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SOIL FACTORS RELATED TO URBAN SUGAR MAPLE DECLINE[1]

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Abstract. A study was conducted on soils surrounding forty roadside sugar maple (*Acer saccharum*) trees situated in an urban environment. The study examined the differences between declined and non-declined sites. Discriminant analysis implicated the following four soil properties with decline: depressed levels of exchangable K, elevated levels of exchangable Na, high total soil N, and a lower component of sand. In addition, thin sections of soil indicated a reduction in macropore space in the upper surface of crusted or compacted soil. Soil crusting and compaction appeared to be directly related to the devegetated condition of soil bordering roadways. The frequency with which decayed roots were found along roads, and under crusted or compacted soil, and in some cases the absence of any roots, suggest a possible root/shoot imbalance. Root mortality is likely the result of the interaction of low oxygen, low moisture, and high Na levels in encrusted or compacted soils.

Decline of sugar maple (*Acer saccharum*) trees is most pronounced among roadside and shade trees, less common within sugar-bush stands, and infrequent in undisturbed forest settings. Decline has been noticed most frequently in urban areas throughout the northeast and northcentral U.S. (Westing 1966). Large numbers of sugar maple trees were reported to be in a state of decline during the early 1900's and again in the late 1930's and early 1960's (Kessler 1965).

Extensive investigations into the decline of sugar maple have spanned both biotic and abiotic factors. The environmental factors most frequently suspected are drought cycles and high salt levels engendered by the application of road salt in winter months (Westing 1966). In addition, soil compaction has been viewed as one of the major contributing site disturbances in urban areas (Ruark *et al.* 1982a). This compaction can be caused by vehicular and pedestrian traffic or can be induced by lack of surface vegetation where soil aggregates are subject to alterations by raindrop impact. Lull (1959) estimated that a raindrop 2mm in diameter reaches 95% of its terminal velocity within seven meters of fall. The crowns of many urban trees are too high to effectively moderate the impact of rainfall. In fact, drops tend to coalesce on leaf surfaces resulting in raindrops that are considerably larger than those which strike the ground unimpeded. Evans and Buol (1968) described crust formation as a series of steps. The removal of the vegetative cover initiates the process, followed by a breakdown and slaking of aggregates by raindrop impact, and dislodged silts and very fine sands are washed into pores. This results in a thin crust as the surface densifies and final crust formation is enhanced by further deposition of dispersed particles. Upon drying, this crust can become extremely rigid.

Soil aeration and infiltration can be adversely affected by the blockage and realignment of the macropore network in the surface centimeter of exposed mineral soil. Standard methods for assessing bulk density, such as weight over volume measurements, are usually ineffective in detecting localized soil compaction or surface crusting because of the relatively large volumes of

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soil involved. Micromorphological techniques have been developed which make it possible to microscopically observe and measure features in the soil matrix using thin sections of soil (Brewer 1976).

This study, conducted in central Massachusetts, focused on the involvement of physical and chemical soil properties in the decline syndrome of roadside sugar maples and attempted to examine the impact of soil compaction on the soil structure.

Materials and Methods

Soils underlying forty mature, roadside sugar maple trees were sampled under the crown periphery to a depth of 30 cm using a ten-point composite technique developed for urban soils (Ruark *et al.* 1982b). Soil texture ranged from sandy loam to loamy sand. Trees were selected to fall into two main categories containing 20 trees each. One group consisted of severely declined trees, while the others appeared healthy and lacked any decline symptoms. All trees ranged from 50-106 cm dbh. Tree vigor was gauged in accordance with a visual crown rating system developed for sugar maple (Mader *et al.* 1969). Severely declined trees were defined as having more than five percent of the upper crown branches in dieback stages. The distance of a tree stem from the nearest road ranged from 0-6 m, with the average distance being 2.5 m. At least 60% of the area under each tree's crown consisted of unpaved soil.

