Foliar Chlorosis in Field-Grown Red Maples

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Abstract. Franksred red maple (*Acer rubrum* 'Franksred') trees were sampled from nursery fields in 2003 and 2004 to determine the cause of a common foliar chlorosis. Plots in 21 and 39 different nurseries were identified in 2003 and 2004, respectively. A single plot from each nursery was sampled in June of each year, whereas two to four plots per nursery were sampled in September. Each plot consisted of 20 consecutive trees in a single row. From each plot, a foliar tissue sample was analyzed for the complete range of essential nutrients. Plant height, stem diameter, leaf chlorophyll content, and a subjective plant quality rating were also recorded. From each plot, a soil sample was collected and analyzed for pH, EC, organic matter, and a range of essential nutrients. The foliar chlorosis was determined to be incited by manganese (Mn) deficiency. Tissue Mn was highly correlated with soil pH. Chlorotic plants were smaller with less stem diameter than nonchlorotic plants. Sufficiency ranges for tissue and soil tests were determined and are provided for red maple nursery production.

Field-grown red maple (*Acer rubrum* L.) often develops foliar chlorosis during mid to late summer. Although this problem is particularly common in the Pacific Northwest, it has also been observed in nursery production in other parts of the country (personal observation). The condition can be characterized initially as mild interveinal chlorosis in expanding foliage. As symptoms intensify, entire leaves turn chlorotic accompanied with interveinal necrosis. The problem has most often been associated with manganese (Mn) deficiency. Manganese deficiency has been documented in Mn-sensitive plants growing in mildly acid to alkaline soils. Oregon soils in the nursery producing region (North Willamette Valley) typically have low soil pH (<5.5). Nonetheless, many nursery growers and crop consultants have diagnosed Mn deficiency with foliar tissue tests. This condition in nursery production has never been thoroughly studied.

Chlorosis in red maples incited by Mn deficiency has been documented in urban landscapes. Teuscher (1956) first described maple chlorosis in a trade publication. He indicated the chlorosis was incited by planting in heavy alkaline soils and generically suggested that the condition could be remedied by amending the soil with a conditioner and fertilizing with NH_4SO_4 . Smith (1976) later stated that the problem in nursery and landscape situations is likely Mn deficiency and offered that foliar sprays of $\text{Mn}(\text{SO}_4)_2$ are effective for alleviating symptoms. Foliar sprays of $\text{Mn}(\text{SO}_4)_2$ and Mn chelate in

Oregon are often ineffective (personal observation). Smiley et al. (1985) documented Mn and nitrogen (N) deficiency in urban red maples throughout the Great Lakes region. He attributed low Mn levels in urban red maples to high soil pH and high organic matter levels. Later, a related study by the same primary author reported that of all soil factors measured, Mn deficiency in red maple foliage was most highly correlated to soil pH. Furthermore, among trees observed, most chlorotic maples were planted in soil with pH greater than 6.6 (Smiley et al., 1986). This same study reported that foliar Mn could best be described as a function of soil pH and organic matter ($n = 118$, $r^2 = 0.49$). Greenhouse research in sand culture by Boyce and Sydnor (1983) seems to contradict the landscape research by Smiley et al. (1986), because they showed franksred red maple new stem growth increased with increasing pH from 5.5 to 7.5. However, oxidation of plant available Mn^{2+} to unavailable forms of Mn (III) and Mn (IV) is regulated primarily by pH-dependent soil microorganisms (Russell, 1988). It is unlikely that Mn availability is affected in sterile sand culture with no organic matter the same way it is in biologically active landscape soils. Overall, the literature suggests that chlorosis symptoms in red maples is primarily a pH-induced Mn deficiency, as observed by local nurseries. However, the literature does not offer specific guidelines for growing red maples in a production environment, specifically production of bare-root red maple whips (lightly branched trees 2 to 2.5 m tall).

Production of bare-root red maple whips is uniform across the majority of nurseries in Oregon. Small plants from either tissue culture or rooted cuttings are planted and allowed to grow freely in year 0 (no pruning or training). In late winter just before year 1

(usually February), trees are coppiced nearly to soil level. Multiple adventitious buds emerge from the remaining stub in early spring, from which one is selected and trained up a stake to develop a single leader whip with light branching. Trees are dug and sold both at the end of year 1 and some are kept and grown for a third year (year 2) into larger trees with more branching. These trees are generally grown in rows that are 1.2 to 1.5 m apart and spaced 0.3 m within the row.

