DECLINED URBAN SUGAR MAPLES: GROWTH PATTERNS, NUTRITIONAL STATUS AND SITE FACTORS[1]

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Abstract. Adverse soil conditions are suspected as potential causes of declined sugar maples (*Acer saccharum*). Poor availability or imbalances of nutrients, possibly in conjunction with unfavorable physical conditions, are likely causes of poor crown condition and dieback associated with urban sugar maples. This study examined soil and foliar nutrient status in relation to the urban sugar maple growth pattern and decline symptoms.

Forty mature sugar maples (44 to 106 cm diameter at a height of 1.37 m) were sampled along roads and in yards in the Amherst/Northampton, Massachusetts area. Trees were chosen from the following categories: 1) yard, non-declined; 2) road, moderately declined; 3) road, severely declined; and 4) road, non-declined. Soil and foliage samples were analyzed for physical and chemical properties by standard methods. Ring measurements on increment cores were used to determine relations between current and past growth rates for declined classes. Severely declined trees exhibited significantly reduced growth and less annual fluctuation than other categories dating back to the early 1970's period just following the severe drought of the mid 1960's. Relative measures of ring growth provided stronger statistical differences between classes than did absolute values.

The results of soil and foliar analyses for each group were statistically evaluated by means of one way analysis of variance and discriminant analysis to identify those soil and/or foliar properties most closely related to decline classes and growth rates. The analyses indicated that certain soil and foliar properties are related to the decline of the maple trees studied and that foliar analysis is a useful indicator of soil problems. These properties are the lack of or poor availability of nitrogen; higher soil bulk density; lower sand content; elevated soil and foliar Na levels and low concentrations of foliar N, Ca, Mg, and K. The interaction of these properties was associated with reduced growth and accompanying decline of roadside sugar maples.

Key Words: sugar maple, maple decline, tree growth, urban trees, drought, soil and foliar analysis.

Decline of urban sugar maples (*Acer saccharum*), continues to be an important problem in the Northeast (Westing, 1966). Sugar maple has been widely planted and is especially valued as a street tree because of its aesthetic qualities. Cities and towns make large expenditures to plant and maintain sugar maples. In recent decades decline and subsequent death of sugar maples along New England roadways has received much attention.

Sugar maple declines and dieback are not new. Large numbers of sugar maples were in a state of decline in the early 1900's, late thirties, and early sixties (Kessler, 1965). Decline seems most prevalent among road and shade trees in urban environments and less common in forest settings, presumably because urban environments include additional stress factors not likely to be encountered by forest trees (Tattar, 1978).

Affected trees deteriorate over a period of several years and usually exhibit the following symptoms: chlorosis of the foliage, sparse upper crown (due to lack of foliage), reduction in leaf size, progressive dieback of branches and twigs from the outer and upper portions of the crown, premature abscission of leaves, reduced growth rate, and root necrosis (Westing, 1966; Mader and Thompson, 1969). Such changes may occur in very old trees as part of the natural aging process; however, in street trees they appear to be initiated prematurely by the stress factors common to urban locations.

Tree decline is manifested in the ring growth patterns which are detectable by increment core measurements. Such measurements have been previously used to study maple decline and fertilizer response in forest and sugarbush stands (Mader and Thompson, 1969; Newbanks and Tattar, 1977). A major objective of this study was to assess the onset and course of urban sugar maple decline patterns by increment core analysis. The other major objectives, expanding on the previous work of Ruark et al. (1983), were to assess soil conditions, particularly nutrient status, as shown by soil and foliar analysis, as causes leading to the decline of urban sugar maples in western Massachusetts.

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A complex set of factors controls the overall health and vigor of a particular tree. Soil properties are major factors of the physical environment which determine tree growth. Nutrient uptake by trees is influenced both by the ability of the soil to supply needed nutrients as well as the plant's capability to utilize them. Nutritional deficiencies will generally manifest themselves by visual symptoms in the foliage of the tree. However, as Leaf (1968) pointed out, the ability to identify a specific deficiency for a given species not only requires careful observation, but often also requires analysis of both the tree foliage and the surrounding soil. All three techniques—visual symptoms, foliar analysis, and soils analysis—are commonly used in the diagnosis of nutrient deficiencies or toxicities (Armson, 1973; Mader, 1973).