Each main group of trees was partitioned into two sub-groups comprised of ten trees on non-compacted sites and ten on compacted sites. Compaction was defined as a visually obvious increase in surface bulk density and an absence of vegetative cover. All compacted sites had at least 25% of the vegetative cover missing from the soil surface under the tree crown. Bulk density in the upper 15 cm averaged 1.43 g/cc on compacted sites, while non-compacted sites averaged 1.22 g/cc. The four sub-groups, containing ten trees each, were as follows:

1) Compacted and declined
2) Compacted and non-declined
3) Non-compacted and declined
4) Non-compacted and non-declined

Laboratory analyses were conducted on the composite soil samples to determine exchangable Ca, Mg, K, Na, total N, organic matter content, cation exchange capacity, conductivity, pH, and bulk density. Per cent base saturation was computed from the sum of cations. Soil texture was assessed by the hydrometer method and dry sieving. Moisture retention curves and corresponding pore volume estimates were constructed from data obtained with a pressure plate extractor. The resultant data for 23 variables were analyzed by discriminant analysis and one way analysis of variance.

Within each sub-group three trees were selected for micromorphological study. Undisturbed soil samples were taken in 3 x 5 x 2.5 cm sampling boxes from locations at each of the 12 sites. In general, one point was selected on an unaltered, grassed area within a yard, while the other point was located in a compacted and/or a roadside location. The samples were air dried, vacuum impregnated, and thin sections of soil were prepared according to procedures described by Jongerius and Heintzberger (1975). The sections were examined with a petrographic microscope to observe the occurrence and condition of roots, and the presence of features associated with compaction. In addition, the thin sections were photographed under circular polarization for quantification of void space (Ruark *et al.* 1982c). The percent area occupied by voids larger than 30 microns was assessed on the Quantimet 720 image analyzing system. Thirty microns is generally considered to be the lower size limit for macropores.

Results and Discussion

Discriminant analysis implicated four soil properties with decline. They were the levels of exchangable K and Na, the amount of total soil N, and the percent sand. The same four variables were detected using analysis of variance.

The level of exchangable soil K was inversely correlated with decline, although the actual mean values for this nutrient did not differ greatly between declined and non-declined sites (Table 1). The local ratio of K to Na appears to be more important. Although the literature on K/Na uptake competition is lacking for tree species, some reports dealing with row crops indicate a depression in K absorption when Na is present in large amounts (Epstein 1976). The uptake of K can also be depressed by low soil oxygen levels (Brady 1974). Since foliar levels were not measured, further comment here is not possible.

The C/N ratio was significant in the probability function. Levels of organic matter were not much different between declined and non-declined sites. The fluctuation in this ratio is accounted for by the significant increase in total soil N detected on declined sites. This increase in soil N can be attributed to the lessened ability of declined trees to absorb N. This suggestion is supported by the high portion of decayed roots observed in thin sections taken from both the yard and road sides of declined trees. Total N was not partitioned into nitrate, ammonium, or organic N, so the make-up of the N pool is impossible to pinpoint.

Declined trees exhibited highly significant elevated soil Na levels (Table 1). More specifically, the Na levels near the road appeared very high for these trees (Table 2). This second table also reports high Na levels for compacted, non-declined sites. The reduced permeability in compacted soils may prevent leaching of excess Na. The higher sand contents associated with non-declined sites possibly reflect the favorable infiltration and percolation of coarse textured soils (Table 1). This improves salt removal and promotes aeration as well. Soils with a small component of silt and clay could also be expected to resist soil crusting since fewer grains are available to fill the voids between skeletal grains. If crusting is precluded, higher infiltration and gaseous exchange rates can be maintained.

The formation of soil crust is triggered by the removal of vegetative cover. In an urban setting the major factors responsible for devegetation along roadsides appear to be pedestrian and vehicular traffic, as well as the deposition of large amounts of Na and debris. Corridors ranging up to a meter in width are often denuded along roads. These bands are riddled with surface deposits of gravel, sand, and other debris which melt out from piles of plowed snow. This residual material, if not removed each spring, physically smothers the ground vegetation. The melt water has a high concentration of Na. Some of this water probably manages to infiltrate the plugged surface along the road, while much of it moves over the surface towards the road and sidewalk. This melt water may be depositing large amounts of Na at an ever increasing distance from the road as the crusted band expands annually.

