The question of cuticular thickness as it relates to Mn also needs study. The answer may explain the lack of efficient water use in Mn deficient plants, necrosis of upper leaves, and the vertical differences in symptoms observed in maples. Finding the soil test procedure which can correctly predict foliar Mn levels would be useful and should not be difficult. Once relations are established, soil testing for Mn may more accurately predict deficiencies.

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