The objective of this research was to identify the cause of chlorosis in franksred red maple trees throughout year 1 and 2 of production, and to develop minimum and maximum values for soil and tissue nutrient parameters that would lead to high-quality red maple trees.

Materials and Methods

2003. On 12 June 2003, plots were delineated in fields with franksred red maple (*Acer rubrum*) in 21 nurseries throughout the north Willamette Valley in Oregon. Soil types for each field varied but could be generalized as silt loam soils with little or no slope. Nurseries were selected based on their willingness to participate. All fields contained trees that were planted in 2002 and were in year 1 of production at the time of sampling. Each plot consisted of 20 consecutive trees within a single row (Ellis, 1975). A single plot was randomly selected in each field, avoiding only the borders of the field. From each plot, two to three recently matured leaves from each tree were pooled for a single foliar tissue sample (Mills and Jones, 1996). A soil sample was taken by collecting ≈ 12 soil cores to a depth of 15 cm within the root zone (≈ 30 cm on either side of the tree row) of the 20 trees. Tissue and soil samples were analyzed for nutrients listed in Tables 1 and 2, respectively. Trees were individually measured for height, stem diameter, chlorophyll content using a SPAD 502 Chlorophyll Meter (Minolta Camera Co., Ramsey, N.J.), and plant quality on a scale from 1 to 10 where 1 is a chlorotic tree of poor quality and 10 is a vigorous tree with dark green foliar color. Plant quality ratings were assigned solely by the author.

On 6 Sept., the same data were collected from the same plots. In addition, two or three additional plots per nursery were surveyed so that a total of 71 plots were sampled. Many fields contained regions with chlorotic plants and other regions with nonchlorotic plants. When possible, separate plots were established in chlorotic and nonchlorotic regions of the same field.

2004. Similar methods were used throughout 2004 with the following exceptions. Thirty-nine plots were delineated on 22 June 2004. Among those, 16 plots contained trees in year 1 of production, whereas the remaining 23 plots contained trees in year 2. On 9 Sept., additional plots were again identified in each field so that a total of 90 were sampled (32 year 1 and 58 year 2 trees).

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Table 1. Soil variables that explain foliar Mn in field-grown franksred red maple (*Acer rubrum*) tissue as determined by the stepwise selection process.

Samples collected, June 2003			Samples collected, Sept. 2003		
Parameter	Partial r ²	P value	Parameter	Partial r ²	P value
pH	0.702	<.0001	pH	0.5181	<0.0001
Soil Mg	0.068	0.0284	Soil K	0.0804	0.0006
Soil B	0.043	0.0575	Bases	0.0464	0.0193
Soil K	0.036	0.0597	Organic matter	0.0385	0.0403
Soil NH ₄	0.019	0.1494	Soil Zn	0.0303	0.0499
Cumulative r ²	0.868		Soil Mg	0.0189	0.0692
			Soil Fe	0.0161	0.1012
			Soil S	0.0128	0.1267
			Cumulative r ²	0.7573	
Samples collected, June 2004			Samples collected, Sept. 2004		
pH	0.5643	<.0001	pH	0.2685	<0.0001
Soil K	0.0455	0.0478	Soil P	0.0597	0.0067
Soil Mg	0.0247	0.1335	Soil S	0.0586	0.0052
Cumulative r ²	0.6344		Cumulative r ²	0.3868	

All soil and plant analyses were done according to methods described by Gavlak et al. (2003). Soil pH and EC (electroconductivity) were measured with a 1:2 soil to water ratio. Soil phosphorus (P) was measured colorimetrically by Bray P1. Soil NH₄ and NO₃ were determined colorimetrically with KCl and Ca(SO₄)₂ extractants, respectively. Soil calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) were extracted with ammonium acetate (CH₃COONH₄) and measured by atomic absorption and emission. Soil zinc (Zn), manganese (Mn), iron (Fe), copper (Cu), sulfur (S), and boron (B) were extracted with diethylenetriaminepentaacetate (DTPA) sorbitol and analyzed by inductively coupled plasma emission spectrometry (ICP). Soil organic matter was determined by Walkley-Black and a colorimetric determination. Plant total N was determined with an Elemental Rapid-N Total Nitrogen Analyzer (Analysensysteme GmbH, Hanau, Germany). Plant P, K, Ca, Mg, S, Mn, Fe, B, Cu, and Zn were analyzed by a wet ash digest and ICP.

