SALT-RELATED DAMAGE TO WOODY ORNAMENTALS

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INTRODUCTION

Various salt compounds are used to raise the melting point of ice and snow in northern urban areas to facilitate traffic and pedestrian movement and to eliminate unsafe road and sidewalk conditions. These compounds commonly are sodium chloride or calcium chloride applied unmixed or mixed with sand, fine gravel, or coarse tailings. The amounts applied have increased over time as traffic and traffic speed on highways have increased along with the miles of highway. Dirr (1976) quotes Westing's (1969) estimate of 12 million tons of salt applied to northeastern United States highways annually. Chicago freeways receive as much as 80 tons per lane mile and 15 to 25 tons per 2-lane mile is applied in several New England states. Elliott and Linn (1987) quote a quantity of about 88 million tons nationwide.

Physiology of salt damage to plants and their sensitivity

The salt spray does the most harm to plants (Smith, 1975) by coating the twigs, buds, and leaves of plants. Witches' brooms or tufting are common on trees heavily coated each winter with salt spray. The salt coats the buds and kills them by desiccation of the bud scales which then allows the bud embryo to be exposed and become dried out. The tree responds by spouting at adventitious buds, multiplying the number of shoots at the end of each twig. The tree, especially conifers such as eastern white pine, red and Austrian pines may eventually succumb by desiccation if the coating is frequent and heavy.

The direct damage of salt spray to the foliage and twigs is clearly detectable in most cases. Lumis et.al. (1975) describe the characteristic symptoms as:

Evergreens:

- needle browning moderate to extreme beginning at the tip;
- needle browning and twig dieback on the side facing the road;
- no needle browning or dieback on branches near the ground or under snow;
- needle browning and twig dieback less severe further from the road;
- browning usually first evident in late February or early March and becoming more extensive through spring and summer.

Deciduous:

- leaf buds on the terminal part of branches facing the road very slow to open or do not open;
- new growth arises from the basal section of branches facing the road, resulting in a tufted appearance;
- flower buds on the side facing the road do not open but flowering normal on backside.

Gibbs and Burdkin (1983) report London plane tree crowns affected as far as 45 meters (150 feet) from the road. Death of much of the foliage occurs after spring flush and the remainder becomes scorched on the leaf margins and veins. The indirect damage and eventual mortality due to high levels of soil sodium and chloride ions are more difficult to detect. The symptoms are similar to other stress symptoms, especially those of moisture stress and nutrient deficiencies. There is a time lag for the effects to show either because of one instance of a heavy dose or a continual low level dose that has accumulating effects and eventually builds up to a toxic level. Plants under salt stress are susceptible to insect and disease injury. McDonald (1982) reports that high salt levels increases the susceptibility of rhododendrons and chrysanthemums to Phytophthora root rots.

Ion antagonism is the major effect on plants by an excess of sodium. It competes with and reduces the uptake of potassium, calcium, magnesium especially, and can interfere with other nutrient cations. Fertilization with calcium and potassium will reduce the effects of excessive sodium provided that the addition of fertilizer does not drastically increase the soluble salt concentration. The chloride anion is highly soluble and does not bind strongly to the soil adsorptive surfaces as does the sodium. But it can interfere with the uptake of other anions especially phosphates as well as the sulfates and nitrates. Chloride toxicity can be reduced by fertilization with sulfates.

Salts in the soil

Salt may enter the soil mostly as spray on the surface, that contained in snow and ice and windrowed by plows on the soil surface, or as runoff from road and sidewalk surfaces. The amount of salt that enter the soil is related to (Hutchinson, 1967, 1974):

- extent of soil surface freezing during salt runoff periods;
- soil surface and internal drainage;
- slope and immediate microrelief;
- existence of drainage diversion structures;
- rate and number of salt applications;
- timing of application during the season;
- cation exchange capacity of the soil profile.

The amount of soluble salts in the soil may be measured by electrical conductivity. There is a direct relationship between soluble salt content in the soil solution and the electrical conductivity of the solution (Figure 1). The analysis has been used for many years in determining alkaline and saline soils of dry regions of the world. It is also used for soils that are exposed to de-icing salts. One of the effects of deicing salts on soil is to decrease (become more negative) the osmotic potential of the soil solution (Figure 2). This increases the amount of energy the plant must expend to absorb the water from the soil. Amrhein and Strong (1990) found the electrical conductivity of soils from six U.S. roadside locations ranged from an average of 0.57 dS/m on Cape Cod to 4.04 dS/m at Donner Pass, California. The maximum value, 8.83 dS/m, was in the surface horizon at the latter location. Sensitive plants may be restricted from locations with the upper values. The level at Donner Pass shows that only salt-tolerant species will grow there.

