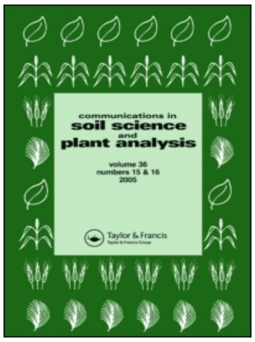

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SODIUM ACCUMULATION IN SOILS AND PLANTS ALONG MASSACHUSETTS ROADSIDES

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ABSTRACT

The most common de-icing material applied by the Massachusetts state highway department is sodium chloride (NaCl). In Massachusetts, the rate of application of de-icing agents is about 240 lb (110 kg) of sand and 12 lb (5.5 kg) of NaCl per lane mile (1.6 km). The objective of this research was to examine injury to plants along roadsides and to assess relationships of damage to the amount of Na detected in plants and soils. The damage on most plant species was manifested as burning or browning of the leaves or needles. Coniferous species, especially pines (*Pinus* spp.), were sensitive to NaCl injury. In coniferous species, the damage appeared as browning on the ends of the needles, but new growth was not affected. Most of the damage occurred on the needles on the tree side that faced the road and where salt spray from cars or plows could have been a factor in the degree of damage. Widespread damage was also seen on spruce (*Picea* spp.), sumac (*Rhus typhina*), and mountain laurel (*Kalmia latifolia*) along roadsides. With sumac, injured plants had only

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10% of the foliage as uninjured plants. Some salt-tolerant species, apparently undamaged by NaCl, in the same vicinity as the damaged plants, were various oaks (*Quercus* spp.), maples (*Acer* spp.), grasses (mixed species), ferns (mixed species), and yarrow (*Achillea millefolium*). The Na concentrations in the leaves of pines, sumacs, grasses, and oaks decreased as the distance from the road increased. The Na concentrations in pine needles were 3356 mg kg^{-1} at 10 feet, 1978 at 15 feet, and 1513 mg kg^{-1} at 20 feet. The Na concentrations in maple leaves decreased with the Na concentrations being 249 mg kg^{-1} at 10 feet and falling to 150 mg kg^{-1} at 30 feet. The concentrations of Na in roadside soil ranged from 101 mg kg^{-1} at 5 feet to 16 mg kg^{-1} at 30 feet from the roadside, with a marked decrease in the Na concentration in the soil after 15 feet. The pH decreased as the distance from the road increased ranging from 7.60 at 5 feet to 5.78 at 30 feet. The electrical conductivity values decreased as the distance from the road increased and ranged from 0.16 dS m^{-1} at 5 feet to 0.12 dS m^{-1} at 30 feet. This study suggests a relationship between Na accumulation, in leaves and in soil, and injury to roadside plants.

INTRODUCTION

Salts are applied to highways during winter months to help de-ice the roadways. Some of the salts used in the de-icing procedures have been shown to have phytotoxic effects on plants (1,2,3). Research has shown that different plant species have varying susceptibility to damage from NaCl (3). The method by which the NaCl comes into contact with the plant, either by salt spray or by soil-borne salt, is one of the most important factors in determining the severity of foliar damage (4).

Sodium damage to plants along roadsides is caused by salt sprays from plows and vehicles passing on the road or by the accumulation of Na in the soil (2,4). Research with pines (*Pinus* spp.) has shown that salt coating of the needles acts as a non-selective herbicide (1,2). The salt on the needles creates an osmotic stress resulting in water loss and cell plasmolysis, ultimately ending in injury (1,2). The severity of the damage to the plants from salt spray decreases the farther plants are from the road. Blomqvist (5) reported that 90% of salt in roadside soils is detected within 40 feet of the road. Research showed that the most severe damage to foliage was on plants within 30 feet of the road (6,7). Salt spray injury was usually greater on the side of the plant that faced the road (2,4). McBean and Al-Nassri (8) found that of the salt deposited on the road, 10 to 25%

was spread through the air and found within 30 feet of the road. However, the distance of the trees from the side of the road is only one factor affecting severity of damage. According to Sucoff (4), as the amount of daily traffic increased, the amount of salt required to maintain the road also increased in a linear relationship. Soil properties such as slope of terrain, drainage, texture, duration of freezing in the soil, and the degree of soil compaction affect the amount of Na that reaches the rhizospheres of plants (6). High levels of Na in the soil also can alter the physical properties of the soil by dispersing soil aggregates, which would lead to puddling of finer textured soils (9). Sodium replaces K and other cations on the soil exchange complex and can lead to nutrient deficiencies (9). In most cases, although salt is applied in the winter, the symptoms of salt damage do not appear in the leaves until the spring. The increase of injury in the spring is attributed to the increased intake of water. When the temperatures warm up in the spring, and new growth is forming, the rate of transpiration in the plants increases along with the translocation of water, nutrients, and Na (2,9). However, plants that do not come into direct contact with Na from salt spray are not injured as severely as the plants that do (9).

