FACTORS AFFECTING ACCUMULATION OF DEICING SALTS IN SOILS AROUND TREES

by R.G. Hootman, P.D. Kelsey, R. Reid, and K. von der Heide-Spravka

Abstract. Parkways, street tree planter boxes, and highway medians and roadsides are locations where soil accumulation of deicing salts is highest. Sodium chloride is the most common deicer applied in the United States. Sodium chloride and other salts accumulating in the root zone may instigate and exacerbate street tree decline. Salts affect soil aggregate stability, porosity, and water and nutrient uptake in trees. Data collected in Chicago, Illinois show much higher soil sodium (1,272 µg/g) and chloride (348 µg/g) in the center of newly installed, narrow, raised medians along Lake Shore Drive after one winter, compared to the center of wide medians along the roadway (236 µg/g sodium and 23 µg/g chloride). Proximity to high speed traffic and its associated spray and splash were reasons for this. In suburban Downers Grove, Illinois, grade level street tree planter soils had extremely high levels of sodium (1,426 µg/g to 2,277 µg/g) compared to adjacent raised planter soils. The raised planters did not receive salt-laden runoff, splash, plowed snow, or direct application from salt spreaders.

Urban parkway and street tree planters present hostile environments for plants. Deicing salts, primarily sodium chloride, contribute to the harsh environments. Trees and large shrubs are of particular concern because of their monetary and aesthetic value. Excessive soil salts cause many of the same symptoms in plants as salts deposited directly onto tissue, though patterns and severity of symptoms may differ. Direct damage to plants from soil salts include reduced moisture uptake by plant roots. The plants subsequently exhibit scorched foliage due to desiccation of the tissue. Roots and associated mycorrhizae may also be killed (5). Transport of excessive sodium or chloride to the above-ground tissue may result in dieback and lack of vigor (6). Indirect impacts of salts include sodium competition with potassium, calcium, magnesium and other cations, potentially reducing nutrient uptake in plants (16). Excessive sodium breaks down soil structure by dispersion of colloids resulting in reduced pore space. Rubens (15) reports that soil sodium at 10% of cation exchange capacity will begin impacting physical soil properties.

Soils immediately adjacent to salted roadways are most susceptible to increased sodium and chloride levels. The majority of this is attributed to salt-laden splash and meltwater runoff. More than 90% of salts spread onto roadways are transported no further than 15 m (49 ft) from the road (3). Langille (11) found that soil sodium levels had increased from 18 µg/g to 68 µg/g after one winter within 12 m (39 ft) of a new interstate highway in Maine. Although a statistically significant change, these soil concentrations were not above the 250 µg/g threshold of sodium and chloride considered excessive to most trees. Kelsey and Hootman (10) found an average of 846 µg/g of sodium in the upper 10 cm (4 in) of roadside sidewalk planter soils in suburban Chicago. In two parkway sites, Kelsey and Hootman (9) found soil sodium levels as high as 620 µg/g to a depth of 15 cm. Sodium levels in each of these studies were extremely high and potentially injurious to most trees. Hofstra et al. (6) noted significantly higher soil sodium and chloride within 30 m (100 ft) of an Ontario roadway. Sodium was as high as 700 µg/g and chloride as high as 1000 µg/g within the 30 m (100 ft) distance.

Site characteristics affect salt runoff and accumulation. Iverson (8) found potentially phytotoxic sodium levels in depressions receiving expressway runoff compared to nearby uplands, and Piatt and Krause (14) note significantly greater chloride accumulation in soils downslope from a roadway compared to upslope.

Total deicing salt use in cold climates has been rising since 1970 due to increasing roadway construction and public safety concerns. Rates of application per lane-km, however, have not risen significantly (3,4,7). Urban regions tend to have higher application totals, and winters with more storms have more salt usage (4,7). Gales and

VanderMeulen (4) indicate metropolitan Detroit averaged about 22 metric tons (mt) of salt applied per lane-km (40 tons [t] per lane-mi) per winter from 1965 to 1990, while Michigan overall averaged 14 mt per lane-km (25 t per lane-mi) for the same period. The Illinois State Toll Highway Authority (ISTHA) (7) has averaged nearly 21 mt per lane-km (37 t per lane mi) per winter along the section of Interstate 88 at The Morton Arboretum near Lisle, Illinois, or 126 mt per km (220 t per mi) of six lane expressway. Municipalities in the Chicago, Illinois region average about 13 mt per lane-km (23 t per lane-mile) (18).

