SOIL DESALINATION TO COUNTERACT MAPLE DECLINE[1]

by James M. Rubens

Abstract. Sugar maple decline can often be traced to contamination of streetside soils by winter de-icing salts (NaCl) application. The deleterious effects of sodium and chloride ions in tree rooting soils can be explained by salt ions' effect upon soil properties and tree metabolism. The symptoms of *salt-induced maple decline* can be enumerated but are quite similar to the symptoms of other stress-induced maple declines. Salt contamination of soils and therefore salt injury to plants can be reduced by a technique of application of powdered gypsum to the soil surface, named *soil desalination.* Trees so treated are also fertilized. *Soil desalination* is a protective rather than a curative treatment and will be of little benefit to a sugar maple suffering *irreversible decline.*

Sugar maples growing within urban environments have been beset by a disease termed *maple decline.* Maple decline can be attributed primarily to environmental stresses, important among which is winter de-icing salts (NaCl) runoff and subsequent contamination of roadside tree zone soils. Salt-induced maple decline is impossible to diagnose with certainty due to symptom similarity with other stress-induced maple declines, but may be inferred after examination of the tree's growth environment and past history. Salt-induced maple decline can be counteracted by a combination of soil desalination and a number of other methods, provided the subject tree has not passed the stage of irreversible decline. This paper includes a literature survey and background information on subjects related to maple decline and to the use of gypsum as a soil amendment to reduce soil salts.

Salt-induced maple decline

The sugar maple is a species of a moderately deep, spreading rather than a tap rooted habit, requiring a moist, well drained, fairly fertile, and medium textured soil. Life span is 200-400 years in adequate growth environments. Soils in the area of adaption of the sugar maple can primarily be classified as podzolic: partially leached on base nutrients, acid in pH, and formed under the influence of a humid climate.

Sugar maples have been a widely planted street tree, especially during the first half of this century. Maple decline is usually associated with urban streetside growth environments; so in its area of adaption, the sugar maple probably represents a municipal maintenance liability second only to the American elm. Maple decline in urban areas involves a gradual die-back and death of the tree, resulting in four direct costs: 1) periodic deadwood removal, 2) eventual removal cost, 3) replanting or replacement cost, and 4) loss in value of the mature tree ($1500-$4000 in residential areas).

Salt-induced maple decline is a disease of streetside trees of the snow belt states of the northeastern United States and southeastern Canada where de-icing salts are regularly applied during the winter. In the United States the distribution of maple decline is bordered roughly by the western border of the State of Wisconsin and extends throughout USDA Climatic Zones 5 and north. In Canada the disease extends within populated areas of the Provinces of Quebec, Nova Scotia, and Ontario. Maple decline affects street trees in the region of approximately forty percent of the United States population (Salt Institute, 1974).

Westing (1968) in a literature review on the causes of maple decline found both forest and street sugar maple decline to be unrelated to pathogenic attack, but to natural and man-made environmental stresses including soil contamination by road salt (NaCl), drought, climatological irregularities, low soil fertility, obstructive bedrock, overmaturity, maintenance abuse (such as overtapping), what this author has termed *soil deoxygenation* (caused by pavement, compaction, inadequate draining, fill and poor soil aeration), and also unusually severe multi-year in-

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sect defoliation. The two predominant causes of maple decline found by this author after examination of many thousands of streetside sugar maples are salt and pavement. There is great inter-specific variation in tree resistance to both of these environmental stresses. Sugar maples are very low in resistance to both where the pin oak possesses high resistance to both stresses.