Tolerances to salt damage vary widely among different plant species. Species of coniferous trees tend to have a more widespread amount of damage than other species. The symptoms of salt damage on pines were manifested as chlorosis or browning on the tips of the needles, whereas the new growth was not affected (1,3). In severe cases, the needles were completely brown and necrotic, and growth was suppressed (3). Salts applied to the roots resulted in a lesser degree of injury to the needles, and no growth suppression, than the salts that were applied directly to the needles (3). Deciduous species tend to be more tolerant to salt spray or to soil-borne salt than coniferous species. In deciduous trees, the symptoms of salt damage manifested as post-flushing dieback and foliage discoloration (10). Deciduous species, which lose their leaves in the fall, are not as susceptible to salt spray as the coniferous species, which retain their foliage throughout the winter. In the spring, when new growth is forming, the concentrations of Na in the soil are lowered by leaching, resulting in much lower incidents of foliar damage than might occur from direct deposition of salt on the foliage.

Sodium chloride works effectively as a de-icing agent with temperatures falling to -8°C, and $CaCl_2$ is effective down to -20°C. Research has shown that by increasing Ca concentrations, the effects of stress from applications of NaCl can be reduced (11). Bogemans (12) demonstrated that substituting 20 to 30% of $CaCl_2$ for NaCl resulted in a 50% decrease of Na in the needles of spruce. Although $CaCl_2$ is less phytotoxic than NaCl, $CaCl_2$ is more expensive and difficult to handle and store (13). Therefore, since NaCl is the main de-icing agent used in Massachusetts, this study focused on the toxic effects of Na to various plant species.

MATERIALS AND METHODS

Sampling

Leaf and soil samples were taken from sites along Massachusetts roadsides that had apparent salt damage and from sites that showed no visible signs of salt damage to vegetation. The sampling sites included Massachusetts Routes 2, 8, 9, 63, 116, and 181, US Routes 2 and 202, Interstate 91, various sites on the University of Massachusetts, Amherst, campus, and from a forest area where no salt had been applied (Table 1). Soil samples and leaf samples were taken from each site. Soil samples were taken in 5- or 10-foot (1.5 to 3 m) increments, perpendicular to the road. The soil samples were taken with a soil corer to a depth of 12 inches (30 cm). For each sample, three sub-samples of single cores were obtained and thoroughly mixed to form one sample. Leaf samples were taken from vegetation that showed signs of Na damage on the foliage and also from healthy plant species on which no signs of injury were visible. The leaf samples taken from healthy plant species were collected from all sites sampled, including sites where no injury was visible on any species.

Soil Analysis

Soil samples were placed in an oven and dried at 70°C for 72 hours. After the soil was dry, pH, electrical conductivity, and Na concentrations were determined.

EC and PH

To determine electrical conductivity (EC) and pH, the soil samples were extracted by a saturated paste method (14). The soils were saturated with distilled water and were allowed to sit for one hour with no shaking. The soils were then filtered by suction, and EC and pH were determined on the extract.

Soil Extraction

The soil samples were extracted with Morgan's universal extracting solution (15). The Morgan's solution was prepared by dissolving 100 g of ammonium acetate in 1 liter of distilled water. The acetate solution was adjusted to pH 4.7 with glacial acetic acid. Ten grams of each soil sample were weighed into 100-mL beakers, and 40 mL of Morgan's solution were added. The samples