Relationships between all variables were observed using scatterplot matrices. Data were analyzed with multiple regression and the stepwise selection process to develop models using the general linear model procedure in SAS (SAS Institute, Inc., Cary, N.C.). Trees were grouped according to their plant quality ratings as having a high rating (≥ 9) or low rating (≤ 8), and these two groups were compared for height and stem diameter using *t* tests. Assigning a high rating to trees with plant quality ratings ≥ 9 was decided

arbitrarily by the author based on his observations in the fields. The same guideline was used to calculate minimum and maximum tissue and soil test guidelines for high-quality franksred red maples in Tables 4 and 5.

Results

When samples were collected in June 2003, all trees appeared vigorous with dark green foliage and had plant quality ratings of nine or higher. Despite excellent foliar color, trees differed greatly in levels of foliar Mn, from 10 to 535 ppm. A stepwise selection process revealed that soil pH was the most influential factor on foliar Mn (Table 1). Soil pH accounted for 70% of the observed variability in foliar Mn, whereas other significant factors explained relatively little variation. Scatterplot matrices revealed identifiable patterns in the relationships among foliar Mn, soil Mn, and soil pH. Equations were fit for each relationship (Table 2). Foliar Mn had a linear relationship with soil Mn. There was a strong exponential relationship between foliar Mn and soil pH as well as soil Mn and soil pH. Smiley et al. (1986) reported that the logarithm of foliar Mn in urban red maple could be described as a function of pH and organic matter. Our results reported in Table 2 are similar in that our exponential equations are simply the inverse of logarithmic equations as presented by Smiley et al. (1986).

By Sept. 2003, trees at some nurseries appeared healthy, whereas others were chlorotic and stunted. There was a polynomial

relationship between plant quality ratings and foliar Mn (Fig. 1). Plant quality increased as foliar Mn increased up to ≈ 110 ppm Mn and then decreased. More interesting was the relationship between plant quality ratings in September and foliar Mn levels the preceding June (Fig. 2). September plant quality ratings increased as June foliar Mn levels increased up to 200 ppm. Above 300 ppm foliar Mn, plant quality began to decrease, indicating a toxic relationship from excessive Mn. There was no relationship between June plant quality and June foliar Mn, primarily because all trees appeared healthy with dark green foliage despite variation in foliar Mn. These data suggest that Mn deficiency occurs early in the growing season, although visual deficiency symptoms do not occur until later in the summer. Furthermore, it indicates that early-season Mn deficiency can be detected through foliar analyses long before visual symptoms manifest. SPAD readings were not correlated to plant quality ratings and were not useful in discriminating between healthy and chlorotic trees. Interveneal chlorosis incited by Mn deficiency causes green and yellow regions on the leaf, making SPAD readings erratic even with high sample numbers (30) per leaf. SPAD meters would not be a useful tool in managing chlorosis incited by Mn deficiency.

Similar to samples collected in June, variation in foliar Mn in September was primarily explained by soil pH with several other factors identified by the stepwise selection process as significant ($P \leq 0.15$) but explaining relatively little variation (Table 1). Foliar Mn again showed a linear relationship with soil Mn and an exponential relationship to pH (Table 2).

Samples were collected in 2004 from trees in year 1 and 2 of production. Unlike 2003, plant quality ratings of trees in June ranged from poor to excellent. Plant quality was again a function of foliar Mn, indicating a Mn deficiency. The relationship between plant quality ratings and foliar Mn was similar for both year 1 and year 2 trees (Fig. 3). Year of production was not a significant factor in the models generated. This suggests that franksred red maples respond similarly to soil pH conditions in both years of production, which confirms observations by growers and the author. Samples collected in June again showed that foliar Mn was primarily dependent on soil pH. Relationships between foliar Mn, soil Mn, and soil pH were similar to those observed in 2003 (Table 2).

Samples collected in Sept. 2004 resulted in models with less precision. Soil pH still explained most of the variation in foliar Mn, although the partial r² for these samples was low (0.2685; Table 1). Similarly, the relationship between foliar Mn and soil Mn or soil pH was significant but with lower r² values (Table 2).

Neither tree height nor stem diameter was correlated to any of the soil or tissue parameters measured. However, with the exception of year 1 trees in 2004, trees with high plant quality ratings (≥ 9) had greater

Table 2. Relationship among foliar Mn (f), soil Mn (s), and soil pH (p) in tissue and soil samples from field-grown franksred red maple (*Acer rubrum*).