Some, but not all salt-induced maple decline symptoms are very similar to those of other stress-induced maple declines. A salt-induced decline leading to death may proceed over the course of 3 to 15 years, progressing from the mild to the severe symptoms very roughly as listed: premature autumn leaf coloration, premature leaf fall, reduced green leaf coloration, reduction in leader and vertical terminal growth resulting in the tree's assuming an unnatural rounded shape, reduction in leaf size, reduction in annual growth of twigs, marginal leaf scorch, abortion of terminal buds, marginal leaf necrosis, cup shaping of leaves due to marginal necrosis and irregular growth, tufting or clumping of foliage and sparseness of leaves, failure to leaf out in spring, progressive die-back of extreme branch tips, twigs, and branches continuing inward and downward, weakening and drying of live wood resulting in greater incidence of live branch breakage, minor and then extensive necrosis of trunk cambial layer sometimes with annular canker-like cambial healing and die-back in one to three layers, and finally death. The die-back of branches and limbs begins with the leader most vertical but slightly facing the street. During a more rapid decline, a number of these symptoms may be skipped altogether.

Environmental stresses may act synergistically upon a tree. Tree maintenance resulting in the removal of one stress may allow an otherwise declining tree to withstand the effects of a second stress. Several years of the sublethal effects of salt are usually required before any chronic injury becomes visible. A young sugar maple transplanted into salt contaminated soil may flourish for five to fifteen years before showing decline symptoms.

Salt behavior and effect upon soils and trees

Of sugar maples studied in southeastern New Hampshire, 93% were found to be healthy along *unsalted* roads while only 12% were healthy along *salted* roads (Rich, 1971). Lacasse and Rich (1964) studied 443 sugar maples and found a strong inverse correlation between trunk distance from pavement edge and severity of decline symptoms, and a strong positive correlation of decline symptoms with soil salt contamination as measured by soil conductivity. Decline correlated also with the amount of sodium found in twigs and with amount of chloride in leaves. Depending upon drainage and topography, the authors found decline to be prevalent only within thirty feet of the pavement edge, extending to fifty to one hundred feet where topography allowed brine to run downhill over the soil surface. The authors found decline not to correlate with topsoil depth, type, or nutrient levels; but poor subsoil drainage did correlate with decline symptoms. No correlation was found between decline symptoms and dbh indicating maple decline not to be age related. Finally no pathogenic organisms surveyed could be found consistently associated with decline. The above findings allow us to exclude all the environmental stresses listed above as major contributors to streetside maple decline in New Hampshire, excepting salt and in some cases, soil deoxygenation.

The City of New Haven, Connecticut provides an interesting control. There, economic considerations have prevented street salting except for the downtown area for at least 11 years. By this author's observation, declining sugar maples along unsalted streets nearly always had in excess of 60-70% of the soil within their drip lines paved. This observation allows construction as a rough gauge of the extent to which pavement must become a problem before it can be considered a contributing factor toward maple decline.

Hutchinson (1967) reports that levels of both sodium and chloride along salted roads increase and that salt contamination of soils spreads further from the road with the length of time salting has been practiced. Sodium tends continually to rise, where chlorides tend to peak quickly, thereafter rising and falling with brine and rainfall leaching through the soil. Significant salt contamination extends 15-30 feet from the edge of the pavement, and further along high speed highways such as the Interstate System. Roadside salt contaminated soils in the eastern United States must be classified according to the USDA system as approaching *non-saline alkali,* as sodium rarely occupies more than 15% of soil cation exchange capacity (CEC). Such soils should not be termed *saline.*

Hutchinson (1967, 1971) finds both sodium and salts levels in roadside soils to be quite variable, generally being within the range of 30-550 ppm. Some of the factors contributing to this variability are:

1. extent of freezing of the surface soil during brine runoff periods
2. surface and internal drainage (porosity)
3. slope and immediate microrelief or topography
4. existence of drainage ditches, culverts, and curbing to divert brine flows
5. rate and number of salt applications
6. when during the season salt applications are made
7. CEC of surface and subsoil.

All of these factors can be manipulated to influence soil salt contamination and extent of subsequent plant injury.