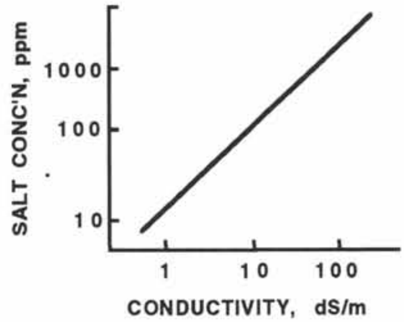

Figure 1. The relationship between soil salt concentration and electrical conductivity.

The sodium replaces other cations on the soil-exchange sites creating a potential nutrient imbalance. The adsorbed sodium tends to disperse soil colloids, filling small pores, which reduces water infiltration and gaseous diffusion. Being highly soluble, the sodium chloride is easily carried into natural waterbodies, contaminating the water. The salts themselves corrode concrete, various metals, asphalt, and other unprotected surfaces. The sodium chloride stimulates the release of heavy metals from sediments.

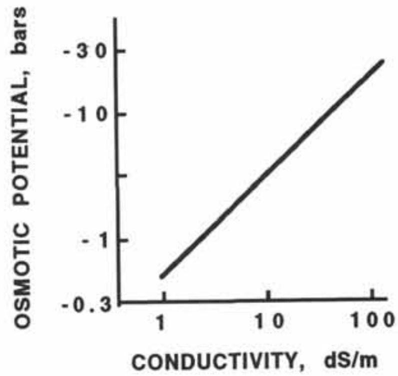

Figure 2. The relationship between soil salt concentration and osmotic potential.

The soluble salt concentration, usually given in parts per million (ppm), or as determined by electrical conductivity (dS/m) are not totally satisfactory for soil salt analysis and the effects on plants. Because plant nutrients are salts, a portion of the soluble salt concentration, and in turn the electrical conductivity, is contributed by them. Thus, a soil high in soluble nutrients will exhibit high soluble salt concentration. For the effects of de-icing salts we are interested primarily in the sodium concentration and its relation to other soil cations. The analyses that avoid this problem are the sodium adsorption ratio (SAR) and the exchangeable sodium percentage (ESP), which have been found more satisfactory in research studies (Kelsey and Hootman, 1990). The sodium adsorption ratio is calculated as

$$SAR = Na^{+} / ([Ca^{++} + Mg^{++}]/2)^{1/2}$$

and the exchangeable sodium percentage as

$$ESP = (Exch.\ Na^{+}/Cation\ Exchange\ Capacity) \times 100\%.$$

The apparent critical value for the SAR is 12. Most plants are susceptible to damage at soil levels above this value. ESP values greater than 15 indicate only salt-tolerant species would survive. Also, soil aggregates begin to break down at this value with some evidence showing at a value of 10. The effect is to decrease soil aeration and water permeability, soil drainage, and increase bulk density (Richards, 1954). Some salt-laden soils may have a low EC but very high SAR and ESP values indicate salt problems. A soil with a low electrical conductivity (EC=1-2.5 dS/m) may have a high sodium hazard at a SAR of 18 or greater. In a soil with very high EC (greater than 22.5 dS/m) medium hazard is reached at a SAR value of 2 and high is reached at a SAR of 6.5.

Materials used as de-icing salts and relative phytotoxicity

Sodium chloride

This compound (NaCl) is the most common and least expensive of any of the available de-icing compounds. It is usually obtained from rock salt mining operations. However, it creates more problems than any of the other compounds because of its complete dissociation into sodium and chloride ions. It greatly increases the problem with osmotic potential of the soil solution and may cause "salting out," -- the plants suffering from lack of water and nutrient insufficiency. The sodium disperses the soil colloids and may create ion antagonism with potassium, calcium and magnesium. The chloride ion becomes toxic to plant roots (Blaser, 1976). As explained earlier, its phytotoxicity tends to be greater than other de-icing compounds.

Calcium chloride

Not used as widely as sodium chloride, the calcium ($CaCl_2$) it contains contributes to the calcium reserve when washed into the soil from sidewalk or roadway surfaces. It is a little less effective as a de-icing agent but it is less corrosive than sodium chloride. It is more expensive than sodium chloride but cheaper than other alternatives. It is phytotoxic in excessive amounts because of the chloride ion content. It does not affect the osmotic potential of the soil solution as greatly as sodium chloride does.

