# EFFECTS OF ROAD SALT ON EASTERN WHITE CEDAR (*THUJA OCCIDENTALIS* L.)[1]

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ABSTRACT

Experiments were conducted to determine effects of de-icing compounds on growth of eastern white cedar (*Thuja occidentalis* L.). The amount of salt (principally rock salt) used for de-icing on southern Ontario highways depends on temperature, slope and road curvature and on the frequency of snow and ice storms. A combination of these factors results in spatial and temporal fluctuations in salt concentrations. Salt enters the roadside environment as salt spray, dust or runoff.

Analysis of snow and soil samples and filter paper discs attached to foliage of cedar trees along highways in the London, Ontario area, collected during winter and spring, showed that concentrations of salt decreased with distance from the pavement and were directly related to weather conditions. Highest levels of Na and Cl were recorded after freezing rains. Sides of cedar trees facing the highway contained significantly higher concentrations of foliar Na and Cl, indicating that spray was a principal vector.

Positive correlation was obtained between salt concentration in soil and injury to foliage. Water stress also increased with increased salt concentrations. Critical levels of Na and Cl causing damage to foliage were 0.13 mg and 0.42 mg per g of soil or 3 mg and 8 mg per g of plant tissue, respectively.

Growth chamber experiments indicated effects of humidity and temperature on severity of injury to white cedar from specific dosages of salt applied to foliage as spray. A relative humidity of 90% or greater resulted in greater injury for a specific dosage than occurred with seedlings exposed to 70% relative humidity or less. Elevated temperatures increased the rate of salt injury.

Results from these studies provide a basis for planning highways so as to reduce damage to the roadside environment, and suggest additional areas for future study.

# RÉSUMÉ

On conduisit des expériences pour déterminer les effets du sel, déglaçant les routes, sur la croissance du Thuya (*Thuja occidentalis* L.). C'était du sel gemme et les quantités utilisées sur les routes du sud de l'Ontario dépendent de la température, la pente, la courbure du chemin et la fréquence des tempêtes de neige et de pluie verglassante. Globalement ces facteurs produisent des fluctuations spatiales et temporelles de la concentration du sel. De chaque côté de la route, le sel pénètre sous forme de poudre, poussière ou solution.

On analysa des échantillons de neige, de sol et de papier filtre (disques) attachés au feuillage de Thuyas le long des routes principales près de London, Ontario. Les substances, récoltées en hiver et au printemps avaient des concentrations de sel qui diminuaient avec la distance de la chaussée et elles variaient directement selon les conditions du temps. Les plus grandes quantités de Na et de Cl se trouvaient après des pluies verglassantes. Le feuillage faisant face à la route avait significativement plus de Na et de Cl, et donc la poudre se révélait un vecteur principal.

Dans le sol, la teneur du sel variait directement selon les dommages aux feuilles. Le stress dû à l'eau augmentait avec la teneur du sel. Les teneurs critiques de Na et de Cl causant des dommages aux feuilles s'établissaient à 0.13 mg et 0.42 mg par g de sol ou 3 mg et 8 mg par g de tissu foliaire, respectivement.

En chambre de croissance, on nota des effets de l'humidité et de la température sur la sévérité des blessures causées par des doses spécifiques de sel poudreux pulvérisé sur le feuillage. Une humidité relative de 90 ou plus produisit plus de dommages qu'une humidité relative de 70 ou moins. Les températures élevées augmentaient le taux de dommages.

Selon cette étude, on peut établir une base de planification des routes principales de façon à réduire les dommages. Les auteurs suggèrent aussi des domaines additionnels d'études à effectuer.

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## INTRODUCTION

In Ontario, application of coarse salt (95% NaCl and 5% $CaCl_2$) to roadways is the principal method of de-icing roads in winter. It is an efficient and economical method of improving road conditions. Salt forms a brine with a lower freezing point than water and prevents bonding of ice and snow to pavement. In an average winter a typical highway around London, Ontario, receives approximately 9 kg of salt per metre of pavement per lane.[3] Salt, scattered on roads, enters the terrestrial and aquatic ecosystem by snow plowing, runoff, splash or spray from wet pavement, or as dust from dry pavement.

The severe effects of salt are evident on roadside vegetation. Lacasse and Rich (1964) have suggested that maple (*Acer* sp.) decline in the immediate vicinity of roadways in New Hampshire was the result of excessive amounts of salt applied for de-icing purposes. Several species of woody vegetation such as white pine (*Pinus strobus* L.), beech (*Fagus grandifolia* Ehrh.) and red osier dogwood (*Cornus stolonifera* Michx.) are highly sensitive to road salt, whereas grassy vegetation is usually more resistant (Cordukes and Parups 1971, 1972). In spite of the injurious side effects of salt, no economical alternative method of snow and ice removal from roadways is as yet available. Research is therefore needed to determine the effects of salt on various species of plants that grow along highways.

Eastern white cedar (*Thuja occidentalis* L.) is grown frequently as a hedge along roadsides in the London, Ontario area. It has a fast rate of growth and is aesthetically pleasing. Because of its thick intermeshing growth habit it acts as a natural windbreak and a barrier to sound (Little and Noyes 1971). Moreover, eastern white cedar is winter hardy, fairly resistant to pests and diseases and can exist in a wide range of soil and moisture conditions. According to Lumis et al. (1973), eastern white cedar is only intermediate in salt tolerance and can show severe dieback of branches exposed to salt spray (Fig. 1).

The studies outlined in this paper were aimed at investigating salt damage to eastern white cedar along highways near London. Studies were conducted to examine the following questions:

(a) What are the principal sites of salt uptake by the plant?

(b) Is plant growth affected by salt deposited on foliage?

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[3] Jephson, H.E. 1976. Ontario Ministry of Transportation and Communications, London (personal communication).

Figure 1. Roadside hedge of white cedar (*Thuja occidentalis* L.), located 8 m from the pavement, showing severe dieback of foliage.

(c) In what quantities do Na and Cl ions accumulate in plant tissue?

(d) What are the critical concentrations of Na and Cl ions with respect to injury symptoms in plant tissue?

(e) How does salt concentration in soil and foliage along roadsides vary during the year?

(f) How do environmental factors such as temperature and relative humidity influence the amount of damage?

It is hoped that the results will improve our understanding of overall interactions among salt application, roadside vegetation, soil condition and environmental factors.

## MATERIALS AND METHODS

*Study Area*

Experiments were conducted in greenhouses and research facilities of the Department of Plant Sciences, University of Western Ontario, London (43° N Lat. and 81° W Long.). Concentrations of salt in plant and soil were also determined in samples taken along roadways located near London.

*Source of Trees*

White cedar trees were obtained from a commercial establishment in Tillsonburg and from the Provincial Forest Station, Ontario Ministry of Natural Resources, Midhurst. Trees ranged in height from 25 to 50 cm and were 3 to 4 years old with well developed root systems. Root-to-shoot ratios calculated on a dry weight basis ranged from 2:1 to 3:1. Trees were planted during the spring and fall of 1974 in 20 cm diameter clay pots filled with a greenhouse potting soil mixture and were grown in the greenhouse until required.

*A. Measurement of Salt in the Roadside Environment*

The following methods were used to measure concentrations of salt at various sites near two London area highways (Fig. 2).