De-icing salt applications are most harmful during early spring after March 1 in USDA climatic zones 7 through 5b and after March 15th in zones 5a and northward. During the early spring soils tend to be partially thawed and salts can leach into the soil more readily. Sugar maples draw upon soil water after March 1-15 so minimization of salt use following these dates is particularly desirable. And since chlorides move downward through the soil horizon rapidly, tree chloride uptake can be reduced by ensuring that rainfall leaching has reduced soil chlorides before significant tree water uptake begins. Walton (1969) has shown that Norway maples are harmed most by late season salt applications following March 15th. Thus it is during the last one to two storms that maximum restraint in salt use should be exercised.

Hutchinson further finds that background sodium levels are within the range of 30-40 ppm and that background chloride levels are usually zero. Variability of sodium levels along salted roads is noted above; chlorides vary generally within the range of 0-300 ppm. Other workers have found isolated values ranging up to 2500 ppm for sodium. Salt toxicity is more a function of relative rather than absolute values, so percent of soil CEC occupied by sodium will be a better indicator of potential injury to plants. In the northeastern United States salted roadside sodium levels probably vary within the range of 5-10% of soil CEC, with few values above 10% of CEC. However Hutchinson found a value of 17% of CEC on one Maine test site. There is no information concerning the threshold soil sodium or chloride levels at which toxicity to sugar maples begins. Finally, it should be noted that salt leaches downward through the soil horizon, lateral leaching being negligible.

Sodium is highly persistent in soils. As brine leaches through the soil sodium readily exchanges with base nutrients such as calcium, magnesium, potassium, and the other secondary and minor base nutrients, reducing overall soil fertility and disturbing nutrient balance. Enough sodium will cause soil pH to rise, but this is not yet noted as a problem in acid northeastern soils. When sodium levels reach about 15% of soil CEC, soil aggregates begin to break down leading to loss of soil air and water permeability, reduced soil drainage, and increased soil bulk density (United States Salinity Laboratory Staff, 1954). Sodium has also been found to cause loss of silicates, humic acid, organic matter, and irreversible loss of soil structure (Plice, 1949). Sodium at 10% of CEC approaches the level at which soil physical properties are disturbed.

Chlorides are highly water soluble and are anionic and so do not bind strongly to soil colloids. Twelve inches of rainfall will leach most chlorides below two feet in depth even in clay soils. Chlorides reach very low and even unmeasureable levels in the soil as early as May and June (Lacasse and Rich, 1964; Hutchinson, 1967). Chlorides therefore represent a toxicity problem only during the early part of the growing and transpiration season.

The detrimental effects of salt upon plants fall within three categories: osmotic, nutritional, and toxic (Levitt, 1972). Literature on maple decline often attributes a part of the detrimental effect of salt on sugar maples to the increase in osmotic pressure of the soil water resulting in "physiological drought." However, increases in soil water osmotic pressure attributable to salt are small compared to the osmotic pressure of 60 bars measured in tree conductive tissue (Kramer and Kozlowski , 1960). Even at near drought conditions, most streetside salt contaminated soils will have a salt-induced osmotic pressure increase not exceeding .5 bar, with the highest salt levels inducing incremental osmotic pressures of only 2 bar. At 2 bar the toxic and nutritional effects of salt would be overwhelmingly predominant (Levitt, 1972).

Salts' nutritional effect upon trees results from ion antagonism with required plant nutrients. Sodium competes with and reduces plant uptake of potassium, calcium, magnesium, and other cationic nutrients. Potassium uptake is most severely reduced. Evaluation of a variety of species disclosed that sodium in soils reduced calcium uptake by 10-40% (French, 1959). The nutritional effect of salt can best be understood as a disruption of nutrient balance, or the relative availability of nutrients and salts. For two soils with equivalent absolute sodium levels, on a low calcium soil plants take up sodium more readily than on a high calcium soil (Kotheimer, 1967). Chloride's nutritional effect results from ion antagonism, particularly with phosphate, but also with sulphate and nitrate, resulting in depressed availability of essential anionic nutrients and disruption of anionic nutrient balance.