This study examines various planter types and roadway scenarios around those planters to determine their influence on the accumulation of deicing salts in the soil.

Methods

Two study areas were selected: the median of Lake Shore Drive in Chicago and streetside sidewalk planters in the central business district (CBD) of Downers Grove, Illinois. The two areas reflect dichotomous salt-use scenarios because of environmental and traffic pattern differences.

Lake Shore Drive has eight lanes of traffic and a 65 km per hour (40 mph) winter speed limit. Four sites on the Drive were chosen to represent various roadway and median characteristics that might affect deicer application, dispersal, and deposition. Two sites were within a narrow, raised median

Figure 1. Narrow median planter along Lake Shore Drive, Chicago, with Lake Michigan in the right background. The planter is raised 0.8 m (2.5 ft) above the roadwaw. Photo credit: Jim Nachel

Figure 2. Grade level and raised planters in Downers Grove. Photo credit: Jim Nachel

and two sites were within a wide, road-level median. Traffic counts at each site show essentially equal traffic levels (2). The narrow median is 3 m (10 ft) wide and raised 0.8 m (2.5 ft) above the roadway (Figure 1). The wide median is about 30 m (100 ft) across and level with the roadway. One surface soil sample (0-15 cm deep, 0-6 in) was gathered on 28 December 1992 and on 30 March 1993 in the center of each median site.

Streets in the Downers Grove CBD are two lanes and speeds are less than 50 km per hour (30 mph) due to the stop-and-go traffic at intersections. A soil sample was taken at each of two grade level planters and each of two raised planters in 1991; only one grade level planter and one raised planter were sampled in 1993 (Figure 2). Samples in Downers Grove were taken at depths of 0-10 cm (0-4 in) and 20-30 cm (8-12 in).

All soils were tested for pH, electrolytic conductivity, elemental concentrations, cation exchange capacity, and base saturation. Sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) were calculated for each soil (1, 17). These are given below.

(Eq. 1) SAR = $Na^+/([Ca^{++}+Mg^{++}/2)1/2$.
(Eq. 2) ESP = (Exchangeable Na^+/Cation Exchange Capacity)x100%.

Results and Discussion

Snowfall during the winter of 1992-93 at Chicago's O'Hare Airport was officially 118 cm (46 in), about 13 cm (5 in) above average (12, 13). The airport is not on the lakefront. Lakefront data were not available. There were also freezing rain and mixed precipitation events; the total number of deicing events in each study area is not known.

Lake Shore Drive median, Chicago. The winter of 1992-93 was the first in which the narrow, raised planter soils were in place; the wide median had been physically undisturbed for about 45 years. The December sample was gathered after deicing for the season had begun and does not reflect the new, pre-deicing, uncontaminated planter soil. The high soil sodium, chloride, SAR, and ESP in the new raised planters on 28 December reflect how quickly deicing salts had already accumulated in the soil (Table 1).

The two planter types each increased in sodium, chloride, SAR, and ESP between the beginning and end of the study (Table 1). Sodium and chloride increased to extremely high levels in the narrow median after only one season, although variation was quite high (Table 1 and Figure 3). Sodium saturation in this planter soil increased during the winter at the expense of calcium and magnesium saturation (Figure 4). Potassium showed little change. The close proximity of the narrow median to traffic and associated heavy splash and spray is the reason for the elevated levels. The high speed of the traffic was significant in causing the heavy splash and spray.

The wide median was much lower in sodium, chloride, SAR, and ESP throughout the winter compared to the narrow median, although variation was high (Table 1). This median does not receive direct splash or runoff, only aerial deposition, thus, this median had relatively low levels of deposition and accumulation, as evidenced by the soil sodium concentrations at the start of this study.

Soil pHs above 8.3 signify sodium-affected chemistry; this is not typical of humid region soils. Where sodium deicers are used extensively in the Chicago area, soil pHs have been found as high as 9.9 (10). Though elevated, no pHs on Lake

Table 1. Mean soil salt properties.