(a) Filter paper disc samples: Round filter paper discs (4 cm in diameter) were attached to foliage of trees located between 20 and 24 m from the edge of the pavement on Highway 4 (Fig. 2). One filter paper disc was attached to the foliage of each of six trees, 1.5 m above ground, on 10 and 24 January, 7 and 21 February, and 7 March, 1975, and detached 2 weeks later. Single discs attached to three individual trees at the research

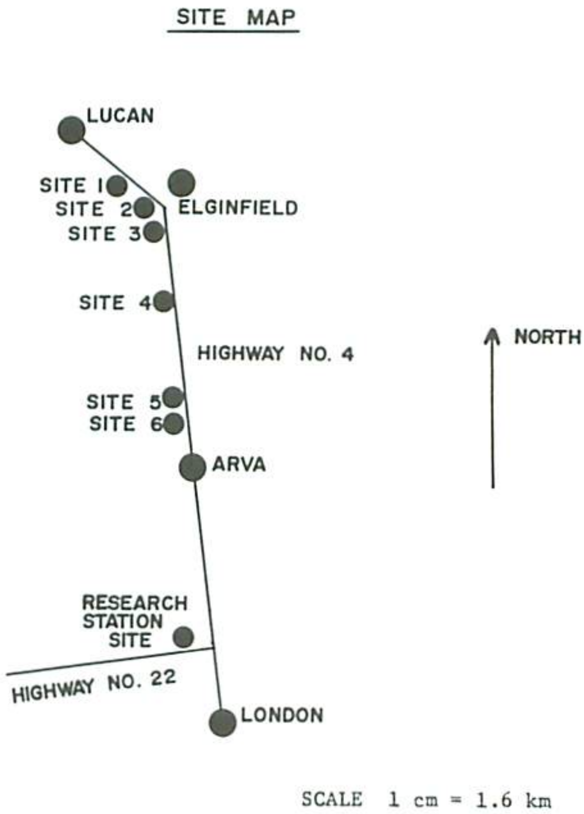


Figure 2. Map of Highway 4 showing the locations from which snow, soil, filter paper discs and foliage samples were collected.

station located approximately 1000 m from Highway 4 were collected on the same dates (control). A second sampling station was set up on the north side of Highway 22 (Fig. 2). A filter paper disc was attached to a post (1.5 m above ground) located 4 m from the edge of the pavement. Single discs were changed daily during February to determine temporal variations in salt drift from the highway.

Immediately after collection, filter paper discs were placed in glass vials and oven dried at 50°C. Salt was eluted from individual discs by soaking in 10 mL of de-ionized distilled water for 24 hr. Individual solutions were filtered; concentrations of Ca and Na ions were determined by atomic absorption spectrophotometry and of Cl ions by the Orion solid state chloride electrode method.

(b) Snow samples: Snow samples were obtained by pushing a soil sampler to ground level. Samples were collected at the six locations on Highway 4 at 0, 2, 4, and 8 m from the edge of the highway shoulder on 24 January, 7 and 21 February, and 7 and 14 March, 1975. For each sample, three cores were obtained and bulked. These samples were melted at room temperature, and filtered and analyzed for Ca, Na and Cl ions as above.

(c) Soil samples: Soil samples were collected on 21 March, 14 April, 13 May and 10 June, 1975 from each of the six locations outlined above at distances 0, 2, 4 and 8 m from the edge of the shoulder. Soil cores were taken to a depth of 30 cm with a 2 cm diameter soil sampler. Three cores were taken for each sample and bulked. Samples collected on 13 May and 10 June were divided into two subsamples, the top 8 cm and 8 to 30 cm, and bulked. Soil samples were air-dried, crushed to pass a 2 mm screen and extracted with 1 M $NH_4C_2H_3O_2$ according to the method of Walsh and Beaton (1973). Extracts were analyzed for exchangeable Ca and Na by atomic absorption spectroscopy and Cl ions by the Orion solid state chloride electrode method.

(d) Foliage samples: Eastern white cedar foliage samples were collected from trees along Highway 4 to which filter paper discs had been attached. A sample was obtained from the side of the tree facing the road and the side away from the road. Green foliage samples were collected 1.5 m above ground on 24 January, 7 and 21 February, 7, 14 and 21 March, 14 April, 13 May and 10 June, 1975. Individual samples were air dried to constant weight at 50°C and ground in a Wiley mill to pass a 40 mesh screen. Samples were extracted with 1 M $HNO_3$ according to the method of Yoshida et al. (1972) and were analyzed for Na, Ca and Cl ions as before.

### B. *Salt Application to Soil and Foliage*

(a) Application of salt to soil: Thirty-three previously potted 4-year-old eastern white cedar trees from Midhurst Provincial Nursery were graded for height (45 cm) and spread, and were repotted into 10 cm diameter plastic pots containing 300 g of air-dried soil on 12 November, 1974. Examination of the root systems on 8 May, 1975 indicated that these trees were well established. At this time, trees were transferred to a greenhouse maintained at 21-25°C (day), 15°C (night) and a relative humidity (R.H.) of 50-70%.

On 10 June, 1975, 20 mL of various Na Cl solutions (0, 0.5, 1.0, 1.5, 2.0 and 2.5 M) were added to the soil of each pot. Plants were watered daily and soil was maintained at approximately field capacity. The experimental design was a randomized block with three replications. A foliage sample was collected from each treated tree at 6, 14, 19 and 21 days after application. Leaf moisture stress was determined on these samples according to the method of Barrs (1968). Water saturation deficit (W.S.D.) was calculated by the equation:

$$\text{W.S.D.} = \frac{\text{Saturation wt} - \text{Fresh wt}}{\text{Saturation wt} - \text{Dry wt}}$$

Leaves were submerged in water for 24 hr, and were blotted and weighed to determine saturation weight. Foliar dry weight was determined after drying to constant weight at 50°C. The experiment was terminated after 21 days.

Injury was indexed according to the following scale:

| Damage rating | Visual description of foliage | Roots |
|---|---|---|
| 1 | healthy, fewer than four foliage tips discolored | healthy, white tips a few burnt tips |
| 2 | fewer than 20% discolored | more than 50% burnt tips |
| 3 | 20 to 40% discolored | a few tips not burnt |
| 4 | 40 to 60% discolored | all tips burnt but |
| 5 | 60 to 80% discolored | roots still reddish |
| 6 | more than 80% discolored | roots black |

Leaves (green and discolored components) and roots were analyzed for Na, Ca, potassium (K) and Cl by the methods previously described.

(b) Foliar application of salt solution: Sixteen 3-year-old eastern white cedar trees graded for size and spread were sprayed individually with 10 mL solutions of 0, 0.1, 0.5 or 1.0 M NaCl. The solution was sprayed on the foliage with a microsprayer at 0.14 $g.cm^{-2}$. The soil surface was covered with aluminum foil to protect it from spray drift. Four single-tree replications were used for each treatment. Trees were placed in a growth chamber maintained at a constant temperature of 15 $\pm$ 0.5°C and 12 hr photoperiod. Light intensity at the top of the canopy was adjusted to 3230 lux to approximate winter light conditions and R.H. was maintained at > 90%. The experiment was terminated after 29 days and the plants were assessed for qualitative damage. Samples of discolored and green tissue were collected for later analysis. In all experiments involving sprayed foliage, an unwashed sample was taken for measurement of delivered spray concentration. All other samples were washed in distilled water to remove surface salt prior to analysis.

*C. Environmental Factors and Salt Damage*

Experiments were conducted to determine the effects of varying humidity and temperature on growth, injury, and survival of 3-year-old eastern white cedar trees. Transplanted trees were grown in a glasshouse for 10 months under natural light conditions with temperature control to maintain internal temperature above 0°C. Plants were moved into a growth chamber 48 hr before treatment. Each tree (treatment) was sprayed with 10 mL of a 1.0 M solution of NaCl. All treatments were replicated four times. Immediately after spraying, pots were returned to the growth chambers and trees were exposed to a light intensity of 3230 lux, 12 hr photoperiod, and varying R.H. and temperature regimes. At the termination of each experiment individual tree damage was estimated qualitatively as described in section *B* (a). Trees were cut at ground level and green and discolored aerial tissues were separated for analysis.

(a) Relative humidity: Trees were exposed to a constant temperature of 15 ± 0.5°C in growth chambers maintained at > 90% or < 70% R.H. Relative humidity of < 70% was maintained by silica gel in pans in the growth chamber. A humidifier was used to maintain R.H. at > 90%.