Relationship	Year	Month	Equation	r ²
Foliar Mn and soil Mn	2003	June	$f = 6.00s - 19.34$	0.578
		Sept.	$f = 4.38s + 13.44$	0.453
	2004	June	$f = 5.22s - 8.37$	0.604
		Sept.	$f = 1.80s + 16.39$	0.181
Foliar Mn and soil pH	2003	June	$f = 464167e^{-1.49p}$	0.725
		Sept.	$f = 262708e^{-1.52p}$	0.475
	2004	June	$f = 130496e^{-1.42p}$	0.566
		Sept.	$f = 2435e^{-0.72p}$	0.221
Soil Mn and soil pH	2003	June	$s = 824e^{-0.604p}$	0.450
		Sept.	$s = 944e^{-0.729p}$	0.521
	2004	June	$s = 1201e^{-0.790p}$	0.674
		Sept.	$s = 801e^{-0.615p}$	0.516

Table 3. Stem diameter (cm) and height (cm) of franksred red maple (*Acer rubrum*) trees receiving high-plant quality ratings (≥ 9) and low plant quality ratings (≤ 8).

	2003				2004							
	Year 1 trees ²				Year 1 trees				Year 2 trees			
	June		September		June		September		June		September	
Foliar color rating	Stem diam.	Height	Stem diam.	Height	Stem diam.	Height	Stem diam.	Height	Stem diam.	Height	Stem diam.	Height
Low rating (≤ 8)	0.56 b ³	56.5 b	1.36 b	173.9 b	0.87 a	96.6 a	1.40 b	192.9 b	1.86 b	249.6 b	2.38 b	276.4 b
High rating (≥ 9)	0.81 a	85.7 a	1.53 a	199.4 a	0.88 a	96.1 a	1.63 a	223.6 a	2.32 a	283.4 a	2.71 a	327.2 a

²Year 1 and year 2 trees are trees that are in their first and second year of shot growth after copicing, respectively.

³Means within the same column with different letters are significantly different according to Fisher protected least significant difference test ($\alpha = 0.05$).

Table 4. Nutrient ranges in tissue analysis of high-quality franksred red maple (*Acer rubrum*).

Nutrient	Units	Minimum	Maximum
Nitrogen	%	2.8	3.1
Phosphorus	%	0.28	0.38
Potassium	%	0.9	1.1
Calcium	%	0.45	0.65
Magnesium	%	0.15	0.20
Sulfur	%	0.18	0.22
Iron	ppm	120	250
Manganese	ppm	50	120
Zinc	ppm	45	56
Copper	ppm	6	8
Boron	ppm	13	19

Table 5. Soil chemical properties of fields with high-quality franksred red maple (*Acer rubrum*).

Nutrient	Units	Minimum	Maximum
pH		5.0	5.8
SMP pH		6.0	6.4
Organic matter	%	3.0	4.4
Phosphorus	ppm	50	100
Potassium	ppm	160	220
Calcium	meq	6	10
Magnesium	meq	1.0	1.6
Sulfur	ppm	9	18
Iron	ppm	50	120
Manganese	ppm	20	40
Zinc	ppm	1.8	2.7
Boron	ppm	0.2	0.3
Copper	ppm	1.0	2.1
Soluble salts	mmhos	0.2	0.9

height and stem diameter than trees with low plant quality ratings (≤ 8) (Table 3). This indicates that Mn deficiency will affect growth of franksred red maple trees.

Discussion

Throughout the study, soil Mn was not selected as a variable in the stepwise selection process. Table 2 demonstrates a strong relationship between soil Mn and pH, indicating that either is correlated to tissue Mn or tree health. That is, pH and soil Mn explain the same information so that adding soil Mn into the model would not have improved it and thus the stepwise process would have dropped the term. Smiley et al. (1986) reported that urban red maples in soils with greater than 70 ppm soil Mn were healthy. Soils Mn levels in our study were far lower than this averaging only 22 ppm ($\mu = 22$, $\sigma = 17.1$); thus, the rule of thumb by Smiley would have little relevance in Oregon nursery production. Soil Mn may be informative within a soil type, but tissue Mn will be indicative of plant health anywhere.

Fig. 1. Relationship between franksred red maple (*Acer rubrum*) foliar manganese (Mn) and plant quality ratings (where 1 = low quality with chlorotic foliage and 10 = high-quality tree with dark green foliar color) in Sept. 2003.