Both sodium and chlorides themselves are taken into plants growing on salt contaminated soils and both contribute to decline as a result of toxic effects. Chloride toxicity is not proportional to the concentration of chlorides but to the ratio of the concentrations of chlorides and sulphates. Chloride toxicity can therefore be reduced by increasing sulphate availability (Levitt, 1972). Additionally, chloride uptake and toxicity are greater when inadequate calcium supplies result in too high a potassium to calcium ratio.

Chlorides are transported much more rapidly than is sodium into extreme tree tissues such as leaves. Sodium does not reach leaves or twigs at high concentrations until later stages of decline (Button and Peaslee, 1967). Lower portions of the plant such as roots and trunk hold sodium perhaps until the involved tissue dies, then allowing sodium to pass to branches and twigs. This may account for trunk cambial necrosis during the later stages of decline. Plant cells depend upon an approximate 10 to 1 mono to divalent cation balance to remain selectively permeable. An excess of sodium could contribute to increases in cell ion permeability. Chloride ion uptake selectivity by tree roots seems to be impaired by sodium concentrations in sap exceeding 75 ppm (Button and Peaslee, 1967). During the middle and later stages of decline, the sodium build-up within the tree may lead to even greater uptake of chlorides. Thus sodium and chloride interact during the decline, chlorides predominating in visible effect during the early stages and sodium during the later stages of decline.

The question of the relative contribution of sodium and chloride to maple decline is unanswered. Experimentally, this problem could be best resolved by growing sugar maples in noncontainer soil plots subject to normal leaching and precipitation rates and then introducing sublethal but chronically injurious equinormal quantities of sodium sulphate, calcium chloride, and as a control calcium sulphate regularly during the dormant season onto root zone soils. To duplicate actual conditions quantities of salts introduced should result in declines proceeding over many years.

Severity of decline symptoms, however , correlates most closely with chlorides as a percent dry weight of leaves taken from injured portions of the tree. And at isosmotic concentrations in hydroponic growth media chloride is significantly greater in acute toxicity than sodium. Brown et al (1953) found calcium chloride to be more toxic than sodium chloride at isosmotic concentrations. A degree of uncertainty and contradiction is apparent in the literature on this subject.

However, when an equivalent number of sodium and chloride ions are introduced into the soil medium the relative influence of sodium is significantly increased. And sugar maple decline is a chronic rather than an acute disease. And Strong (1944) found sodium chloride to be five to ten times as toxic to trees as calcium chloride when applied at equal rates to rooting soils. Most chlorides taken up by deciduous trees are accumulated in leaves and are sloughed off at autumn leaf drop (Holmes, 1958). Most of the sodium taken up remains in the permanent tissues of the tree (Lacasse and Rich, 1964).

Salt resistance determination

Maple decline is likely when foliar chlorides as a percent of dry weight exceed .15%. This figure is a mean and can vary widely from tree to tree. Visible injury does not occur until foliar chloride levels reach about .4%. The fact that decline symptoms correlate with foliar chloride levels is the basis for a quick qualitative test which can be performed by the arborist making a diagnosis of salt-induced maple decline. Eight average sized leaves (.75 g without the stem) are taken from damaged portions of the tree exposed to full sunlight during the months of July or August when foliar chloride levels peak. The leaves are stuffed into a 100 ml beaker and boiled for 20 minutes in 30 ml distilled water. Water is added as required to keep the boiling solution at approximately 30 ml. At the end of the boiling period .1M silver nitrate is added drop by drop to the solution of boiled leaves. A distinct cloudy precipitate surrounding the first drop indicates high foliar chloride levels and the probability of severe injury. A pale diffuse cloud of white precipitate after ten drops indicates the probability of mild to moderate injury of the tree by salt. It should be noted that the rise in foliar chloride levels during the spring and summer is more pronounced for moderately than severely injured trees.

Absence of sugar maple decline symptoms has been found to correlate closely with a *metabolic index* which is the ratio of calcium, magnesium, potassium, and phosphorus to chloride and sodium, all elemental percent dry tissue weight (Button, 1970).