Soil condition and tree nutrition are especially important for trees grown in an urban setting. Urban sites are often subjected to soil removal or disturbance during road construction resulting in loss of organic matter and nutrients (Mader and Cook, 1982). Trees absorb most essential mineral elements from the soil via the root system. Alteration of the soil environment may interfere with the uptake of these nutrients and lead to tree decline and eventual death. The interrelationships among soil properties and tree nutritional status, as reflected in foliar analyses, may help to ascertain causes of decline.

Methods

Field sampling procedures. Forty sugar maple trees were included in the study, ten in each of four categories consisting of yard, non-declined; road, moderately declined; road, severely declined; and road, non-declined. The trees selected were widely dispersed in a more or less random distribution along roads and in yards throughout the communities of Amherst and Northampton, Massachusetts. So few declined trees occurred in yards at some distance from a road that this category was not included. Healthy, non-roadside trees were sampled as controls for comparison with those from roadside environments. The trees sampled were mature, excluding very old, large decadent individuals. They ranged from 44 to 106 cm in diameter at a height of 1.37 m, with all but seven between 50-80 cm. Roadside trees were within 10 m of the edge of the road while yard trees were more than 10 m from the road. The criteria for tree vigor was based on the visual crown rating system developed for sugar maple by Mader et al. (1969). The criteria for the categories were:

> *Yard, non-declined:* No branch or twig dieback. Foliage full size with no chlorotic appearance.
>
> *Road, moderately declined:* Some dieback of twigs and branches of upper and outer portions of the crown. Foliage abnormally small, curled, and yellowish.
>
> *Road, severely declined:* Trees with at least two or three dead branches 3-4 feet long. Foliage usually chlorotic and some scorching or browning present.
>
> *Road, non-declined.* No branch or twig dieback. Foliage full size with no chlorotic appearance.

Trees exhibiting obvious injuries, excessive pruning, or large girdling roots were excluded from sampling, as well as sites influenced by recent road construction or fertilization. Residents were questioned, when possible, about any special adverse factors and observations on the course of decline.

Growth analysis. Individual tree diameters and increment cores were taken at 1.37 m height to obtain a quantitative measurement of tree growth. The increment cores were smoothed with a fine grade sandpaper and then briefly surface-moistened with water to accentuate the growth rings. The radial growth increment for each of the last twenty years (1962 to 1981 inclusive) was measured with a DeRouen dendrochronometer. Diameter inside bark (dib) was estimated by multiplying tree diameter by the average ratio of inside to outside bark diameter for sugar maple (0.932) as determined by Stayton and Hoffman (1970). Diameters inside bark for the preceding 20 years were estimated by progressively subtracting ring growth from estimated dib. The ratio of the most recent five years' growth to the previous fifteen years' growth for both diameter and basal area was calculated. To simplify conversion the ratio was multiplied by three. Values less than one indicate decreasing rates of growth; more than one, increasing rates. In addition, the diameter growth for the past 20 years (1962 to 1981 inclusive) was divided into four 5-year growth periods and analyzed for significant differences between decline categories.

Soils analysis. In June 1982 ten-point composite soil samples were collected around the crown periphery of each tree and separated into two depths; 0-15 cm and 15-30 cm (Ruark et al., 1982). Soil samples were air dried in the laboratory and then passed through a two-millimeter sieve to remove coarse material and organic fragments. The percent by weight of organic matter for the original soil was calculated from weight loss on ignition at 600° Celsius in a muffle furnace.

Particle size distribution in the soil was determined by the hydrometer method (Jackson, 1958; Mader, 1980). Soil cation exchange capacity (CEC) and exchangeable cations were determined by 1 *N* ammonium acetate extraction at pH 7.0 (USDA 1972). The concentrations of soil Ca and Mg were determined by atomic absorption; soil Na and K by atomic emission. The total soil nitrogen was determined by a semi-micro Kjeldahl method (Mader and Hoyle, 1964). Available soil phosphorus levels were determined by the weak acid extraction method as described by Nelson et al. (1953). The bulk density was derived from 100 cc undisturbed core samples.