Urea fertilizer

This material ($CO(NH_2)_2$ is a commercial nitrogen fertilizer with a moderate salt index. It tends to melt snow and ice to a lesser extent. It is used on some commercial ski slopes to make the snow more granular. It has the added effect of fertilizing the ski trail vegetation. This latter effect is most noticeable on the mountain soils with their low fertility. This material becomes phytotoxic when applied in excessive amounts that may occur mainly on heavily used walkways, etc. Elsewhere its fertilizer value is beneficial. For urban use, the fertilizer may be mixed with sand.

Methods to prevent salt damage

Use of Alternate Materials

Substitutes for sodium chloride, the most commonly applied deicing salts, have been sought because of its adverse impact on plants, soil, structures, vehicles, and road surfaces. Calcium chloride is somewhat less corrosive but is more expensive.

Sand. Sand is chemically inert and not really a de-icing compound unless mixed with salt. It contributes a large degree of friction to the road surface and prevents skids. It is used widely in rural and wild country areas where there are few drainage structures and sand is plentiful. It has the disadvantage of clogging culverts, storm drains and ditches. Sand is the usual material applied in watersheds and other areas sensitive to salt application.

Calcium-Magnesium Acetate. A favorable substitute appears to be calcium magnesium acetate (CMA) (Elliott and Linn, 1987). This compound does not corrode surfaces as does the chlorides, melts snow and ice just as effectively, and is less toxic to aquatic organisms. There may be temporary release of heavy metals in strongly buffered acid roadside soils, but the acetate solubilization may be reduced as the acetate neutralizes the soil. Further, the acetate ferments in the soil leading to its decomposition. The CMA overall has less effect than the chlorides on heavy metals entering aquatic systems (Amrhein and Strong, 1990). Thus, continued use of CMA may not pose a problem in the release of heavy metals and would be an improvement over present conditions. However, CMA is much more expensive than sodium chloride or calcium chloride. The question arises over its increased cost being offset by the reduced costs of damage to infrastructures and vehicles and the negative environmental impact of the usual deicing salts.

A suggestion for deicing sidewalks near plants is to mix small amounts of urea-based fertilizer with sand. If frequent applications are necessary, there is danger of over fertilization with the urea fertilizer. Alternate applications with pure sand and the fertilizer/sand mixture may reduce the potential problem.

De-icing Salt Barriers

Fences. Placement of physical barriers along roadsides to prevent the splash and dispersal of salt onto roadside soils and vegetation is very common in Europe (Hvass, 1985). Temporary fences composed of straw or other inexpensive materials are constructed at curbside. The best protection is provided by straw fencing 60 cm high and lined on the inside with plastic to prevent penetration of the saltwater. Attempts to reduce salt damage and the amount entering the soil by using plastic erosion control sheeting as fencing along a major divided highway in Chicago have had some success.

Covers. The soil surface may be temporarily covered with a low sloping roof about 6 inches above the ground so that salt-laden snow or splash water drains away from the vegetation and soil back onto the roadway. Precipitation during the dormant season reaches the soil through trunk space openings in the roof and by stemflow. This is very expensive and would be used only in areas with very high aesthetic value. The only instance known to the author is in the Netherlands.

Raised beds or berms. Another technique is to construct raised beds at least 20 to 40 cm higher than the sidewalk surface or berms that have soil surfaces well above the street level. Not only does this design protect the soil and trees from traffic and salt spray and salt-containing snow windrows, the soil rooting volume is significantly increased to the benefit of the planted vegetation.

Soil Flushing

Using low salt-content water to flush a salty soil is commonly used in irrigated fields of southwestern United States and elsewhere. Agronomists calculate how much water with a known salt concentration needs to be applied to reduce the salt concentration of a salty soil to a tolerable level. In most areas where de-icing salts are used on roadways there is usually readily available water for flushing, but the manual labor and equipment involved can be expensive and the value of the plant material may not be perceived by officials as being of high priority. Informal research in Syracuse, New York shows that spring snow melt combined with heavy rains will flush most of the sodium from the upper soil profile by June of years with average snow and rainfall. Flushing is more effective on sandy soils than on clayey or silty soils. About 12 inches of water will leach most of the chloride ions below 24 inches in clayey soils (Rubens, 1978).