Several deciduous and evergreen species other than the sugar maple are very poorly resistant to salts (NaCl) in rooting zone soils. Littleleaf linden can be rated as fair to pool in salt resistance, where red oak and honeylocust are high in salt resistance. Dirr (1976) may be consulted for a good resistance listing of most of the common species. These ratings are however highly subjective and often contradictory. Little distinction is made between airborne and soil salt resistance by most authors. Airborne salt injury to above ground tree tissue is a problem only near to the ocean and near high speed highways where brine is whipped into the air as a fine mist.

Dr. Dirr has undertaken the development of sorely needed screening techniques to determine tree salt resistance. His work is partially supported by an International Society of Arboriculture grant. Monk and Wiebe (1961) found actual tree salt resistance to correlate quite well with results of a screening technique they devised. Cells were subjected to a number of increasing salt concentrations. Subsequent cell viability was indicated by plasmolysis of cells after their removal from salt solutions.

Soil desalination

Roadside contamination by salt of tree rooting zone soils in the eastern United States is a problem similar to salinization or alkalization of arid zones soils in the Western United States, parts of the USSR, Israel, and is similar to salt contaminated soils of the Netherlands reclaimed from the seabed. It is fortunate that the technology to reclaim these lands has been perfected as a result of several nations' research efforts over the past fifty years. Of the methods which have been devised to reclaim salt contaminated soils, agricultural gypsum application is the method most suitable for use on eastern roadside soils. Gypsum is non-acidifying, nontoxic to plants, is relatively inexpensive, easy to handle, and commercially available. Gypsum has been used in parts of the arid western US to restore barren high sodium soils to full agricultural productivity, allowing growth of even salt sensitive crops (Kelley, 1951).

Gypsum affects salt contaminated soils in several ways, the most important being reduction in soil sodium levels. That gypsum substantially reduces soil sodium levels has been amply demonstrated in the western United States (United States Salinity Laboratory Staff, 1954). Tests on gypsum's effect on sodium levels in eastern roadside soils have recently shown comparable beneficial effects. In a Maine experiment gypsum reduced soil sodium by up to 76% after only one and one-quarter years. Those test sites continue to be monitored as of the date of this writing. Three gypsum application methods used in the Maine experiments were effective in the following order: surface application, subsurface application, surface application combined with mechanical soil aeration (Jacobs, 1976). Subsurface application was presumably *not* more effective in reducing soil sodium at the 12-18 inch depth due to the rapidity of leaching and reaction deeper in the soil of the surface applied gypsum. It is not explained why mechanical aeration reduced the effectiveness of the surface applied gypsum. Results are reported in Table 1 from Jacobs (1976) data as corrected by Jacobs in personal correspondence with the present author.

Table 1. Reduction in soil sodium at various depths 1¼ years following gypsum application by various methods at a rate of 15 tons per acre equivalent.

	Reduction in soil sodium (%)			
soil depth	*surface*	*subsurface*	*surface & aeration*	*control*
0-6"	76	58	16	16
6-12"	53	61	62	25
12-18"	43	34	29	17

Gypsum reduces sodium levels as a result of an ion exchange reaction between gypsum's calcium and sodium. Gypsum's sulphate combines with the sodium freed from soil colloids to form water soluble sodium sulphate which leaches downward with precipitation and out of tree rooting zone soils.

Other experimentation in the eastern United States has lead Hutchinson (1974) to conclude ... "that gypsum caused substantial sodium reduction within a few months following application and thereafter the residual material continued to maintain that reduction over a three year period in spite of continued salting of the adjacent highways. Apparently a system of infrequent gypsum applications along highways ... would be adequate to keep sodium levels from becoming excessive." The fact that gypsum can continue to reduce salt over a number of years means that soil treatment need not be performed each year, minimizing the cost of the practice. Another author has stated: "applications of gypsum ($CaSO_4$) to the soil have a tendency to improve soil structure, reduce uptake of sodium, and reduce visible injury to foliage" (Rich, 1973). Gypsum application therefore reduces soil sodium levels leading to a reversal of loss of soil aggregation, reduced sodium-plant toxicity, and of course to reduced sodium uptake by plants.