Foliar analysis. Foliar samples were taken in late August of 1982. The samples were obtained from the lower portion of the crown at four points, taking 25 mature, undamaged leaves per point. The leaf samples were composited into a single sample for each tree. Foliage (minus petioles) was dried at 70°C, ground in a Wiley mill, and analyzed for total N, P, Cl, Na, Ca, Mg, and K by standard methods (Greweling, 1976; Mader and Hoyle, 1964; Nelson et al., 1953). The soil chemical properties were expressed on a sieved soil ($<$ 2 mm) basis, while physical properties were expressed on the original soil basis. Foliar Na, P, K, N, Mg, Ca, and Cl were expressed on a percent basis.

Statistical analysis. The growth, soil and foliar data were assembled into a data file for analysis with the Statistical Package for the Social Sciences (SPSS) (Nie et al., 1975). To assess which variables were significantly related to decline, they were tested by a one way analysis of variance (ANOVA) program, employing both group comparisons and the Duncan Multiple Range Test. The soil data were analyzed for the two sampling depths, separately and combined, to ascertain if a single depth sample would suffice. Differences between depths were not important so further analysis of the soil data was based on the combined depths. In addition to the ANOVA, discriminant analysis was used to further evaluate those variables that were significantly related to maple decline.

Results

The roles of many adverse factors in decline of roadside sugar maples have not yet been clearly identified in spite of much research on both biotic and abiotic factors. This study was aimed at evaluating the influence of soil and nutritional conditions on decline. The patterns of current and past growth rates of declined trees was one focal point in this study. Growth patterns by decline categories are presented in Figures 1 and 2. The severely declined trees showed markedly decreased growth compared to trees in other categories. Differences between the other categories are not clear. Long-term growth

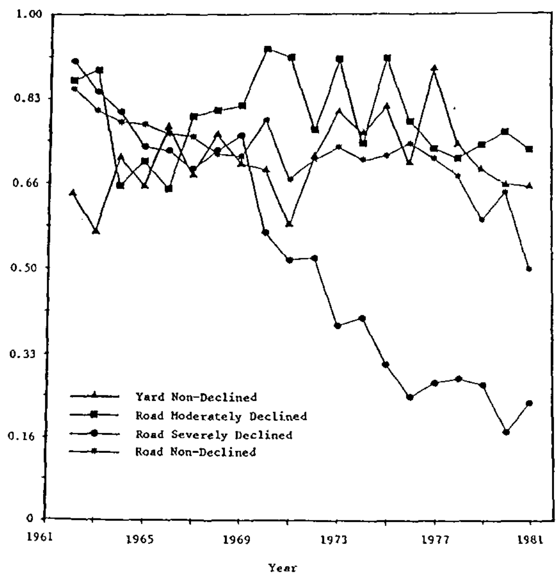

Fig. 1. Mean annual diameter growth versus time by decline classification.

decline is clearly evident in the severely declined category, where reduction in growth rates dates back to about 1970. Steep drops in growth in the early 1970's occurred just after the severe drought of the 1960's in which rainfall was only 74% of normal over the five-year period from 1962-1966, including two of the four lowest years of record.

Tables 1 and 2 present the data and significance of growth rate changes. Striking differences occur between the severely declined category and the others. The most recent 5-year growth (1981 to 1977 inclusive) shows significant differences between the severely declined and other classes, substantiating the conclusions drawn from Figures 1 and 2.

Analyses of the soil and foliar data provided insight into how these variables are associated with each other and with sugar maple decline.