Table 1. Plant Species Sampled from Each Roadside

Highway	Species Sampled: Damaged	Species Sampled: Healthy
Mass. Route 2	Pine (*Pinus strobus*), Blue Spruce (*Picea pungens*)	Maple (*Acer rubrum*), Mixed Fescue (*Festuca* sp.), Sumac (*Rhus typhina*), Oak (*Quercus* sp.)
Mass. Route 8	Pine (*Pinus strobus*)	Maple (*Acer rubrum*), Mixed Fescue (*Festuca* sp.)
Mass. Route 9	Pine (*Pinus strobus*, *Pinus resinosa*), Sumac (*Rhus typhina*), Poplar (*Populus* sp.)	Maple (*Acer rubrum*), Mixed Fescue (*Festuca* sp.), Ferns, Oak (*Quercus* sp.), Poplar (*Populus* sp.), Ash (*Fraxinus* sp.), Yarrow (*Achillea* sp.)
Mass. Route 63	Pine (*Pinus strobus*, *Pinus resinosa*)	Maple (*Acer rubrum*), Mixed Fescue (*Festuca* sp.)
Mass. Route 116	Pine (*Pinus strobus*), Blue Spruce (*Picea pungens*)	Maple (*Acer rubrum*), Mixed Fescue (*Festuca* sp.), Sumac (*Rhus typhina*), Oak (*Quercus* sp.)
Mass. Route 181	Pine (*Pinus strobus*, *Pinus resinosa*)	Oak (*Quercus* sp.)
US Route 20	No damaged species	Maple (*Acer rubrum*), Mixed Fescue (*Festuca* sp.)
US Route 202	Pine (*Pinus strobus*, *Pinus resinosa*)	Maple (*Acer rubrum*), Mixed Fescue (*Festuca* sp.)
Interstate 91	Pine (*Pinus strobus*, *Pinus resinosa*), Spruce (*Picea pungens*), Sumac (*Rhus typhina*)	Maple (*Acer rubrum*), Mixed Fescue (*Festuca* sp.), Sumac (*Rhus typhina*), Oak (*Quercus* sp.)
UMASS Campus (no salt area)	No damaged species	Maple (*Acer rubrum*), Pine (*Pinus strobus*), Mixed Fescue (*Festuca* sp.)
Forest (no salt area)	No damaged species	Maple (*Acer rubrum*), Mixed Fescue (*Festuca* sp.), Ferns (*Osmunda claytoniana*, *Polystrichum acrostichoides*, *Dennstaedtia punctilobula*)

were extracted for 30 minutes on a platform shaker at 120 rpm. The samples were leached by gravity filtration with the Morgan's solution until a 50-mL volume was collected for each sample.

Plant Analysis

Tissue Ashing

Leaves were dried in an oven at 70°C for 72 hours. The samples were ground through a 40-mesh screen. A mass of 0.200 g was weighed for each sample and placed in a porcelain crucible. The samples were ashed in a muffle furnace at 450°C for 8 hr. After the samples cooled, 5 mL of 0.075 *M* HNO_3 were added to the ashed samples. After the ash dissolved, the samples were then transferred to a 50-mL volumetric flask. The crucibles were washed three times with 5-mL portions of the HNO_3 solution, and the solution was brought to volume. The HNO_3 solution was used in the samples and in the standards to keep the matrix of the two solutions the same (16).

Determination of Sodium

Portions of the soil extract or of the dissolved ash were placed in volumetric flasks and brought to volume after adding 2.5 mL of 20,000 mg KCl L^{-1} solution as an ionization suppressant. Each of these portions was then used to measure the concentrations of Na by atomic emission spectroscopy (17).

RESULTS AND DISCUSSION

Plant Analysis

The plant species that had the most widespread and severe damage over all of the sampling sites were pines and sumacs. The damage to the needles appeared as browning or burning and was mainly on the side of the tree facing the road. The concentration of Na in the leaves of the damaged pines was about 75 times the average Na concentration in healthy pine needle samples (Table 2). Healthy samples of pines averaged 28 mg kg^{-1} Na in the needles, compared to an average of 2130 mg kg^{-1} Na in the samples of damaged needles (Table 2). Also, the Na concentration in the needles decreased as the distance from the road increased ranging from 3356 mg kg^{-1} at 10 feet (3 m) to 1513 mg kg^{-1} at 20 feet (7 m) (Fig. 1). The damage to the needles facing the roads is suggested to be primarily from

Table 2. Mean Sodium Concentrations in Leaves of Various Plant Species

	Na Concentration in Leaves ($mg\,kg^{-1}$)			
	Healthy		Damaged	
Species	Mean	Range	Mean	Range
Ash	193	193	n/a	n/a
Ferns	1280	283–4131	n/a	n/a
Grass	928	203–2300	n/a	n/a
Maple	428	0–1693	n/a	n/a
Mountain Laurel	n/a	n/a	423	423
Oak	197	120–283	n/a	n/a
Pine	28	28	2139	250–3431
Poplar	338	338	310	310
Sumac	177	110–268	209	133–340
Spruce	n/a	n/a	616	208–1575
Yarrow	123	123	n/a	n/a

n/a indicates no observations were made.

salt spray. Evergreen trees retain their needles throughout the winter, thus increasing the chance of damage to the needles by spray, relative to plant species that drop their leaves during the winter.