The treatments were as follows:

| Treatment | Length of exposure and R.H. |
|---|---|
| Control | 20 days at less than 70% |
| Control | 20 days at greater than 90% |
| Sprayed | 1 day at greater than 90%, 19 days at less than 70% |
| Sprayed | 3 days at greater than 90%, 17 days at less than 70% |
| Sprayed | 6 days at greater than 90%, 14 days at less than 70% |
| Sprayed | 20 days at greater than 90% |
| Sprayed | 20 days at less than 70% |

This experiment was terminated after 20 days.

(b) Temperature: Growth chambers were maintained at > 90% R.H., 12 hr photoperiods and constant temperatures of 5, 10 and 15 ± 0.5°C. The temperature treatments were as follows:

| Treatment | Length of exposure and temperature |
|---|---|
| Control | 35 days at 5°C |
| Sprayed | 35 days at 5°C |
| Control | 35 days at 10°C |
| Sprayed | 35 days at 10°C |
| Control | 35 days at 15°C |
| Sprayed | 35 days at 15°C |
| Control | 18 days at 15°C |
| Sprayed | 18 days at 15°C |
| Control | 18 days at 5°C |
| Sprayed | 18 days at 5°C |
| Sprayed | 1 day at 5°C, 1 day at 15°C, 16 days at 5°C |
| Sprayed | 1 day at 5°C, 3 days at 15°C, 14 days at 5°C |
| Sprayed | 1 day at 5°C, 6 days at 15°C, 11 days at 5°C |

### D. *Statistical Methods*

Data obtained from growth chamber experiments on effects of R.H. and temperature were subjected to multivariate one-way classification analysis (Morrison 1967). Only with these data was the basic assumption fulfilled that there was a common covariance matrix. Data from the remaining experiments were subjected to univariate one-way ANOVA after the requirements of Bartlett's test for homogeneity (Dixon and Massey 1969) had been fulfilled. Duncan's New Multiple Range Test was used to discriminate among means of significant ($P > 0.05$) treatments. Correlations were calculated according to the program of Lee (1971).

## RESULTS

### A. *Salt Content in the Roadside Environment*

In the London district, the amount of a given de-icing agent applied to roadways by the Ontario Ministry of Transportation and Communication is determined primarily by the severity of weather conditions. The average application of salt is 127 $kg.km^{-1}$. Under abnormally severe weather conditions, e.g., freezing rains, up to 226 $kg.km^{-1}$ is applied.[3] This procedure results in major temporal variations in salt concentration. Although the precise amount of salt applied to the study area was not determined directly, indirect measurements of the amount of salt entering the roadside environment was determined by analysis of soil, snow and foliage samples collected throughout the winter and spring months.

(a) Concentration of elements from filter paper discs: Analysis of eluates from filter paper discs attached to white cedar trees in the study area indicates that Na, Ca and Cl ions accumulated and varied with time of sampling (Table 1). The highest levels were obtained after periods of inclement weather. The significantly higher levels recorded on 24 January and 14 March coincided with freezing rain (Appendix).

Wide variations were observed in the concentrations of Na, Ca and Cl ions from filter paper discs sampled daily during February 1975 (Fig. 3). Although the highest concentrations of Na and Cl ions were recorded during periods of severe weather, Ca levels, in contrast, were higher on clear windy days (Appendix). The highest levels corresponded to days when the soil adjacent to the highway was exposed.

(b) Concentration of elements in snow samples: Analysis of snow samples collected at various times and at increasing distances from the highway indicates, as would be expected, that levels of Na and Cl ions decrease with increasing distance from the

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[3] See footnote on page 1.

Table 1. Concentration of Na, Cl and Ca in filter paper discs collected at fortnightly intervals from 24 Jan. to 21 March, 1975.

| | Concentration of elements (ppm/cm$^2$) | | |
|---|---|---|---|
| Date of collection | Na | Cl | Ca |
| 24 Jan. | 47.1 b | 56.1 b | 18.1 a |
| 7 Feb. | 15.3 ab | 23.8 ab | 11.4 a |
| 21 Feb. | 10.7 a | 20.1 a | 16.3 a |
| 7 Mar. | 38.9 ab | 56.3 b | 19.2 a |
| 14 Mar. | 50.8 b | 59.2 b | 38.2 b |
| 21 Mar. | 4.8 a | 11.8 a | 19.7 a |

Values in each column followed by the same letter are not significantly different at P = .05.

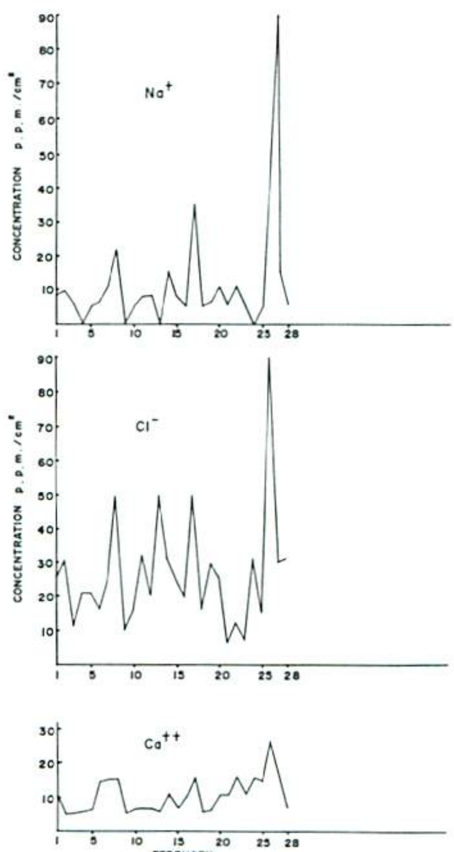


Figure 3. Daily concentrations of Na, Cl, and Ca determined from filter paper discs collected during February, 1975

Table 2. Concentration of Na, Ca and Cl determined from snow samples collected at 0, 2, 4, and 8 m from the edge of the pavement (ppm).

| Sampling date | Distance from the edge of the pavement (m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 2 | | | 4 | | | 8 | | |
| | Na | Ca | Cl | Na | Ca | Cl | Na | Ca | Cl | Na | Ca | Cl |
| 24 Jan | 384a | 78a | 759a | 171a | 159b | 442ab | 82ab | 42a | 137b | 26ab | 66a | 79b |
| 7 Feb | 1636b | 208b | 2014b | 210a | 83ab | 171b | 37ab | 33a | 38ab | 17a | 33a | 22ab |
| 21 Feb | 206a | 90a | 300a | 76a | 110ab | 131a | 13a | 26a | 9a | 6a | 46a | 9a |
| 7 Mar | 2291c | 61a | 4128c | 242a | 82ab | 294ab | 109b | 59a | 149b | 55b | 44a | 66b |
| 14 Mar | 74a | 215b | 133a | 37a | 44a | 65a | 36ab | 27a | 51ab | 10a | 19a | 20ab |

Values in each column followed by the same letter are not significantly different at P = .05.