Application of Gypsum

Gypsum (Ca_2SO_4) is added to saline and sodic soils to reduce excess salt effects. The amount to be applied depends on the type of salt and the salt concentration, the cation exchange capacity and organic matter content of the soil. Some soils may require as much as 500 pounds per 1000 square feet. Sulfur itself is more efficient and would reduce the amount applied by a factor of 5.

Soil Replacement

Replacement of contaminated soil is common in Europe and not as common here. Special equipment has been developed to vacuum the soil after it has been mechanically loosened or formed into a slurry by hydraulic means. Fresh soil material is put into place. The major problem encountered with this technique is potential damage to the small and medium tree roots. In addition, the roots must be protected from desiccation during the temporary exposure to air and sunlight. Proper sequencing of soil removal and replacement is critical to a successful operation. Elaborate means are required. Some damage must be expected even when the work is accomplished with extreme care. Soil replacement for woody ornamental and smaller plants usually includes the replacement of the plants too. Post replacement care of the vegetation is a vital part of the operation. Arborists in Belgium, Germany and the Netherlands have developed this technique to a high degree. Several practicing arborists in California have adopted the method. The only example of major soil replacement in the eastern United States known to the author is the Benjamin Franklin Parkway in Philadelphia. However, the failing oaks were replaced as well, eliminating the problem of potential root damage.

Planting of Salt-tolerant Species

If salt problems are anticipated during the planning stages of a project, it is wise to use salt-tolerant species initially. This forethought eliminates many future problems. Dirr (1976) lists the most salt-tolerant species as *Elaeagnus angustifolia* L., *Gletditsia triacanthos inermis* (Honeylocust), *Hippophae rhamnoides* L., *Pinus thunbergii* (Japanese black pine), and *Robinia pseudoacacia* (Black locust). See Table 1 for salt tolerance of other species. Townsend and Kwolek (1987) report the relative susceptibility of 13 pine species to salt spray. Lumis, et.al. (1975) give the salt tolerance rating of 71 woody ornamental species. Dirr (1976) gives the ratings for 123 tree species. Turgeon (1985) rates the warm season grasses Bermudagrass, zoysiagrass, and St. Augustinegrass as most salt tolerant. Cool season grasses most salt tolerant are the creeping bentgrass followed by tall fescue and perennial ryegrass. He does not mention the bluegrasses.

Conclusion

The use of road and sidewalk salt will continue as long as there are vehicles and pedestrians in the urban areas of northern climates. Specific research must be carried out on the salt tolerance of existing and newly introduced cultivars. Dirr (1976) offers a strong caution to the use of salt tolerance ratings without specific research:

> "Evaluations of salt-induced injury should be based on the salts, concentrations, application methods (aerial- versus soil-applied), osmotic effects, shoot or leaf contents of chloride ions, and perhaps, shoot levels of sodium. Elimination of any of these factors could result in misinterpretation of the salt resistance or susceptibility of a particular plant. Plant survival in saline soils does not automatically imply survival where salt is aerially applied and vice versa."

Table 1. The salt sensitivity of selected plants. Compiled from several sources.

Tolerant	Moderately tolerant	Moderately sensitive	Sensitive
Bermuda grass	Brome grass	Alfalfa	Apple
Nutall alkali grass	Clover, berseem	Timothy	Apricot
Tall fescue	Fig	Pear	Peach
Rosemary	Orchard grass	Forsythia	Roses
Salt grass	Sudan grass	Privet	Azaleas
Wheat grass crested fairway tall	Rye, hay perennial	Clovers, red alsike Ladino sweet	Pines: Red White Scots
Wild rye altai Russian	Trefoil, birdsfoot	(Kentucky bluegrass?)	Rhododendrons
Bougainvillea	Wheat	Junipers	Serviceberry
Red oak	Larches	Red maple	Dogwood
Norway maple	Sugar maple	White birch	Yew
Horsechestnut	White ash	Crabapple	Hemlock
Blue spruce	Lilac	Hawthornes	White spruce
White oak	Honeysuckle	Alder	Sugar maple
Black gum	Mountain ash	Bur oak?``	Balsam fir
Siberian pea tree	Wheat grass, western		American highbush cranberry
Russian olive			Norway spruce
White spruce			Douglas fir
Austrian pine			American linden
Bur oak?			Winged euonymus
Jackman's potentilla			Black walnut
Rugosa rose			
Buffaloberry			
Vanhoutte's spirea			
Snowberry			
Japanese black pine			
Alpine currant			
Honeylocust			
Mugo pine			

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