Sumac also had widespread damage along the roads sampled. Many sumacs were severely damaged, appearing to have less than 10% of the leaves remaining on the plant. The mean concentration of Na in healthy sumac samples, $177\,mg\,kg^{-1}$, did not differ greatly from the mean Na concentration in the leaves of damaged sumacs, $209\,mg\,kg^{-1}$ (Table 2). It appeared that most of the damaged leaves had defoliated. The Na concentration in sumac leaves decreased as the distance from the road increased, ranging from $340\,mg\,kg^{-1}$ at 10 feet (3 m) to $150\,mg\,kg^{-1}$ at 25 feet (8 m) (Fig. 1).

Samples of mixed grasses were taken, and the mean Na concentration in leaves was $928\,mg\,kg^{-1}$ (Table 2). No damage was noted on any grasses even in areas where Na damage was evident on other plant species. The Na concentration in grass leaves decreased as the distance from the road increased, ranging from $1383\,mg\,kg^{-1}$ at 10 feet (3 m) to $203\,mg\,kg^{-1}$ at 30 feet (10 m) (Fig. 2).

Fern frond samples contained a mean Na concentration of $1280\,mg\,kg^{-1}$ (Table 2). No visible Na damage was evident on the ferns that were taken from a site where sumacs had severe Na damage. Average Na levels in fern tissue samples taken from the forested area where no salt had been applied were $970\,mg\,kg^{-1}$.

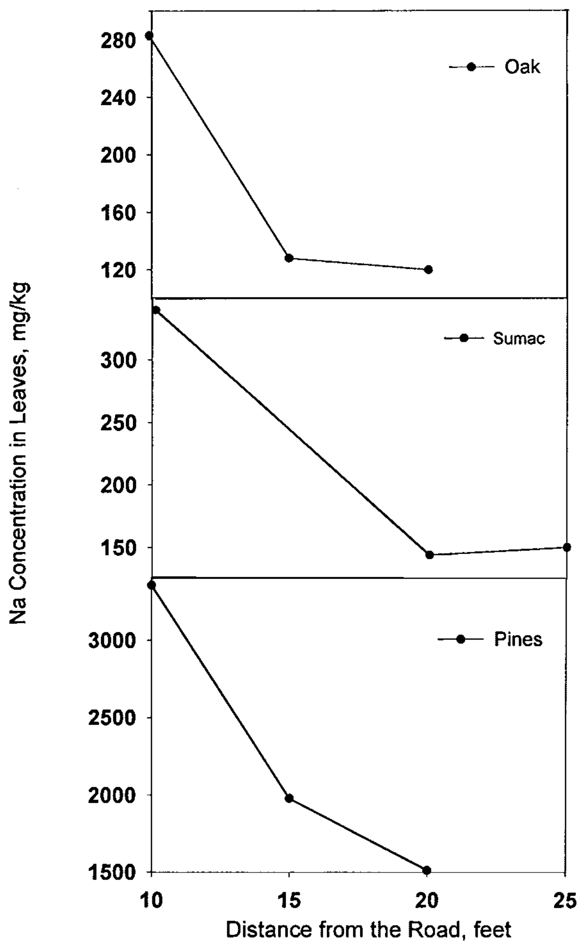

Figure 1. Mean Na concentration in leaves of pines, sumac, and oaks as a function of distance from the road.

Oak and maple species appeared to be salt tolerant. Both species were observed with no apparent damage in areas where damage was evident on other plant species. The average Na concentration was 197 mg kg^{-1} in oak leaves and 428 mg kg^{-1} in maple leaves (Table 2). The concentration of Na in maple leaves decreased as the distance from the road increased, ranging from 249 mg kg^{-1} at 10 feet (3 m), increasing to 168 mg kg^{-1} at 15 feet (5 m), and decreasing to 150 mg kg^{-1} at 30 feet (10 m) (Fig. 2). The concentration of Na in oak leaves