Whether or not this description of the mechanism of devegetation along roads is accurate is of secondary importance. Of prime significance is the fact that once the soil is exposed it is vulnerable to crusting and compacting forces.

When a soil crust is in place the macropore network is no longer continuous to the soil surface. The limited water infiltration and reduced oxygen and carbon dioxide exchange which results can have a detrimental effect on root growth and survival. Soil underlying a crust will have limited water and oxygen early in the growing season. Moisture stress can be further heightened by high salt concentrations. A tree root will respond to both oxygen and moisture stresses by becoming suberized to the root tip (Kramer and Bullock 1966). Once suberized a root can only absorb water if that water is at the root's surface. For this to occur the soil would need to be near field capacity moisture levels, which is not likely during the summer when limited infiltration prevents soil moisture recharge.

Thin sections of soil, taken just beneath the mineral surface, illustrate the impervious nature of crusts. Figure 1 is a photograph of a surface soil crust formed by silts and very fine sands that have filled the pore spaces between the skeletal sand grains. Measurements of macropore area (> 30m) were conducted on the Quantimet 720 image analyzer. Crusted and compacted soils exhibited a significant reduction in percent macropore area when compared to adjacent samples located under grass cover. This effect was confined to the upper centimeter of mineral soil underlying the crust.

In compacted zones the impact on the macropore network ranged down to a depth of 12 cm. Figure 2 illustrates an impact of compaction on the morphology of two root mats taken from the same site. Both mats were oriented horizontally at a depth of 12 cm. The dense root mat occurred under a severely compacted area in response to a

Table 1. The reported values are the means of fifty-two observations. Standard deviations are given in parentheses. Variables with one asterisk were significant at the .05 level when examined with a oneway analysis of variance. Those with two asterisks were highly significant at the .01 level.

	Variable	Decline	Non-decline
	Combined Depths 1 and 2 (0-30cm)		
*	SAND (% by weight in original soil)	51.6 (10.7)	55.3 (11.5)
	ORGANIC MATTER (% by weight in orig. soil)	4.1 (1.5)	3.9 (1.2)
	TOTAL NITROGEN (meq/100g sieved soil)	0.12 (0.04)	0.11 (0.04)
	CARBON/NITROGEN	23.5 (4.0)	25.3 (5.7)
	EXCH. POTASSIUM (meq/100g sieved soil)	0.13 (0.06)	0.14 (0.07)
**	EXCH. SODIUM (meq/100g sieved soil)	0.18 (0.12)	0.12 (0.08)
**	POTASSIUM/ SODIUM	0.95 (0.59)	1.52 (1.00)
	Depth 2 (15-30cm)		
**	TOTAL NITROGEN (meq/100g sieved soil)	0.10 (0.03)	0.08 (0.03)
*	CARBON/NITROGEN	25.3 (4.3)	28.2 (5.7)

lessening of mechanical impedance at that depth. The other mat represents the typical morphology of healthy sugar maple roots found under non-compacted, grassed situations.

Some general patterns in root distribution were observed. Overall, fewer roots were apparent under crusted or compacted areas. When roots did appear under compaction, they were more evident below 15 cm than near the surface. A declined tree tended to have fewer roots under non-compacted, grassed areas than did a non-declined tree. A higher proportion of the roots associated with a declined tree appeared to be in decay. Often there were as many roots near the road as there were in the yard. However, more decayed roots were in evidence at the road on declined sites even when compaction was not indicated. This condition corresponded to locally high Na levels proximal to the road.