Aside from reduction in soil sodium levels, gypsum applications have additional beneficial effects upon the soil including increased soil aeration, percolation, drainage, aggregation, and soil capillarity. Increases in soil capillarity allow water to be drawn upward from water tables more rapidly during droughts (Scotter and Loveday, 1966). Gypsum is commonly used to reduce compaction in clay soils by surface application at the rate of 2 tons per acre. Roadside trees are therefore further benefited by gypsum applications due to reversal of vibrational settling and foot and other traffic compaction. Plice (1949) has noted that applications of 2 tons per acre of gypsum followed by one year and 25 inches of rainfall caused highly compacted soils to become "strikingly friable and permeable to rains."

Hutchinson (1971) finds that following gypsum applications calcium levels rise significantly, magnesium levels rise moderately, and potassium and pH show no appreciable change. Podzolic soils such as are common in the northeastern United States are usually deficient in both calcium and sulphur. Gypsum applications will supply more than adequate quantities of both of these necessary nutrients in most soils.

There is some evidence that gypsum can reduce uptake of chlorides. Jacobs (1976) data show that gypsum applications result in greater soil chloride reductions than those of controls, but the data are erratic. The mass action law would suggest that the sulphate ions supplied by gypsum would tend to reduce solubility of chlorides in soil water. Experimentation has shown that increased sulphates reduce plant chloride uptake (Levitt, 1972). Additionally, increased soil permeability resulting from gypsum applications should allow leaching out of the highly water soluble chloride ions at a more rapid rate. Reduced uptake of sodium allowing root cells to remain selectively permeable may also contribute to reduced chloride uptake.

The ability of gypsum to reduce soil sodium depends upon the leaching downward of sodium sulphate through and below trees' root zone. Successful use of gypsum for soil desalination depends upon an adequate supply of rainfall or artificially introduced water, and upon adequate soil and subsoil drainage. These requirements are nearly always met in the northeast as precipitation ranges above thirty inches annually, and sugar maples are rarely grown where inadequate soil drainage would be a problem.

Rates of gypsum application required to achieve soil salts reduction varies in the literature from 4 to 15 tons per acre. Plice (1949) reports that 4 to 6 tons per acre reclaimed strongly saline soils, and that 12 tons per acre offered the advantage of reducing salts more quickly. Rates of required application depend upon soil CEC, percentage of soil CEC occupied by sodium, and availability of water to solubilize gypsum and bring it into reaction with soil colloids. Limiting factors for speed of the desalination reaction in the east are annual precipitation and gypsum solubility as influenced by fineness of grind and purity. Recommended grind is at least 90% through 100 mesh of agricultural gypsum. As the high rates of gypsum application do not result in plant toxicity (Plice, 1949) or disrupt soil nutrient balances or pH, high application rates are recommended to achieve speed of desired reaction.

Gypsum solubility in water is approximately .25%. Three to four feet of water will dissolve four to five tons per acre of gypsum (United States Salinity Laboratory Staff, 1954). Thus 30-40 inches of precipitation as expected throughout the snowbelt of the eastern US results in the solubilization of 3-4 tons per acre per year of gypsum. High rates of application therefore result in soil sodium being continuously reduced for a number of years as rainfall solubilizes the gypsum. The rate of application will depend upon the desired frequency of repeat applications.

When 25% of soil CEC is occupied by sodium, calcium in soil water replaces sodium with nearly 100% efficiency. However, when soil sodium drops to 10% of CEC, exchange efficiency drops to about 50% (United States Salinity Laboratory Staff, 1954). The exchange efficiency of calcium ions drops to about 25-35% when sodium ions occupy 2-4% of soil CEC (Antipov-Karataev and Kerzum, 1961). Rate of gypsum application required to reduce sodium to the desired level of approximately 2-3% of soil CEC can be calculated given data on the CEC of the roadside soil at hand, assuming sodium not to exceed about 10% of CEC. Rough calculations disclose the need for about 12 tons per acre (55# per hundred square feet) of gypsum on most roadside soils. Reaction will reach equilibrium after 3-5 years accumulated precipitation.