Table 3. Concentrations of available Na, Ca and Cl (mg/g of soil) determined from roadside soils at 0, 2, 4, and 8 m from the edge of the pavement.

| Sampling date | Distance from the edge of the pavement (m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 2 | | | 4 | | | 8 | | |
| | Na | Ca | Cl | Na | Ca | Cl | Na | Ca | Cl | Na | Ca | Cl |
| 21 Mar* | 0.35a | 4.48a | 0.38a | 0.43a | 4.60a | 0.41b | 0.17a | 4.82a | 0.17a | 0.19a | 4.83a | 0.11a |
| 14 Apr* | 0.35a | 4.50a | 0.36a | 0.38a | 4.74a | 0.21ab | 0.17a | 4.76a | 0.17a | 0.10a | 4.82a | 0.31a |
| 13 May* | 0.06a | 4.26a | 0.10a | 0.13ab | 4.50a | 0.34ab | 0.07a | 4.86ac | 0.22a | 0.04a | 4.92ab | 0.19a |
| 10 June* | 0.05a | 4.62a | 0.12a | 0.09b | 5.21b | 0.16a | 0.06a | 5.64b | 0.24a | 0.03a | 5.33bc | 0.13a |
| 13 May** | 0.08a | 4.62a | 0.14a | 0.25ab | 4.65a | 0.24ab | 0.13a | 5.12abc | 0.32a | 0.03a | 4.83a | 0.14a |
| 10 June** | 0.07a | 4.57a | 0.11a | 0.23ab | 5.18a | 0.13a | 0.08a | 5.37bc | 0.33a | 0.03a | 5.56c | 0.11a |

Values in each column followed by the same letter are not significantly different at P = .05.

* upper 8 cm

** 8 to 35 cm depth

Highway (Table 2). Levels of Na and Cl ions showed considerable fluctuation, possibly as a result of variations in application rate (Table 2).

(c) Concentration of elements in soil: In general, concentration of elements in soil samples collected at various distances from the highway showed patterns similar to those in snow samples, but with less extreme variation. The highest levels of Na and Cl ions were recorded in samples collected 2 m from the highway (Table 3), especially during the spring collection dates. Soil concentration of Na and Cl ions exhibited marked seasonal variability (Table 3) with the lowest levels occurring at the later collection dates, e.g., 10 June. The highest concentrations of Na ions were recorded on 21 March in the top 8 cm of soil (Table 3). Samples below the 8 cm depth were restricted at this time because of frozen ground. However, later sampling indicated a reduction in Na and Cl ions in the upper 8 cm of soil with corresponding higher concentrations at the lower depths. Concentrations of Cl ions showed a generally decreasing trend with increased distance from the highway. The level of Ca did not change in samples collected at various distances from the highway (Table 3).

(d) Concentration of elements in foliage of roadside trees: Foliar levels of Na and Cl ions varied with time of collection (Fig. 4). Maximum levels of both elements were recorded during the 14 March peak. Concentrations of Na and Cl ions, in contrast to those of Ca, were higher in foliage collected from the side of trees facing the road than in foliage from the side away from the road (Table 4), indicating that salt transported aerially was a principal vector.

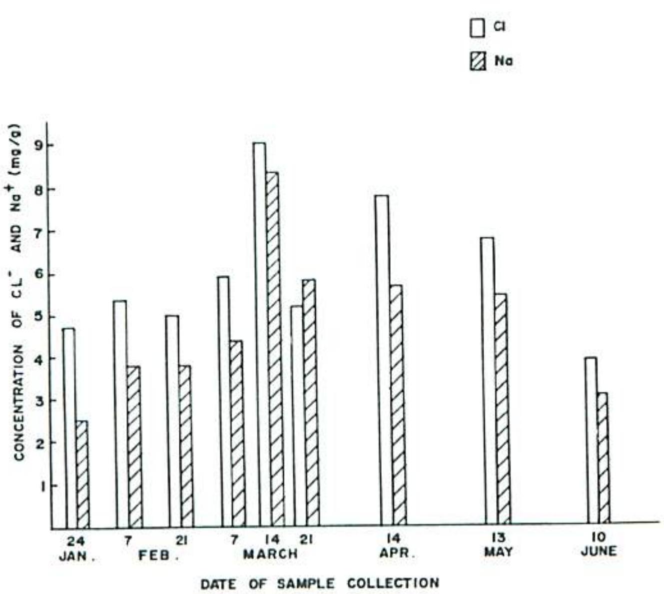


Figure 4. Concentrations of Cl and Na (mg/g) determined in foliage samples collected from January 24 to June 10, 1975.

Table 4. Levels of Na, Ca and Cl determined in white cedar foliage at 1.5 m height, facing the road and away from the road. (Trees were located 20 to 24 m from the highway.)

| Sampling date | Position with respect to road | Na | Ca | Cl |
|---|---|---|---|---|
| | | (mg/g of dry plant tissue) | | |
| 24 Jan., 1975 | facing | 2.53b | 13.62a | 4.75a |
| | away | 0.91a | 13.04a | 4.18a |
| 7 Feb., 1975 | facing | 3.85b | 22.36a | 5.33b |
| | away | 1.07a | 17.28a | 1.87a |
| 21 Feb., 1975 | facing | 3.83a | 14.38a | 5.01a |
| | away | 2.26a | 17.20a | 5.21a |
| 7 Mar., 1975 | facing | 4.31b | 19.34a | 5.94b |
| | away | 0.67a | 18.21a | 2.77a |
| 14 Mar., 1975 | facing | 8.67b | 20.03a | 8.96b |
| | away | 1.06a | 22.19a | 1.59a |
| 21 Mar., 1975 | facing | 5.86b | 17.25a | 5.49b |
| | away | 0.62a | 19.48a | 1.37a |
| 14 Apr., 1975 | facing | 5.66b | 16.54a | 7.83b |
| | away | 1.99a | 16.70a | 1.72a |
| 13 May, 1975 | facing | 5.39b | 17.26a | 6.70b |
| | away | 0.55a | 15.23a | 2.18a |
| 10 June, 1975 | facing | 2.95a | 11.45a | 3.87b |
| | away | 1.26a | 7.19a | 1.07a |

The values of elements in foliage facing the road and away from the road for each sampling date were compared by a t-test. If values are followed by the same letter they are not significantly different at $P = .05$.

## B. *Effects of Salt Application to Foliage and Soil*

(a) Foliar applications: Foliar injury to roadside vegetation, attributable at least in part to aerial movement of highway de-icing salts, is well documented. In the present study various concentrations of salt were sprayed on the foliage of white cedar trees in an attempt to simulate field conditions. In general, injury of treated trees was proportional to salt concentration (Table 5). Although both roots and shoots were examined, injury was confined to the aerial portions of the tree. Injury generally consisted of foliar necrosis (browning) as shown in Figure 5.

Table 5. Injury ratings of 3-year-old white cedar trees of similar size sprayed with different concentrations of NaCl, 29 days after treatment.

| Salt Concentration (M) | NaCl Shoot | NaCl Root |
|---|---|---|
| Control | 1.25* | 1.0 |
| 0.10 | 1.0 | 1.0 |
| 0.50 | 2.50 | 1.0 |
| 1.00 | 3.25 | 1.0 |

* Scale of injury 1 (healthy) to 6 (heavily damaged).

Analysis of plant tissue showed that spraying with NaCl increased Na and Cl content of foliage and roots (Table 6). Discolored foliage contained higher amounts of Na and Cl than did green foliage (Table 6). Not all the salt applied entered the foliar tissue. Unwashed foliage contained greater concentrations of Na and Cl than did washed green foliage. Damage to foliage (Fig. 5) occurred when threshold concentrations in oven-dry weight of plant tissue equalled or exceeded 3 mg of Na per g or 8 mg Cl per g.

(b) Application to soil: Roots have long been considered the principal entrance for de-icing agents into plant tissue (Westing 1966, 1969). In this study application of 0.5 M NaCl to soil produced injury symptoms on white cedar. Soil analysis at the termination of the experiment indicated levels of 130 ppm Na and 420 ppm Cl as a result of this treatment. Control soils showed levels of 20 and 30 ppm Na and Cl, respectively. Initial injury symptoms were observed 8 days after treatment. Damage was proportional to salt concentration (Table 7). Although foliar injury was evident, major damage was restricted primarily to the roots. Roots appeared discolored and stunted, and had few root hairs (Fig. 6). Foliar damage was observed initially at the tips and bases of secondary and tertiary branches, with necrosis progressing both basipetally and acropetally (Fig. 5).

With increased salt concentration in the soil, trees exhibited increased foliar water stress (Table 8).