Site	Date	Depth (cm)	Sodium (μg/g)	Chloride (μg/g)	pH	SAR	ESP
Medians of Lake Shore Drive, Chicago.							
Narrow, raised	Dec. 1991	0-10	424±11	106±26	7.6±0.1	10.8±0.1	9.3±0.3
	March 1993	0-10	1272±443	348±73	7.9±0.5	32.7±12.9	23.7±8.1
Wide, at grade	Dec. 1991	0-10	344±381	56±16	7.6±0.2	8.2±8.9	6.5±6.9
	March 1993	0-10	236±78	23±8	7.6±0.1	5.8±2.1	4.8±1.8
For the planter types in Downers Grove.							
Grade level	Aug. 1991	0-10	1600±686	278±173	8.1±0.1	48.9±18	40.6±9.4
	May 1993*	0-10	1529	129	8.5	41.8	37.6
	Aug. 1991	20-30	1486±586	440±42	8.5±0.1	48.0±15	40.4±7.7
	May 1993*	20-30	2277	223	8.1	63.2	47.7
Raised	Aug 1991	0-10	199±13	220±57	7.5±0.1	3.8±0.8	4.2±1.2
	May 1993*	0-10	217	104	7.8	4.3	4.8
	Aug. 1991	20-30	127±28	180±28	7.3±0.1	2.6±0.1	2.4±0.1
	May 1993*	20-30	93	110	7.4	2.1	1.8

* May 1993 included only one site

Shore Drive were above 8.3 (Table 1).

As noted by Kelsey and Hootman (10), conductivity is not a useful criterion for evaluating sodium chloride affected soils. Electrolytic conductivity data in this study were all less than 1.1 mmhos/cm and are not presented individually.

Downers Grove planters. The data from study sites in Downers Grove vary considerably. The sites with the highest sodium, chloride, pH, SAR, and ESP levels were the grade level sidewalk planters (Table 1). The levels of sodium in these planter soils are higher than other data reported in the region (8,9,10). These planters receive roadway splash and spray, get direct deicer application from spreaders, and receive salt-laden sidewalk runoff. Each of these contributes greatly to the accumulating salts. The soils also have a high clay content, which minimizes leaching of the accumulated salts. This is perhaps best indicated at the 20-30 cm (8-12 in) depth, which showed an accumulation of sodium between 1991 and 1993, with SAR and ESP also increasing.

Despite being located adjacent to the street, the raised planters have significant advantages with regard to salt protection. Unlike Lake Shore Drive, traffic splash is minimal here because of the lower traffic speed. Sidewalk meltwater cannot run off into these planters. The data reflect these observations. Sodium, chloride, SAR, and ESP were very low and do not represent a stressful plant environment (Table 1 and Figure 3). Changes from 1991 to 1993 were negligible, suggesting sodium and chloride deposition was minimal during that time.

Soil pHs in the Downers Grove grade level planters were higher than all other sites in this study (Table 1). Some pHs were above 8.3, indicating sodium impact on soil chemistry.

Summary

Planter type and traffic patterns in an area, among other factors, influence the levels of salt entering the soil. Newly installed median planter soils along Lake Shore Drive, Chicago, in less than one winter season, accumulated levels of deicing salts considered stressful to most woody plants. Two primary factors contributed to this accumulation: 1) narrowness of the planters and their proximity to traffic, which made them susceptible to splash and spray from traffic in both directions, and 2) high traffic speed, which induced greater levels of splash that easily breached the median planter wall. Sites farther from direct roadway splash, spray, and runoff accumulated much less salt. Soils gathered in the center of a 30 m (100 ft) wide median that had been in place on the Drive for several decades, had little salt accumulation over the season and minimal stress values.