Reduction in sodium levels will therefore require a period of time measured in years, and gypsum application will be required on a regular basis to drive salt levels to lowest attainable equilibrium, to counteract repeated winter de-icing salt applications, and to reduce soil sodium in deeper portions of the soil horizon.

Soil desalination as performed by the present author's firm includes fertilization of each tree treated for two reasons. First, fertilization replaces cationic nutrients lost due to the effects of salt. And nutrient levels in many podzolic soils are low before the effects of road salt are considered, contributing to excessively low soil pH. Proper fertilization thus seeks to restore available nutrient balance. Second, the anionic nutrients, particularly phosphate and nitrate, have been shown to reduce chlorides uptake. And phosphates have been shown to increase exchangeability of calcium for sodium, increasing the effectiveness of gypsum.

It is important that the method and type of fertilization used be such that nutrients are not entirely water soluble. The author's firm uses a timed-release fertilizer which can supply nutrients for a three year period. Gypsum and fertilizer applications are therefore repeated each three years to coincide with exhaustion of newly solubilized and available calcium and nutrient supplies.

It has been shown that excessive nitrogen increases plant uptake of both sodium and chloride. The practice of using high nitrogen formulations to induce lush green foliage, though being a good marketing tool for arboricultural firms, is highly undesirable. A slow releasing, organic base nitrogen source is recommended. Also, the fertilizer should contain a supply of magnesium, and other *secondary* and *trace* nutrients likely to be deficient. Formulations and rates of fertilizer application must be based upon soil tests which characterize at least the average soil in the area of treatment. As organic matter has also been shown to increase gypsum effectiveness, an application of fine-textured and well decomposed mulch is recommended for high value trees.

The mechanics of gypsum application concern the logistics of purchase, transport, and physical application of gypsum to the soil. As there is no significant advantage to the more costly subsurface application method, the more economical surface application method is to be used. For surface application of a single tree careful use of a shovel can suffice. For a larger number of trees where hand methods would be impractical and inaccurate, machinery must be utilized. A commercially available hydroseeder was used by the Department of Transportation in Portland, Maine experiments. There, gypsum was mixed in the hydroseeder tank at the rate of 3300 pounds per 800 gallons of water, and careful movement of the machinery and positioning of the spray nozzle permitted even application.

A second method of application utilizes pneumatic solids handling equipment and a flexible application hose. Dust control must be achieved by introducing a water supply at the spray nozzle. The pneumatic equipment is probably the fastest application technology now available.

Gypsum must be applied to the entire soil surface represented by the intersection of the tree's rooting zone and the soil areas affected by salt. Salt contamination along residential streets usually extends no more than 15-20 feet from the pavement. But extent of contamination is highly variable depending upon the local climate, rates of de-icing salt application to roads, the number of years salt has been used, type of salt application equipment used, and speed and density of traffic, snowbank handling practices, existence of curbing and drainage systems, slope and microrelief or topography of the area surrounding the tree, and a number of other more minor factors. It is critical that each tree be examined by a thoroughly knowledgeable person before the area of treatment is determined.

Choice of trees to be treated must also be performed by an arborist entirely familiar with symptoms of salt-induced maple decline. A sugar maple having passed the stage of irreversible decline will not benefit by soil desalination. Generally if a tree has lost a number of branches one-half to one inch in diameter due to the effects of salt, recovery is not possible, and all maintenance — except that required to protect the public safety — should be curtailed. Consider also that soil desalination requires 3 to 45 years to achieve full reductions in soil sodium levels. Thus a tree's decline symptoms and speed of decline as determined during examination must be judged so that the point of irreversible decline can be extrapolated into the future. If irreversible decline is predictable within the forthcoming 3 to 5 year period, the tree should probably not be treated. Some treatments to apparently healthy trees will fail due to the poor predictability of time of onset of irreversible decline. Additionally a few maple declines proceed very quickly, a healthy tree dying in only three to four years. The above are two reasons why soil salts reduction may fail to be of benefit before irreversible decline is passed.