Table 3 summarizes the results of the ANOVA for the soil and foliar properties, which are shown in Table 4. The soil variables significantly associated with maple decline are Na, N, P, sand, silt, and clay. Foliar variables significantly related to decline are Na, N, K, and Cl. The greatest differences occurred between the yard trees and severely declined roadside trees. Roadside soils

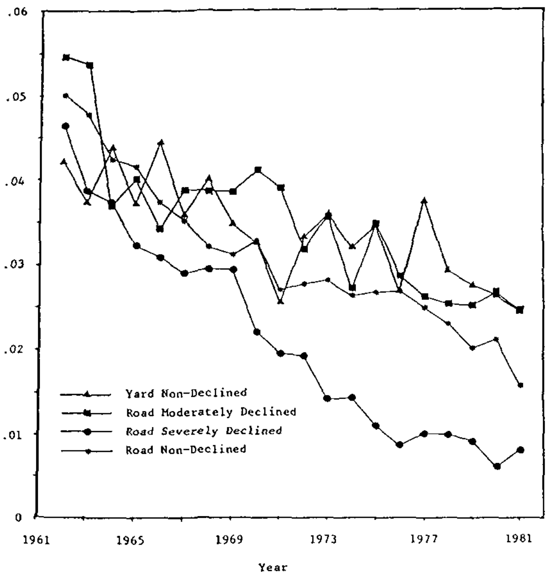

Fig. 2. Mean basal area growth ratio versus time by decline classification.

Table 1. Mean diameter and basal area 5-year to 15-year growth ratio in relation to urban sugar maple decline classes.

Growth ratio	*Yard Non-declined*	*Road Non-declined*	*Road Moderately*	*Road Severely*
Diameter	0.999	1.040	0.988	0.472
Basal Area	1.190	1.165	1.148	0.516

Table 2. Comparison of growth rates by decline classes using Duncan's Multiple Range Test.

Growth rates	*Classification contrasts*[a]					
	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
1981-1977[b]		*[d]		*		*
1976-1972				*		
1971-1967						
1966-1962						
Diameter[c] Growth Ratio		*		*		*
Basal Area Growth Ratio		*		*		*

[a]1 Yard, non-declined; 2 Road, moderately declined; 3 Road, severely declined; 4 Road, non-declined.
[b]5-yr growth periods (inclusive)
[c]5-yr/15-yr growth ratios
[d]* significant at the .05 level

Table 3. Significance of differences between decline classes for soil and foliar properties (Oneway Analysis of Variance).

Variables	*Classification contrasts*					
	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
Soil Na (meg/100g)		**	*	*		
Soil N (%)		**				*
Soil P (ppm)		**	**	**	*	
Sand (%)		**	**	**		
Silt (%)		**	*			
Clay (%)		**	**	*	*	
Foliar Na (%)		**		**		
Foliar K (%)				**		
Foliar N (%)		**	**			
Foliar Cl (§)		*	*			

1 = Yard, non-declined; 2 = Road, moderately declined; 3 = Road, severely declined; 4 = Road, non-declined.
* = Significant at the .05 level
** = Significant at the .01 level

were found to be higher in Na, Cl, P, N, fine fraction (silt and clay), and bulk density, but lower in sand content. Roadside trees had higher levels of foliar Na and lower levels of foliar N and Ca. The relative increases in sodium versus other elements are shown in Table 5.

Discriminant analysis reaffirmed that soil Na and

Table 4. Mean soil and foliar properties for decline classes of urban sugar maples.

Decline class	*Soil Properties*					
	Na	*K*	*Mg*	*Ca*	*P*	*N*
	meg/100g of soil				*PPM*	
Yard, non-declined	0.061	1.125	0.407	1.77	8.72	0.112
Road, moderately declined	0.099	0.139	0.470	2.11	9.38	0.120
Road, severely declined	0.201	0.129	0.422	2.15	19.67	0.142
Road, non-declined	0.150	0.124	0.367	2.07	15.43	0.117

	Sand	*Silt*	*Clay*	*Bulk[1] Density*	*Bulk[2] Density*
	%			*S/cc*	
Yard, Non-Declined	77.73	15.62	2.73	0.98	1.06
Road, Moderatley Declined	68.43	21.46	3.29	.098	1.07
Road, Severely Declined	51.16	28.22	5.38	1.14	1.22
Road, Non-Declined	56.74	23.74	5.94	1.07	1.16