Soil salt indicators varied greatly within and among planter types in Downers Grove. Grade level sidewalk planters had very high sodium, chloride, SAR, ESP, and pH in the soil surface and at depth over the course of two years. Leaching is minimal over time in this planter type due to the

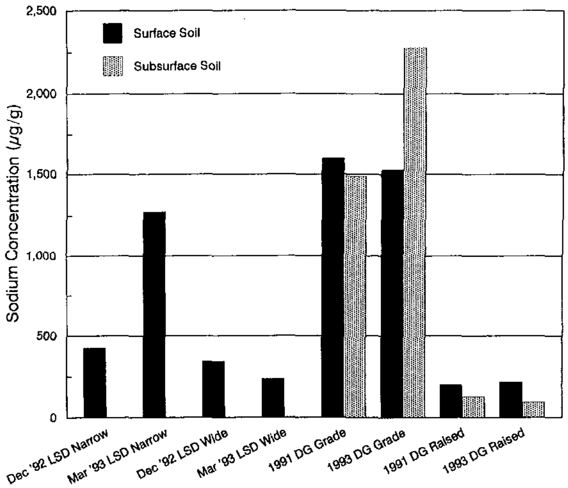

Figure 3. Mean soil sodium in Lake Shore Drive (LSD) and Downers Grove (DG) planters.

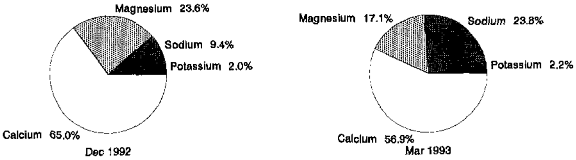

Figure 4. Mean percent base saturation of the narrow median planter surface soils on Lake Shore Drive.

high deposition rates and high clay content of the soil. The high salts in grade level planters were attributed to salt-laden splash and spray from roadway traffic, salt-laden plowed snow, sidewalk meltwater runoff directly into the planter, and direct salt application from road and sidewalk spreading. Levels of salts in raised planters in the same location were very low and not considered stressful.

Several options are available for municipalities to minimize or eliminate deicing salt accumulation in planters. Dobson (3) thoroughly reviews methods of reducing salt damage, including the following:

- Examine the use of abrasives or alternative deicers that do not contain sodium or chloride. The more expensive alternatives could be used selectively on smaller scales, such as near environmentally sensitive areas or on sidewalks.
- Calibrate salt spreaders. In England, application rates were found to be 2 to 8 fold higher than recommended due to failure to calibrate the spreaders.
- Eliminate hand spreading, which promotes uneven application and wastes deicer compound.
- Irrigate planter soils to leach sodium and chloride before spring growth. Be sure to avoid saturated conditions. Leached potassium or magnesium can be replaced through application of fertilizers.
- Apply gypsum (calcium sulfate) to the soil, which decreases sodium buildup by displacing it with calcium. This may also lessen dispersion of soil particles and the resultant loss of soil structure caused by excessive sodium.
- Design and engineer sites to keep salt spray, runoff, and plowed snow away from planters. Ideas include raised planters to eliminate runoff, lowered speed limits to reduce splash and spray, and high-density fabric fencing around planters to reduce splash and spray onto the soil.

Acknowledgment. The authors wish to thank Steve Ruffolo, Assistant Director of Public Works for the Village of Downers Grove, and the City of Chicago for making planter sites available for study. This project was funded in part by a research contract from the Chicago Park District.