Choice of trees to be treated must also include consideration of the relative importance of other environmental stresses which may contribute to the decline of each tree. The most frequent stress factors other than salt will be pavement and disturbance or burial of roots. Soil desalination will be of little benefit if other stress factors will contribute significantly toward a decline and cannot economically be cured. Thus a sugar maple being affected by salt but with 70% of its normal rooting area paved over should not be treated. Soil desalination is therefore used primarily where a tree is presently healthy, showing few or no decline symptoms, and where salt is the prime contributing factor toward an expected decline. Sugar maple is the predominant species requiring treatment, however a number of other species can benefit including red and white pines, red maples, and lindens. Finally, a tree of low value due to its location, small size, or poor form or bole condition should be eliminated as a candidate for treatment where funds are limited.

The author's firm provides soil desalination to municipal or institutional customers in four parts. First, the survey which selects trees and determines exact soil surfaces to be treated. Second is the application of gypsum to reduce salt contamination and to decompact affected soil areas beneath selected trees. Third is a fertilization to provide primary, secondary, and trace nutrients and to help restore soil nutrient balance. Fourth is a recommendation to appropriate municipal decision makers of more than a dozen methods to reduce salt use to practically attainable minimum levels thereby reducing damage of applied salt to trees.

Salt use reduction

The Transportation Research Board (1974) enumerates several methods that a highway maintenance organization can use to reduce annual tonnage of salt use. Reductions of 50% can be achieved without sacrifice in winter highway maintenance standards. There are a number of other methods which can be used to protect trees from soil salt contamination which dovetail into highway maintenance organization objectives. Reduction in use of salt is a saving to the taxpayer, minimizes water supply contamination, and reduces impact upon roadside plants such as sugar maples. It must be noted that no economic replacements for the use of de-icing salts (NaCl) are to be expected during the remainder of this century, and that roadside soil contamination by de-icing salts will continue to be a problem.

Conclusions

The cost of soil desalination on a continuous basis to protect healthy sugar maples not affected by other environmental or man-made stresses is less than costs attributable to non-provision of this maintenance. A sugar maple allowed to decline will incur the costs of periodic deadwood pruning, eventual tree removal, premature replacement of the tree, and loss in intrinsic value of the tree. Before a soil desalination program is undertaken, municipal tree managers should carefully consider the value of the trees requiring treatment, long term objectives of the forestry program, and other more pressing maintenance requirements such as protection of the public safety when funds are severely limited. Utmost in importance is proper planning of the municipal tree planting program so that species selected for various locations are tolerant of environmental stresses, including salt contaminated soils. And then the tree program must harmonize with the other municipal functions in areas such as winter highway maintenance, overhead and subsurface utility construction, and even highway design and engineering.

The abundance of evidence leaves little doubt that gypsum application will reduce sodium levels in roadside salt contaminated soils, leading to reduced salt uptake by plants. That salt is a significant and in many cases the primary contributor to maple decline can be taken as fact. Lacking, however, is exact knowledge allowing for a more predictable estimate of a tree's life span with and without desalination treatment.

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ABSTRACT

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How do we operate? Very simply — with little or no fanfare. Our report incorporates the statement that we examined the plants on the area as pointed out to as by so and so. Our reports are of good and professional appearance and suffciently presentable under any circumstances. Always keep your field notes and all working calculations. We tell what courts or tribunals in which we have appeared. In court — answer only what is asked. Do not volunteer information. Don't get off on a tangent. Do not be lured out of your realm of knowledge and training. Always meet with the lawyer for your client and review some part of the case prior to going to court. Take your own pictures of subject under discussion to illustrate your report.