	Foliar Properties						
	Na	*K*	*Mg*	*Ca*	*N*	*P*	*C1*
				%			
Yard, Non-Declined	0.008	0.895	0.397	2.19	1.95	0.178	0.149
Road, Moderately Declined	0.018	1.036	0.392	2.19	1.84	0.210	0.160
Road, Severely Declined	0.032	0.715	0.352	1.99	1.63	0.152	0.215
Road, Non-Declined	0.018	0.853	0.338	2.05	1.87	0.187	0.215

[1]Taken at a depth of 0-15 cm
[2]Taken at a depth of 15-10 cm

particle size distribution (sand, silt, and clay) are properties associated with maple decline. The strongest contrasts again were between yard, non-declined and severely declined roadside trees. Sodium content was greatest in roadside soils with high silt and clay content, particularly for the severely declined class, while sodium content was lowest in the soils with high sand and low silt and clay associated with the yard trees.

The severely declined category shows clearly marked differences in growth, foliar and soil parameters from the moderately and non-declined roadside categories, and from the yard, non-declined category. There are also clear soil and foliar nutrient differences between the yard, non-declined and the roadside, non- and moderately-declined groups, but growth differences are not significant. The results for classes 2 and 4, moderately-declined versus non-declined roadside trees were somewhat puzzling, and show the difficulty of accurate assessment of early decline status from visual evaluation of crown condition. Almost all the soil and foliar data suggest less favorable conditions for the roadside, non-declined category versus the declined category; i.e., foliar K and Mg levels are lower, Cl higher, soil K is lower and Na is higher, and soil bulk density is higher for the non-declined category. However, these were not clearly reflected in growth or crown condition.

Discussion

The results of the study focus strongly on the excessive sodium chloride in soils and foliage as a major factor associated with the severely declining trees. Many previous studies have also reported probable adverse effects from sodium chloride used as a deicing salt on roads in winter as a cause of sugar maple decline (Baker, 1965; French, 1959; Lacasse and Rich, 1964; Manion, 1981; Rich and Walton, 1979; Ruark et al., 1983; Shortle et al., 1972). High salt concentrations can result in growth reduction, chlorosis, and browning of foliage (Baker, 1965; Manion, 1981). The dieback of crown twigs and branches is also common. These symptoms were particularly noticeable in this study for the severely declined roadside trees.

High salt concentrations have also been shown to inhibit the uptake of such essential nutrients as Ca, Mg, and K by raising the osmotic concentration of the soil solution (Westing, 1966). Excessive amounts of sodium on the soil exchange sites may interfere with nutrient uptake and contribute to decline (Mader and Cook, 1982). High Na concentrations also can deflocculate soil clay and organic matter resulting in the breakdown of soil aggregates and thereby the impermeability to water and air (Bohn et al., 1979). Breakdown of soil aggregates may result in a higher bulk density and contribute to compaction problems. Reduction in air or pore space may cause essential nutrients to become unavailable to plant roots. Changes in soil conditions or the lack of carbohydrates in the roots may cause deterioration of the fine root system and loss of mycorrhizal fungi so that nutrient absorption is impeded (Spitko et al., 1978; Carroll et al., 1983).

The results of this study confirm and expand upon the conclusions reached in the previous study by Ruark et al (1983), and those of Lacasse and Rich (1964), Shortle et al. (1972), and Rich and Walton (1979). It was found that trees on sites with high Na content and higher bulk densities due to compaction were most likely to be declined. When Na levels were lower, as in the yard, non-declined sites with low bulk density and higher sand content, no interference with nutrient uptake was evident. These soils allow rapid leaching of excess Na because of their higher permeability rates. The lower Na content appears to enable more essential nutrients to be taken up

Table 5. Ratios of other soil and foliar nutrients to amounts of sodium by decline classes. Rations based on units as shown on Table 4.