Analysis of plant tissue showed increased Na and Cl concentrations with increased applications of NaCl. Ca and K concentrations in stems and foliage were not altered as a result of treatment.

Figure 5

NaCl-induced foliar injury to eastern white cedar.

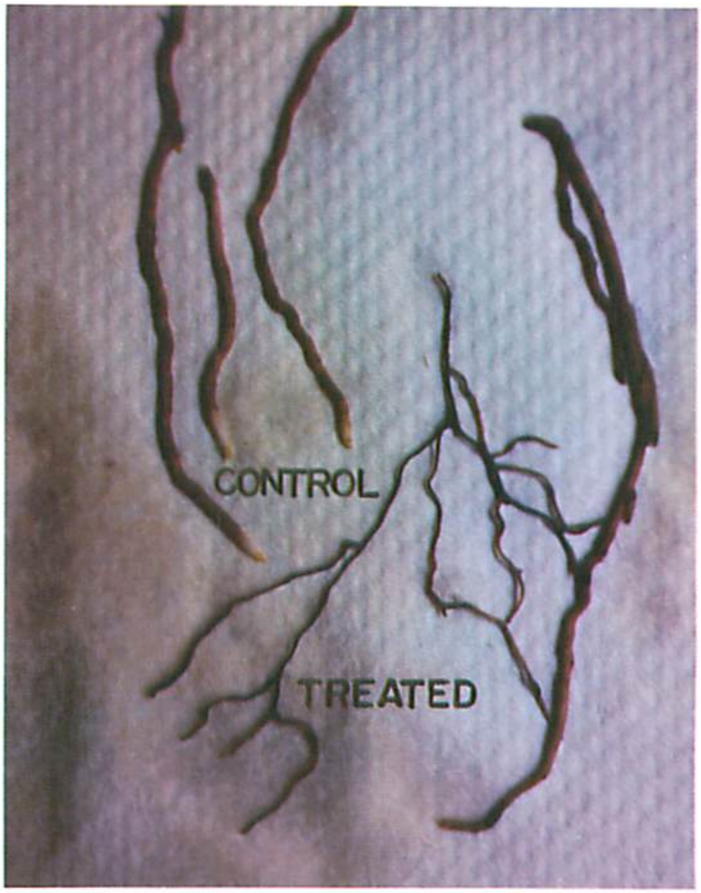


Figure 6

Roots of control and treated plants of eastern white cedar grown in soil containing NaCl. Note the brown root tips of treated plants in comparison with the white tips of the control.

Table 6. Concentration (mg/g dry weight) of elements in various plant parts 29 days after spraying with 10 mL of different concentrations of NaCl.

| NaCl | Unwashed foliage | | | | Washed green foliage | | | |
|---|---|---|---|---|---|---|---|---|
| Concentration (M) | Na | K | Ca | Cl | Na | K | Ca | Cl |
| 0.0 | 0.1a | 5.6a | 14.7a | 2.4a | 0.2a | 6.0a | 15.5b | 2.1a |
| 0.1 | 0.6a | 6.5a | 14.2a | 3.2a | 0.2a | 6.6a | 12.4a | 2.5a |
| 0.5 | 3.2a | 6.9a | 12.6a | 10.4b | 0.9a | 6.9a | 12.3a | 7.8b |
| 1.0 | 9.4b | 7.3a | 12.0a | 19.0c | 3.3b | 6.9a | 11.1a | 19.4c |
| | Washed, discolored foliage | | | | Root | | | |
| 0.0 | 0.6a* | 1.7a | 32.5b | 0.8a | 0.4a | 6.3a | 10.2a | 0.9a |
| 0.1 | 0.1a** | 5.6b | 19.9a | 2.4a | 0.7b | 7.5a | 8.3a | 1.6b |
| 0.5 | 5.6b | 5.3b | 21.3a | 13.1b | 1.1b | 6.9a | 12.4a | 2.0b |
| 1.0 | 10.8c | 6.2b | 14.3a | 20.2c | 1.4c | 5.4a | 10.0a | 1.9b |

* only one replicate

** only two replicates

Values in each column for each plant part followed by same letter are not significantly different at P = .05.

Table 7. Damage ratings and concentrations of elements in various plant parts from white cedar trees grown in soil containing various concentrations of NaCl (Element values are in $mg \cdot g^{-1}$.)

| Concentration of salt (M) | Injury rating | Root | | | | Green foliage | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (Root) | Na | Ca | K | Cl | Na | Ca | K | Cl |
| 0.0 (control) | 1.00* | 2.0a | 10.9a | 11.5b | 2.1a | 0.3a | 13.0a | 8.0a | 0.9a |
| 0.5 | 1.33 | 5.8b | 7.6a | 5.2a | 15.5b | 0.4a | 12.5a | 7.9a | 5.2b |
| 1.0 | 2.00 | 6.9b | 7.9a | 3.0a | 11.4b | 2.4a | 18.4a | 6.9a | 7.6b |
| 1.5 | 3.00 | 6.0b | 8.8a | 3.1a | 10.8b | 9.5b | 21.1a | 7.8a | 14.3c |
| 2.0 | 5.00 | 10.3c | 10.6a | 1.6a | 9.9b | 9.6b | 17.7a | 7.4a | 17.3c |
| 2.5 | 5.33 | 7.4b | 9.4a | 2.9a | 11.2b | 22.5c | 18.8a | 6.2a | 25.9d |
| | (Shoot) | Shoot | | | | Discolored foliage | | | |
| 0.0 (control) | 1.00 | 0.5a | 13.3a | 2.6a | 0.5a | 0.7a | 24.7c | 4.2a | 1.8a |
| 0.5 | 1.00 | 1.9a | 15.1a | 3.4a | 3.4a | 1.5a | 17.1a | 4.4a | 4.5a |
| 1.0 | 2.67 | 8.1ab | 23.1a | 4.2a | 5.8a | 2.9a | 19.7ab | 5.6a | 7.5a |
| 1.5 | 2.33 | 8.3ab | 19.6a | 3.1a | 3.5a | 3.0a | 22.6b | 6.1ab | 16.4b |
| 2.0 | 4.33 | 16.3b | 19.9a | 3.5a | 21.9b | 8.1b | 25.8c | 8.3b | 21.0b |
| 2.5 | 3.67 | 17.2b | 17.0a | 4.6a | 25.3b | 24.2c | 31.9d | 8.5b | 37.8c |

* Scale for injury: 1 (healthy) to 6 (heavily damaged). The roots were not damaged.

Values in a column followed by the same letter are not significantly different at $P = .05$.

Table 8. Water saturation deficit (W.S.D.) of leaves of white cedar grown in soil treated with different concentrations of NaCl.

| Treatment | NaCl Days after treatment 6 | 14 | 19 | 21 |
|---|---|---|---|---|
| 0.0 | 11.4a | 20.8a | 25.4a | 24.1a |
| 0.5 | 14.0a | 23.2a | 21.7a | 25.6a |
| 1.0 | 18.5a | 24.1a | 24.6a | 23.9a |
| 1.5 | 13.4a | 24.5a | 36.0a | 36.3a |
| 2.0 | 21.1a | 47.0b | 71.2b | 79.9b |
| 2.5 | 14.4a | 49.2b | 58.1b | 63.9b |

Values in the same column followed by the same letter are not significantly different at P = .05.

*C. Environmental Factors and Salt Damage*

(a) Effects of relative humidity: Preliminary greenhouse experiments had shown that white cedar trees were not damaged at high salt concentrations when NaCl was sprayed on the foliage, even when salt crystals were clearly visible on the surface of the leaves at approximately 60% R.H. It was hypothesized that severity of foliar damage was probably related to R.H.