The frequency with which decayed roots were found along roads and under crusted soil, and in some cases the absence of any roots, indicate an inadequate rooting habitat. This unfavorable situation is likely a result of the interaction of low oxygen, low moisture, and high Na levels from reduc-

Table 2. Percent exchangeable sodium at twelve randomly selected sites. Samples taken from grassed, lawn situations (L) and denuded, roadside locations (R).

	Compact Decline				*Compact Non-decline*				*Non-compact Decline*				*Non-compact Non-decline*		
No.	*Type*	*0-15 cm*	*15-30 cm*	*No.*	*Type*	*0-15 cm*	*15-30 cm*	*No.*	*Type*	*0-15 cm*	*15-30 cm*	*No.*	*Type*	*0-15 cm*	*15-30 cm*
1	*L*	*0.6*	*0.7*	*12*	*L*	*1.4*	*2.3*	*21*	*L*	*0.5*	*0.6*	*32*	*L*	*0.2*	*2.0*
	L	*0.4*	*0.9*		*L*	*1.6*	*1.8*		*L*	*0.4*	*0.6*		*L*	*0.3*	*0.4*
	L	*0.6*	*0.6*		*L*	*2.6*	*5.8*		*R*	*3.4*	*2.5*		*R*	*0.2*	*0.7*
	L	*0.7*	*1.2*		*L*	*2.1*	*4.9*		*R*	*2.9*	*2.1*		*R*	*0.4*	*0.8*
5	*L*	*1.6*	*1.2*	*17*	*L*	*2.7*	*2.4*	*22*	*L*	*0.5*	*0.6*	*34*	*L*	*0.2*	*2.5*
	L	*0.7*	*0.7*		*L*	*1.1*	*1.7*		*L*	*0.3*	*0.7*		*L*	*1.6*	*0.4*
	R	*2.2*	*2.2*		*R*	*1.4*	*2.0*		*L*	*0.9*	*1.4*		*R*	*2.9*	*3.3*
	R	*1.4*	*3.0*		*R*	*1.9*	*3.3*		*R*	*6.8*	*7.3*		*R*	*1.8*	*4.3*
7	*L*	*0.6*	*0.7*	*20*	*L*	*1.7*	*1.3*	*24*	*L*	*0.4*	*0.8*	*36*	*L*	*0.2*	*0.2*
	L	*1.2*	*1.0*		*L*	*1.7*	*2.1*		*L*	*0.2*	*0.3*		*L*	*0.5*	*0.4*
	L	*1.3*	*1.7*		*R*	*2.8*	*6.7*		*R*	*3.1*	*3.8*		*L*	*0.2*	*0.7*
	R	*7.5*	*14.7*		*R*	*3.5*	*3.9*		*R*	*5.2*	*5.9*		*R*	*1.1*	*0.9*
Average[1] lawn		*0.9*	*(0.4)*			*2.8*	*(1.8)*			*0.6*	*(0.3)*			*0.7*	*(0.7)*
Average road		*5.2*	*(4.7)*			*3.2*	*(1.6)*			*4.3*	*(1.8)*			*1.6*	*(1.3)*

[1] The reported values are means for the combined depths. Standard deviations are given in parenthesis.

Figure 1. Crusting phenomena in the upper 2 millimeters of a barren soil surface. The picture shows two crusted layers, in which most of the finer soil particles are oriented parallel to the soil surface. Voids appear black. Photographed under circular polarization. (30×, 1mm = 3cm)

ed leaching; rather than any one factor in isolation. Since a large portion of a healthy root system is concentrated near the road, a root/shoot imbalance may be set up if root kill at that location becomes pronounced.

Conclusion

When piles of snow melt along roadways large amounts of Na and material debris are deposited. After several years the ground vegetation succumbs to these adverse conditions and the site is denuded. Surface soil crusts may develop from raindrop impact as well as from physical trampling of this devegetated soil. The rate of infiltration and gaseous exchange become severely limited and the result can be localized tree root mortality. This may bring about a root/shoot imbalance if root kill is pronounced. This series of events may play a role in the decline of roadside sugar maple trees.