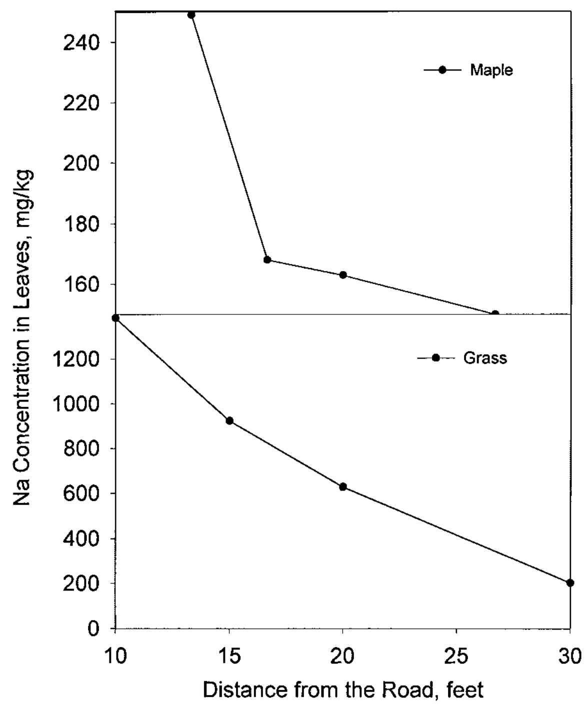

Figure 2. Mean Na concentration in leaves of grasses and maples as a function of distance from the road.

decreased as the distance from the road increased, ranging from 283 mg kg^{-1} at 10 feet to 120 mg kg^{-1} at 20 feet (7 m) (Fig. 1).

Sodium damage was evident on mountain laurel and spruce. The mean concentration of Na in mountain laurel leaves was 423 mg kg^{-1}, and the mean concentration of Na in spruce leaves was 616 mg kg^{-1} (Table 2).

Soil Analysis

The concentration of Na in the soil decreased as the distance from the road increased ranging from 101 mg kg^{-1} at 5 feet (1.5 m) to 16 mg kg^{-1} at 30 feet (10 m) (Table 3). A marked decrease in the concentration of Na in the soil occurred after a distance of 15 feet (5 m) from the road. The decrease in the Na concentration suggests that most of the Na in the soil comes from salt spray and hence falls near the road.

Table 3. Mean Sodium Concentration, pH, and EC in Soil as a Function of Distance from the Road

	Soil Measurements			
Distance from Road (Feet)	pH	EC	Mean Na (mg kg^{-1})	Na Range (mg kg^{-1})
5	7.60	0.16	101	21–295
10	7.13	0.22	145	145
15	6.7	0.23	154	19–270
20	6.48	0.21	89	10–309
30	5.78	0.12	16	2–22

The pH of the soil decreased as the distance from the road increased, ranging from 7.6 at 5 feet (1.5 m) to 5.78 at 30 feet (10 m) (Table 3). The EC of the soil decreased as the distance from the road increased ranging from 0.16 dS m^{-1} at 5 feet (1.5 m), increasing to 0.23 at 15 feet (5 m), and then decreasing to 0.12 at 30 feet (10 m) (Table 3). The high pH and EC values suggest that the soils close to the road are not highly leached of Na and that they have a higher base saturation than the soils with the greater distances from the roadside.

CONCLUSIONS

In general, most of the severe cases of salt damage to plant species were within 15 feet (5 m) of the road. Within 15 feet of the road, salt spray causes a majority of the damage. This injury is suggested also by the fact that most of the foliar damage is on the side of the tree that faces the road. Coniferous species, especially pines, were highly susceptible to salt damage. Regardless of species, the concentrations of Na in leaves were higher in the plants exhibiting damage than the plants of the same species appearing healthy. The Na levels in plant leaves decreased as the distance from the road increased regardless of species. About 90% of the salt that is sprayed from the road is found within 30 feet (10 m) of the road; therefore, the farther plants are from the road the less the chance of the spray to contact the plants. It seemed that deciduous species were more tolerant than coniferous species to Na. Coniferous species have more surface area to intercept the Na from the salt spray than the deciduous species that do not have foliage in the winter.

The concentrations of Na in the soil decreased as the distance from the road increased. The soil pH values were more alkaline at distances closer to the road. It appears that the Na on the soil complex results in a slightly alkaline soil (11). The EC values, a measurement of the soluble salts, were highest at sites close to the

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road than at sites away from the road. High concentrations of Na in the soil can also affect plant species in ways other than direct toxicity by Na. The Na in the soil can reduce soil structure and can have adverse effects on the microenvironment of the rhizosphere by reducing oxygen to the roots and causing puddling of fine-textured soil. The Na can also affect the fertility status of the soil by exchanging with the available nutrients on the soil complex and could eventually lead to nutrient deficiencies with subsequent leaching of cations. When plants are stressed by low fertility or reduced oxygen at the roots or by injured foliage, they become susceptible to diseases. Considerable infestation of diplodia disease (*Sphaeropsis sapinae*) was noted on black pine (*Pinus thunbergii*), which was not sampled in this study.

The concentrations of Na in the leaves of plants and in the soil can be influenced by many factors, such as, amount of NaCl applied to the roads, plant distance from the road, slope of the topography, wind, amount of daily traffic, how often the road is plowed, permeability, and soil texture.

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