Controlled experiments on the effects of R.H. on foliar damage from applied salt indicate that plants sprayed with 10 mL of 1 M NaCl solution and then exposed to 90% R.H. caused clear symptoms of injury within the first week after treatment (Table 9). Little damage was observed in plants treated in the above manner but exposed to 70% R.H. (Table 9). Exposure of treated plants to one day at R.H. 90% was sufficient to induce symptoms of injury. Damage was correlated with foliar concentration of Na and Cl. Plants treated at similar salt concentrations and exposed to 70% R.H. contained significantly lower concentrations of Na and Cl in their tissues. Foliar levels of K and Ca were not affected by treatment:

(b) Effects of temperature:
(1. Constant temperature) White cedar trees were sprayed with 10 mL of 1.0 M NaCl and exposed to constant temperatures of 5, 10 and 15°C and 90% R.H. Injury symptoms appeared 8 days after treatment in both the 10 and 15°C temperature regime (Table 10). At 5°C,

Table 9. Injury rating and concentration of elements in various plant parts from white cedar trees of similar size exposed to different humidity levels following spray with 10 mL of 1 M NaCl per tree.

| Length of treatment (days) | Relative humidity (%) | Injury rating | Unwashed foliage (mg/g) | | | | Washed foliage (mg/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Green | | | | Discolored | | | |
| | | Shoots | Na | K | Ca | Cl | Na | K | Ca | Cl | Na | K | Ca | Cl |
| (control) | | | | | | | | | | | | | | |
| 20 | 70 | 1.0* | 1.6a | 7.6a | 22.8a | 1.7a | 0.7a | 7.1a | 21.0a | 2.2a | 1.8a* | 1.7a | 29.2a | 2.7a |
| 20 | 90 | 1.0 | 1.3a | 8.8a | 16.7a | 2.0a | 0.6a | 8.0a | 15.0a | 1.4a | 1.1a** | 6.5b | 20.8a | 1.9a |
| (sprayed) | | | | | | | | | | | | | | |
| 1/19 | 90/70 | 2.25 | 13.5b | 8.7a | 14.2a | 16.9b | 5.1b | 8.4a | 15.7a | 7.8b | 13.3bc | 5.6b | 25.4a | 15.8b |
| 3/17 | 90/70 | 2.25 | 18.3b | 11.9a | 17.8a | 17.6b | 5.2b | 7.9a | 12.2a | 8.9b | 15.0c | 8.0b | 20.4a | 16.2b |
| 6/14 | 90/70 | 2.75 | 13.4b | 11.3a | 13.0a | 18.0b | 4.7b | 8.2a | 13.6a | 8.5b | 12.1b | 6.5b | 26.3a | 14.1b |
| 20 | 90 | 2.75 | 13.3b | 10.4a | 14.8a | 16.0b | 4.4b | 8.5a | 16.0a | 8.1b | 17.1c | 7.3b | 21.4a | 16.3b |
| 20 | 70 | 1.25 | 18.9b | 9.5a | 12.9a | 18.8b | 1.5ab | 9.8a | 15.9a | 1.7a | 11.9b** | 5.8b | 29.3a | 13.8b |

Scale for injury: 1 (healthy) 6 (heavily damaged). The roots were not damaged.

* only one replicate
** only two replicates



Table 10. Injury rating and concentration of elements in various plant parts from white cedar trees of similar size exposed to different temperatures following spray with 10 mL of 1 M NaCl per tree.

| Treatment | Temp. (0°C) | Injury rating | Unwashed foliage (mg/g) | | | | Washed foliage (mg/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Green | | | | Discolored | | | |
| | | Shoots | Na | K | Ca | Cl | Na | K | Ca | Cl | Na | K | Ca | Cl |
| Control | 5 | 1.00* | 0.2a | 6.6a | 13.9a | 1.4a | 0.2a | 7.8a | 12.2a | 1.1a | 0.8a | 4.6b | 23.7c | 1.4a |
| Treated | 5 | 1.25 | 6.8b | 7.2a | 13.9a | 18.2b | 2.6b | 7.2a | 11.9a | 10.2b | 12.1c | 7.2c | 14.0a | 13.7b |
| Control | 10 | 1.25 | 0.4a | 6.7a | 14.1a | 1.8a | 0.2a | 7.6a | 11.0a | 1.3a | 1.5a | 3.3ab | 20.7b | 1.9a |
| Treated | 10 | 2.50 | 5.7b | 6.0a | 15.6a | 12.1b | 3.9b | 8.0a | 10.7a | 15.8b | 11.0c | 5.1bc | 12.9a | 15.8b |
| Control | 15 | 1.00 | 0.4a | 6.6a | 14.2a | 1.5a | 0.4a | 7.1a | 10.8a | 1.4a | 0.6a | 1.2a | 15.2a | 1.4a |
| Treated | 15 | 2.50 | 5.3b | 7.1a | 14.2a | 13.6b | 5.8c | 7.9a | 10.1a | 8.7a | 7.1b | 3.6b | 15.4a | 17.7b |

* Scale for injury: 1 (healthy) 6 (heavily damaged). The roots were not damaged.

Values in a column followed by the same letter are not significantly different at P = .05.

however, only one plant showed slight browning of leaf tips after 35 days. Internal concentrations of elements in plant tissue indicated that sprayed trees had significantly higher levels of Na and Cl in green and discolored foliage at all temperatures than did the controls. Temperature treatments did not alter K and Ca levels.

(2. Alternating temperatures) As shown previously, trees sprayed with NaCl exposed to a temperature of 5°C for 18 days showed only slight symptoms of injury in contrast with those that underwent 18 days of incubation at 15°C. Trees sprayed with NaCl and exposed to a temperature of 5°C were transferred to a temperature of 15°C for 1, 3 or 6 days. Injury symptoms were observed after 1 day at 15°C and became readily apparent after 3 days of exposure (Table 11).

Concentrations of Ca and K were not altered significantly by any of the temperature treatments. However, Na and Cl levels were significantly higher in all trees sprayed with salt irrespective of temperature (Table 11). Symptom expression was strongly dependent on the temperature to which the plant was exposed. Trees sprayed with salt at low temperatures, though not expressing symptoms at these temperatures, did so readily when the temperature was elevated.

## DISCUSSION

The most common de-icing agent in southwestern Ontario is rock salt. The amount of salt applied depends on temperature, slope and curvature of the road, and the frequency of snow storms and freezing rains. These factors result in spatial and temporal fluctuations in salt concentration on different parts of the highway. Salt enters the roadside environment by salt spray, by being blown as dust or by runoff after rain or snow melt.

The objectives of this study were to determine the effects of salt in the roadside environment on the growth of eastern white cedar. Salt content in plants and from filter paper discs attached to foliage was directly related to the severity of weather conditions. The highest levels of Na and Cl were recorded after freezing rains, probably because of the doubling of salt application in such storms. Ca levels, in contrast, were higher during clear windy days when adjacent soil was exposed, and this suggests that windblown Ca from bare soil may be an additional source of this element.

The concentration of Na and Cl in snow and soil samples decreased with distance from the pavement. Clearly, the high levels of salt along the highway resulted from the salt applied as a deicing agent. These results confirm the findings of Hutchinson (1968), Hall et al. (1972), and Sucoff et al. (1975).