Contrary to observations by Smiley et al. (1986) in landscape trees, our data indicate soil organic matter is not related to foliar Mn in nursery production. Organic matter was only identified by stepwise selection in Sept. 2003, and even then it explains relatively little of the total variation in foliar Mn. However, soil organic matter levels in this study ranged from 1.0% to 4.1%, whereas those in the Smiley study ranged from 3.0% to 9.9%. The authors in the Smiley study reported that high organic matter ($>5.5\%$) was associated with increased chlorosis. The wider range of organic matter levels in the Smiley study probably explains why they found this variable to be significant. Christensen et al. (1950) reported that soil organic matter has relatively little influence on available Mn compared with soil pH. Their research demonstrated that decomposition state, rather than the level of stable organic matter, increases levels of available Mn. Furthermore, they demonstrated this effect is short-lived in neutral and alkaline soils.

Tables 4 and 5 list minimum and maximum levels of tissue and soil parameters measured, respectively. The intent is that they be used as sufficiency ranges for field production of red maples. These values differ from those suggested by Smiley et al. (1986) for urban red maples. Smiley used the mean and the mean plus one standard deviation as the minimum and maximum values, respectively. Assuming data were normally distributed, their minimum and maximum values would have been between the 50th and 68th percentiles of healthy trees according to the Empirical Rule (Freund

and Wilson, 1997). This differs slightly from our approach, in which we used the 25th and 75th percentiles of healthy trees to determine minimum and maximum values. For red maple, Smiley et al. (1986) recommend 138 to 233 ppm foliar Mn as ideal, whereas our data indicate 50 to 120 ppm. Differences in the recommended range cannot be explained solely by the different algorithms used to generate them but might be partly explained by the relative age and size of trees studied. Trees in our study had between 0.5 and 2.7 cm stem diameter, whereas those in the Smiley study were established landscape specimens with 5 to 30 cm stem diameter. Established landscape and forest trees grow slowly at a rate of 0.3 to 0.6 m/year (Dirr, 1998), whereas trees in this study grew up to 2.2 m in a single year. Aggressive growth rates, higher plant densities, and smaller root systems with access to correspondingly smaller soil volumes in nursery production may result in Mn dilution within the root zone compared with landscape trees.

Foliar Mn sprays are the most common remedy used by nursery growers to cure the chlorosis problem in field-grown red maples. However, the general opinion of nursery growers is that these sprays are time-consuming and largely ineffective (personal communication), a sentiment echoed by Kielbaso and Ottman (1976). Mn is not mobile in plants, so applying Mn to foliage only temporarily affects those parts of the plant sprayed. Repeated sprays can be made to continuously supply Mn to new growth. However, Mn that is only supplied to plant

Fig. 2. Relationship between franksred red maple (*Acer rubrum*) foliar manganese (Mn) samples collected June 2003 and subsequent plant quality ratings (where 1 = low quality with chlorotic foliage and 10 = high-quality tree with dark green foliar color) recorded in Sept. 2003.

Fig. 3. Relationship between franksred red maple (*Acer rubrum*) foliar manganese (Mn) and plant quality ratings (where 1 = low quality with chlorotic foliage and 10 = high-quality tree with dark green foliar color) in year 1 and year 2 trees.

foliage will not be translocated from the foliage; thus, plant roots will be Mn-deficient despite sprays that “green up” foliage. Brown et al. (1997) found that wheat (*Triticum aestivum*) treated with foliar Mn was relieved of chlorosis symptoms; however, wheat grown in soils amended with MnSO_4 had higher yields, indicating that Mn must also be made available to plant roots. The most effective way to do this is to either plant red maples in soils with sufficiently low pH and extractable Mn levels or amend the soil.

Smiley et al. (1986) indicated that inversion of soil layers in the Great Lakes region is likely responsible for alkaline soils and the resulting Mn deficiency in red

maples. Messenger (1986) attributed Mn deficiency in urban white oak (*Quercus alba*) to alkaline runoff from parking lots. Higher-than-desirable pH in Oregon field soils, however, is likely the result of repeated or overapplications of lime. Nursery growers routinely make lime applications. Repeated lime applications have raised soil pH in Willamette Valley soils over many years of production from levels near 5 to greater than 6. Most notable in Table 4 is that pH recommendations for red maple is between 5.0 and 5.6. This range is generally lower than most nursery growers consider ideal.

The best management practice for preventing Mn-induced maple chlorosis is to

collect soil samples, measure soil pH, and then avoid planting red maples in fields with pH greater than 5.6. When all planting sites have high soil pH, amending the soil with S to lower pH and adding MnSO_4 to increase available Mn is recommended. Regionally specific lime, S, and Mn rates can be obtained from local agriculture extension offices. Management of Mn deficiency must occur before planting. Postplant remedies are less effective.

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