Literature Cited

1. Black, C.A. 1984. Soil-Plant Relationships. pp 356-404. Robert E. Krieger Publishing Company, Malabar, FL.
2. City of Chicago. 1993. Unpublished traffic count data. Department of Engineering.
3. Dobson, M.C. 1991. Deicing salt damage to trees and shrubs. Forestry Commission Bull. 101, London. 64 pp.
4. Gales, J.E. and J. VanderMeulen. 1992. Deicing chemical use on the Michigan State Highway System. pp 135-184. **In** F.M. D'Itri (Ed.) Chemical Deicers and the Environment. Lewis Publishers, Inc., Boca Raton, FL.
5. Guttay, A.J.R. 1976. *Impact of deicing salts upon endomycorrhizae of roadside sugar maples.* Soil Sci. Soc. Am. J. 40:952-954.
6. Hofstra, G., R. Hall, and G.P. Lumis. 1979. *Studies of salt-induced damage to roadside plants in Ontario.* J. Arboric. 5:25-31.
7. Illinois State Toll Highway Authority. 1992. Unpublished deicing salt usage data. ISTHA Department of Engineering.
8. Iverson, L.R. 1984. Studies of Morton Arboretum and roadside soils next to the proposed highway FAP 431. Illinois Natural History Survey, Champaign, IL. 44 pp plus appendices.
9. Kelsey, P.D. and R.G. Hootman. 1988. *Soil and tree resource inventories for campus landscapes.* J. Arboric. 14:243-249.
10. Kelsey, P. and R. Hootman. 1990. *Soil resource evaluation for a group of sidewalk street tree planters.* J. Arboric. 16:113-117.
11. Langille, A.R. 1976. *One season's salt accumulation in soil and trees adjacent to a highway.* HortScience 11:575-576.
12. National Oceanic and Atmospheric Administration. 1992. Climatological Data, Illinois. December, Vol. 96 (12). NOAA, Asheville, NC. 31 pp.
13. National Oceanic and Atmospheric Administration. 1993. Climatological Data, Illinois. January-April, Vol. 97 (1-4). NOAA, Asheville, NC.
14. Piatt, J.R. and P.D. Krause. 1974. *Road and site characteristics that influence road salt distribution and damage to roadside trees.* Water, Air, and Soil Pollut. 3:301-304.
15. Rubens, J.M. 1978. *Soil desalination to counteract maple decline.* J. Arboric. 4:33-42.
16. Seatz, L.F. and H.B. Peterson. 1964. Acid, alkaline, saline, and sodic soils. pp 292-319. **In** F.E. Bear (Ed.) Chemistry of the Soil. Reinhold Publ. Corp., New York.
17. United States Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. USDA Agric. Handb. 60. U.S. Gov. Print. Office, Washington, DC.
18. Village of Downers Grove. 1992. Unpublished deicing salt usage data. Department of Public Works.

Assistant to the Director, Research Soil Scientist, and Research Assistant, respectively
The Morton Arboretum
Route 53
Lisle, IL 60532,
and
Village Forester
801 Burlington
Downers Grove, IL 60515

Résumé. Le chlorure de sodium est le sel de déglaçage le plus couramment utilisé aux États-Unis. Le chlorure de sodium, ainsi que les autres sels utilisés, s'accumule dans la zone des racines, et peut créer et amplifier des problèmes de dépérissement chez les arbres de rues. Les sels affectent la stabilité des agrégats du sol, la porosité du sol ainsi que l'eau et les éléments minéraux disponibles pour l'arbre. Des données recueillies à Chicago en Illinois montrent des concentrations de chlorure de sodium plus élevées dans le centre des terre-pleins surélevés de construction récente de la rue Lake Shore en comparaison avec le centre de terre-pleins plus larges. Dans la banlieue de Chicago, les plantations d'arbres au niveau de la rue ont des concentrations plus élevées de sel comparé aux plantations surélevées à proximité. Les plantations surélevées ne reçoivent pas autant de sel en provenance de la fonte, des éclaboussures, des amoncellements de neige ou directement des épandeuses d'abrasifs.

Zusammenfassung. Sodiumchlorid ist das in den USA am häufigsten angewendete Enteisungsmittel. Sodiumchlorid und andere Salze, die sich in der Wurzelzone akkumulieren, können de Rückgang von Strassenbäumen in Gang setzen und verschlimmern. Die Salze beeinflußen die Stabilität der Bodenaggregate, die Porösität und die Wasser-und-Nährstoffaufnahme in Bäumen. Die erhobenen Daten in Chicago, Illinois, zeigen einen viel höheren Sodiumchloridgehalt im Zentrum von neu errichteten, erhöhten Mittelstreifen der Seeuferstrasse verglichen mit dem Zentrum von breiten Mittelstreifen. In den Vorstadtbezirken von Chicago haben die Böden der Grünstreifen, die in Ebene mit der Straße liegen, verglichen mit höher gelegenen Grünstreifen extrem hohe Sodiumwerte. Die höher gelegenen Pflanzstreifen bekommen weniger salzbelastetes Spritzwasser, seitlich hochgepflügten Schnee oder direkte Salz-Applikationen von den Streufahrzeugen ab.