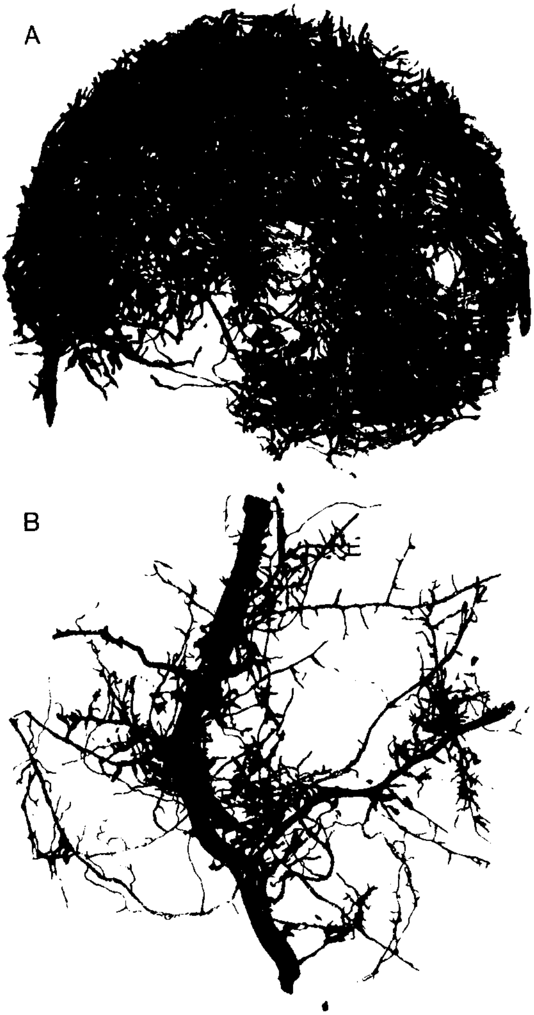

Figure 2. Photo of 2 root mats oriented horizontally at 12 cm depth on the same site. The dense mat (A) occurred under a severely compacted area; the other mat (B) was found under a non-compacted grassed area.

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ABSTRACTS

Tattar, T.A. 1982. **Understanding soil stress.** Am. Nurserymen 155(10): 23-26.

Soil is probably the most important environmental factor controlling tree health. The physical and chemical properties of a soil are very important to all of the plants growing in it. To prevent physical and chemical soil stress, one needs to know what causes these problems and take the necessary steps to guard against them. Some of the more common ways stress occurs are discussed. It is also important to remember that man can have tremendous impact on the condition of a soil. His actions could alter or disturb it, bringing about changes in its physical properties, its chemical properties, or both. For example, most urban and suburban soils, especially along streets, have been disturbed and are unsuitable for growing shade trees. A disturbed soil is one that has been altered from a forest or field condition. For the most part, disturbed soils have been altered by the disruptive activities of man. In addition, soil structure is altered by earth-moving equipment used in excavation and trenching. Abundant subsoil fill from these activities is often mixed into the surface soil. Most urban and suburban soils near buildings and roads have been so altered that they bear little resemblance to the soils in nearby forests and fields. These soils are usually hostile root environments for transplanted trees and shrubs.

Macdonald, J. 1982. **Mechanical tree climbing.** Arboricultural Journal 6: 139-144.

Two major concerns in tree surgery are the inter-related problems of climber fatigue and safety. The former can affect the operation in three ways. A tired climber has dulled enthusiasm for the job, his concentration is diminished and, because his physical ability is temporarily impaired, his performance while in the tree can be well below par and therefore the operation may become dangerous. The new machine developed at Westonbirt will go a long way in providing an easy answer to many of these tree climbing and pruning problems. The machine has a two-man industrial platform with a weight capacity of 200 kilograms. Drive to each wheel is independent and is ideal for allowing unlimited maneuverabiity between obstacles such as young trees and shrubs. There are controls on both the carriage and platform — the machine is normally driven using the controls on the platform which means that time is not lost in raising and lowering the arm.