Table 11. Damage ratings and concentration of elements in various plant parts from white cedar trees of similar size exposed to alternating temperatures following spray with 10 mL of 1 M NaCl per tree.

| Length of treatment (days) | Temp. °C | Injury rating | Unwashed foliage (mg/g) | | | | Washed foliage (mg/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Green | | | | Discolored | | | |
| | | Shoot | Na | K | Ca | Cl | Na | K | Ca | Cl | Na | K | Ca | Cl |
| 1/1/16 | 5/15/5 | 1.75* | 9.3a | 5.1a | 14.4a | 17.9a | 1.5ab | 5.0a | 11.1a | 4.7ab | 3.3ab | 5.2a | 14.7a | 6.2ab |
| 1/1/13 | 5/15/5 | 2.75 | 11.5a | 5.1a | 14.3a | 17.9a | 2.9a | 5.0a | 11.1a | 9.0ab | 5.3ab | 5.6a | 14.0a | 9.2ab |
| 1/6/11 | 5/15/5 | 3.25 | 10.3a | 7.0a | 15.1a | 18.3a | 3.3a | 5.2a | 11.3a | 9.8a | 8.4a | 5.2a | 15.6a | 17.1a |
| 18 days | 15 C | 2.75 | 9.7a | 6.8a | 12.2a | 18.8a | 3.3a | 5.5a | 11.6a | 11.2b | 9.0a | 6.6a | 14.6a | 16.3a |
| 18 days | 5 C | 1.25 | 10.4a | 5.9a | 14.8a | 18.5a | 1.4ab | 5.3a | 12.7a | 3.4ab | 3.2ab | 5.8a | 14.1a | 5.4ab |
| Control | 5 C | 1.00 | 0.2b | 4.5a | 14.3a | 1.7b | 0.2b | 5.1a | 14.0a | 1.7a | 0.2b | 5.9a | 14.6a | 1.9b |
| Control | 15 C | 1.00 | 0.2b | 5.0a | 14.2a | 2.0b | 0.2b | 5.2a | 14.3a | 1.8a | 0.2b | 5.2a | 16.4a | 1.9b |

* Scale for injury: 1 (healthy) to 6 (heavily damaged). The roots were not damaged.

Values in a column followed by the same letter are not significantly different at P = .05.

It was assumed by Lacasse and Rich (1964) and Westing (1966, 1969) that toxic concentrations of salt in plant tissue in the field were due to uptake from soil. The levels of Na and Cl measured in the present study do not support this assumption. Controlled experiments indicate that injury to white cedar trees became apparent only when levels of Na and Cl in the soil were 0.13 mg/g dry weight and 0.42 mg/g, respectively. Such high levels resulted in increased foliar concentration of Na and Cl and extreme foliar water stress. In the field such high levels were reached only once, at 2 m from the pavement on 21 March, 1975. The concentrations of Na and Cl at a distance of 8 m or more from the pavement did not exceed 0.04 mg/g of soil. This concentration is far below the critical level for injury. Therefore, it may be concluded that the primary cause of damage to the foliage was not salt uptake from the soil. Several researchers (Hofstra and Hall 1971, Hall et al. 1972, Sucoff et al. 1975, 1976) have suggested that high concentrations of injurious salt observed in the plant resulted from salt drift that was due to wind, or from salt splash caused by fast moving traffic.

This hypothesis was further confirmed by high salt concentrations found in filter paper disc samples and foliage facing the road. Foliage sampled on 14 March, 1975 showed the highest concentrations of Na and Cl (8.67 mg Na and 8.96 mg Cl per g of plant tissue). In comparison, foliage facing away from the road contained only 1.06 mg Na/g and 1.59 mg Cl/g. Even one month after the last salting, foliage on the side of the tree facing the road contained 5.39 mg Na/g and 6.70 mg Cl/g. Controlled experiments in growth chambers revealed that the critical concentration for damage to plant tissue was 3 mg Na/g and 8 mg Cl/g. The critical concentration for Cl agrees with that of Hofstra and Hall (1971) who reported that 10% injury in white cedar foliage along Highway 401 occurred at levels of 8 mg Cl/g.

Salt injury is dependent not only on salt concentrations in foliage or soil but also on prevailing environmental factors. Hofstra and Hall (1971) found that the sheltered side of white cedar and white pine trees exhibited less damage than the windward side, probably because the wind had a desiccating effect. Many species of woody plants become less winter hardy when they contain high concentrations of salt (Sucoff et al. 1976, Hofstra and Hall 1971).

Ambient air temperatures are directly correlated with the appearance of injury symptoms. Hall et al. (1972) found that 4-year-old white pine trees sprayed with salt did not exhibit any injury symptoms as long as they were maintained at 1.5°C. Similarly, in the present study white cedar trees showed little evidence of injury at 5°C, although levels of Na and Cl in their tissue were above the critical levels for injury. In this experiment injury became apparent after exposure to a temperature of 15°C, and this suggests that injury is related to metabolic activity of the plant. This would explain why damage along highways appears when temperature increases above 10°C in spring. Lumis et al. (1971) reported that in Ontario salt damage appeared in early March and increased through the spring.

Relative humidity appears to play a significant role in foliar salt absorption. The deliquescent properties of NaCl cause salt to be in solution at relative humidities greater than 90%. Controlled growth studies revealed that plants exposed to various temperature regimes could withstand relatively high concentrations of salt at low R.H. Plants receiving similar treatment at various temperatures but exposed to 90% R.H. for one day exhibited symptoms of injury with accompanying high foliar levels of Na and Cl. There were many days in winter when these R.H. conditions were reached in the field. Therefore it may be concluded that many sprayings, as reported by Hall et al. (1972), or fewer sprayings coupled with high R.H., would produce similar damaging effects even at prevailing low temperatures. Unfortunately, conditions that are most conducive to injury occur during the periods of heaviest de-icing applications (Appendix).

How can salt injury be averted? Westing (1969) suggested increasing the proportion of $CaCl_2$ in the salt mixture or adding soil-improving additives such as $CaCO_3$ and $CaSO_4$. Greenhouse studies[4] showed that the addition of $CaCO_3$ reduced the levels of Na and Cl in plant tissue, but $CaSO_4$ did not.

Further research is needed to develop methods to alleviate salt damage to roadside vegetation and to find alternative efficient, economical and environmentally acceptable methods of de-icing roadways for safe public travel. Hanes et al. (1970) suggested that one alternative was to discontinue bare-pavement maintenance. This would require a basic change in public attitude. Another short-term solution is the planting of salt-tolerant species such as mugho pine (*P. mugho* var. *mugho*), horse chestnut (*Aesculus hippocastanum*) and buckthorn (*Rhamnus* spp.) (Lumis et al. 1973). Further research is necessary to identify possible salt-resistant ecotypes of the commonly planted species. The use of salt-tolerant plants for roadside planting does not, however, solve the problem of increased salt levels in rivers, lakes, ground water supplies and soil. Even though Na and Cl levels in soil may not be injurious to some species, high NaCl application to roadside soils results in a buildup of Na ions at lower levels in the soil profile (Bowers and Hesterberg 1976). In the present study, initially high Na levels were observed in the upper 8 cm

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[4] Foster, A.C. 1977. Effects of road salt on eastern white cedar (*Thuja occidentalis* L.) MSc thesis, Univ. Western Ontario, London. 124 p.

of soil. With later sampling the highest levels were recorded at the lower depths, and this suggests a possible downward movement of Na. According to Daubenmire (1959) increased Na levels in soil result in a dispersal of colloidal particles with subsequent loss of soil structure and overall deterioration of the soil environment.

The present study indicates that salt, through use as a deicing agent, enters the roadside environment as salt spray, dust or runoff, and results in spatial and temporal fluctuations in salt concentrations. The level of Na and Cl ions in soil and foliage was positively correlated with injury of eastern white cedar. Critical levels of Na and Cl causing damage to foliage were 0.13 mg and 0.42 mg per g dry weight of soil or 3 mg and 8 mg per g dry weight of plant tissue, respectively. Environmental parameters of temperature and humidity had a marked effect on salt-induced injury in eastern white cedar and may explain observed damage and symptom expression in roadside plantings of this species.