	Ratios of soil nutrients							*Ratios of Foliar Nutrients*		
Decline class	*K/Na*	*Mg/Na*	*Ca/Na*	*P/Na*	*N/Na*	*K/Na*	*Mg/Na*	*Ca/Na*	*P/Na*	*N/Na*
Yard, non-declined	2.05	6.67	29.0	143	1.84	111.8	49.6	273.8	22.3	243.8
Road moderately declined	1.40	4.75	21.3	95	1.21	57.6	21.8	121.7	11.7	102.2
Road, severely declined	0.64	2.10	10.7	97.9	0.71	22.3	11.0	62.2	4.75	50.9
Road, non-declined	0.83	2.45	13.8	102.9	0.78	47.4	18.8	113.9	10.4	103.8

by the trees because there is less interference in cation uptake from the soil and less competition for exchange sites.

Furthermore, the severely declined trees were found to have higher soil and lower foliar nitrogen content indicating a possible disruption of nitrogen uptake resulting in deficiency. Nitrogen deficiency is characteristic of declining sugar maples (Mader et al., 1969; Rich and Walton, 1979), and the interaction or combination of higher bulk densities and Na content may be major factors contributing to this nitrogen deficiency by inhibiting organic matter decomposition.

Drought may also be an important factor contributing to the onset of sugar maple decline (Westing, 1966; Lacasse and Rich, 1964). Strong (1944) observed that salt injury is most severe during periods of drought. Drought not only causes a deficiency of soil moisture for trees but also may interfere with nutrient uptake because of the combined effects of salt and drought. The soil solution is the major vehicle for transport of nutrients to tree roots and lack of moisture plus high salt concentration in the reduced water volume in soil may interfere with tree nutrition (Mader and Cook, 1982). The stress conditions that result may cause symptoms such as scorch, early leaf abscission, and yellowing, as well as twig and branch dieback. Westing (1966) reported that leaf scorching and early abscission are most prevalent during drought years but that the more severe effects, such as branch and twig dieback, do not become evident until approximately 2 years later. The growth data from this study suggest such a delayed onset of decline after drought which appears to have initiated a long term decline syndrome in the severely declined trees sampled.

Conclusions

In this study severely declined trees exhibited reduction in growth which appears to have been continuing over a time span of about 15 years. The remaining classes did not have significant differences in growth. Ratios of current 5-year to previous 15-year growth provided a more useful and sensitive criterion for demonstrating significant reductions in growth than did average growth over the twenty year period. The patterns observed and the development time suggest that drought or other severe stress on particular sites initiates a decline syndrome from which certain trees are unable to recover, ultimately resulting in the deaths of the trees many years after their growth was first adversely affected. However, other trees of similar initial location, size, and growth rates are apparently not as severely stressed or affected and do not become declined.

Certain soil and foliar properties were associated with severe decline. These were: high levels of both soil and foliar Na; low levels of foliar N, K, Ca, and P; and low amounts of sand and high levels of silt and clay in the soil. The factors of most importance for severely declined trees appeared to be much higher soil Na, lower proportions of sand, and higher bulk densities. The Na may cause dispersal of clay, surface crusting, and combined with the other two factors result in decreased soil permeability, and reduced leaching of Na from the root zone. Foliar K, Mg, Ca, P, and N levels were lowest and Na highest in the severely declined trees located along the road, suggesting that Na interferes with the uptake of the other elements. Foliar N levels were favorable in the yard, non-declined trees and low in severely declined trees, substantiating that N deficiency is a major problem of declining trees as reported previously by Mader et al. (1969).

The results of this study and the previous study by Ruark et al. (1983) suggest that several interrelated factors are characteristic of the roadside decline of urban sugar maples; namely, lack of or poor uptake of such essential elements as N, Ca, Mg, P, and K; higher soil bulk density; lower sand content; and elevated Na levels. The interaction of soil physical and chemical properties may lead to reduced soil aeration, poor breakdown of organic matter, and reduced permeability causing sodium accumulation. These changes may lead to detrimental effects on absorbing roots; poor and imbalanced nutrient availability and uptake, thereby affecting the overall health and vigor of urban sugar maples. Further studies are in progress to evaluate several treatments to ameliorate the unfavorable conditions.

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