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APPENDIX

## APPENDIX

A meteorological summary of temperature, precipitation, relative humidity, wind velocity and weather conditions.

| | Mean temp. (°C) | Total precipitation (cm of water) | Relative humidity (%) (min.) | Relative humidity (%) (max.) | Wind speed (km/hr) | Wind direction | Weather |
|---|---|---|---|---|---|---|---|
| 12 Jan. | -6 | 0 | 48 | 62 | 26 | SW | sunny |
| 13 Jan. | -10 | trace | 64 | 80 | 17 | SW | cloudy/light flurries |
| 14 Jan. | -9 | 0.02 | 65 | 77 | 22 | SW | flurries/cloudy |
| 15 Jan. | -8 | 0.25 | 73 | 84 | 22 | SW | light snow/cloudy |
| 16 Jan. | -8 | 0.25 | 77 | 81 | 27 | W | cloudy/flurries |
| 17 Jan. | -8 | 0 | 67 | 77 | 18 | SW | sunny |
| 18 Jan. | -1 | 0.65 | 66 | 96 | 24 | SW | cloudy/light snow |
| 19 Jan. | -8 | 0.02 | 72 | 88 | 23 | NW | cloudy/light snow |
| 20 Jan. | -16 | 0 | 57 | 72 | 12 | E/SE | clear |
| 21 Jan. | -6 | trace | 72 | 81 | 29 | S | cloudy |
| 22 Jan. | -4 | trace | 70 | 85 | 12 | NW | freezing rain |
| 23 Jan. | -6 | trace | 78 | 84 | 18 | S | light snow |
| 24 Jan. | 0 | trace | 78 | 88 | 15 | S | showers |
| 25 Jan. | 1 | 1.90 | 76 | 100 | 20 | SW | cloudy/rain |
| 26 Jan. | -3 | 0.30 | 81 | 85 | 28 | W | cloudy/snow |
| 27 Jan. | -6 | trace | 63 | 80 | 15 | SW | cloudy |
| 28 Jan. | -3 | 0 | 66 | 92 | 9 | E | cloudy |
| 29 Jan. | 3 | 1.70 | 69 | 92 | 29 | W | rain |
| 30 Jan. | -4 | 0.02 | 75 | 89 | 15 | W | light snow flurries |
| 31 Jan. | -4 | 0.05 | 69 | 86 | 11 | N | cloudy/flurries |

(cont'd)

A meteorological summary of temperature, precipitation, relative humidity, wind velocity and weather conditions.

| | Mean temp. (°C) | Total precipitation (cm of water) | Relative humidity (%) (min.) | Relative humidity (%) (max.) | Wind speed (km/hr) | Wind direction | Weather |
|---|---|---|---|---|---|---|---|
| 1 Feb. | -4 | 0 | 48 | 71 | 13 | NE | partly cloudy |
| 2 Feb. | -6 | trace | 60 | 84 | 7 | NW | snow shower |
| 3 Feb. | -4 | trace | 62 | 84 | 10 | NE | snow/clearing |
| 4 Feb. | -7 | trace | 61 | 70 | 23 | E | snow |
| 5 Feb. | -1 | 0.55 | 88 | 100 | 11 | E | cloudy/trace freezing |
| 6 Feb. | -3 | 0.3 | 85 | 96 | 11 | W | light snow |
| 7 Feb. | -8 | 0.15 | 67 | 92 | 24 | SW | light snow |
| 8 Feb. | -8 | 0.10 | 64 | 84 | 23 | W | cloudy/flurries |
| 9 Feb. | -13 | 0.15 | 63 | 83 | 20 | W | cloudy/snow |
| 10 Feb. | -13 | trace | 53 | 71 | 14 | S | cloudy |
| 11 Feb. | -8 | 0.02 | 74 | 88 | 10 | NE | snow |
| 12 Feb. | -7 | 0.10 | 66 | 88 | 18 | N | snow/blowing snow |
| 13 Feb. | -9 | 0.20 | 70 | 88 | 26 | W | snow/blowing snow |
| 14 Feb. | -7 | 0.02 | 80 | 84 | 12 | W/SW | light snow |
| 15 Feb. | -3 | 0.60 | 78 | 92 | 15 | E | snow in p.m. |
| 16 Feb. | -1 | 0.30 | 85 | 92 | 16 | NE | snow/light freezing rain |
| 17 Feb. | 0 | 0.65 | 88 | 100 | 26 | E | light rain |
| 18 Feb. | 0 | 0.50 | 92 | 100 | 20 | W | light snow |
| 19 Feb. | -1 | 0.10 | 88 | 92 | 20 | W | snow |
| 20 Feb. | -2 | 0 | 69 | 81 | 19 | SW | clearing |
| 21 Feb. | 1 | 0 | 67 | 89 | 12 | SW | sunny |
| 22 Feb. | 3 | 0.85 | 62 | 89 | 15 | SE | cloudy/rain |
| 23 Feb. | 3 | 0.70 | 100 | 100 | 18 | NE | light rain |
| 24 Feb. | 1 | 2.60 | 89 | 100 | 22 | E | rain |
| 25 Feb. | -1 | 1.00 | 85 | 96 | 33 | SW | gusty/snow |
| 26 Feb. | -1 | 0.10 | 69 | 92 | 39 | SW | windy/snow |
| 27 Feb. | -4 | 0.10 | 66 | 78 | 24 | SW | cloudy/flurries |
| 28 Feb. | -2 | 0.20 | 78 | 92 | 19 | W | cloudy/flurries |

(cont'd)

APPENDIX (concl'd)

A meteorological summary of temperature, precipitation, relative humidity, wind velocity and weather conditions.

| | Mean temp. (°C) | Total precipitation (cm of water) | Relative humidity (%) | | Wind | | Weather |
|---|---|---|---|---|---|---|---|
| | | | (min.) | (max.) | speed (km/hr) | direction | |
| 1 Mar. | -6 | 0.10 | 74 | 88 | 17 | W | snow flurries |
| 2 Mar. | -7 | 0.02 | 65 | 92 | 20 | NW | cloudy/flurries |
| 3 Mar. | -9 | 0.05 | 77 | 88 | 6 | W | snowflurries |
| 4 Mar. | -6 | 0.05 | 65 | 84 | 17 | W | snow |
| 5 Mar. | -2 | 0.75 | 69 | 84 | 16 | S | sunny/snow in evening |
| 6 Mar. | 1 | 0.1 | 82 | 96 | 16 | W | snow |
| 7 Mar. | -1 | 1.0 | 85 | 96 | 25 | E | freezing rain |
| 8 Mar. | -9 | trace | 73 | 92 | 19 | NW | sunny |
| 9 Mar. | -11 | trace | 78 | 92 | 14 | SW | flurries |
| 10 Mar. | -7 | 0.1 | 60 | 92 | 5 | NE | snow/partial clearing |
| 11 Mar. | -4 | 0 | 81 | 96 | 9 | E | sunny |
| 12 Mar. | 1 | 0.55 | 72 | 81 | 23 | E/W | rain/fog |
| 13 Mar. | -4 | trace | 74 | 81 | 18 | W | snow flurries |
| 14 Mar. | -6 | 0.35 | 74 | 84 | 28 | NE | snow |
| 15 Mar. | -3 | 0 | 58 | 96 | 11 | S | sunny |
| 16 Mar. | -1 | 0 | 85 | 100 | 8 | S/NE | fog/cloudiness |
| 17 Mar. | 1 | 0 | 67 | 85 | 15 | E | sunny |
| 18 Mar. | 3 | 0 | 47 | 81 | 15 | SE | cloudy |
| 19 Mar. | 4 | 1.00 | 96 | 100 | 14 | NW | rain |
| 20 Mar. | 1 | 0 | 79 | 100 | 18 | NW | clearing |
| 21 Mar. | -1 | 0.30 | 69 | 88 | 18 | E | cloudy/snow and freezing rain |
| 22 Mar. | 3 | 1.60 | 78 | 96 | 31 | W | cloudy/windy/rain |
| 23 Mar. | 2 | 1.20 | 70 | 85 | 16 | W | cloudy |
| 24 Mar. | 1 | 0.20 | 78 | 100 | 25 | E | cloudy/rain |

Recorded at London Airport from 12 Jan. to 24 Mar., 1975.