Soybean plants treated with 5 minutes of EOD FR light had greater shoot dry weights than plants treated with 5 minutes of EOD R light (8). Lack of differences in the present study may be attributed to the fact that a large percentage of total shoot dry weight was produced before light treatments started.

On the day of removal from simulated storage, plants treated with EOD incandescent light had more etiolated shoots than plants treated with EOD fluorescent light or controls (Table 3). This suggests that during storage, plants treated with EOD incandescent light continue to exhibit shoot elongation responses similar to those displayed during production. After 5 days in the IE, there were no differences in percent leaf chlorosis among treatments (Table 3). When compared to differences observed in experiment 1, it can be concluded that altering the R:FR is not enough to affect postharvest leaf chlorosis. Exclusion of either FR or R light must be attained to give an effect, thus making applications of this practice impractical when trying to reduce postharvest leaf chlorosis in the greenhouse. A possible alternative could be found with using a red light source after darkness.

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Effect of Time and Application of Sodium Chloride in the Dormant Season on Selected Tree Seedlings1

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Abstract

Seedlings of *Acer platanoides*, *A. rubrum*, *Quercus palustris*, and *Q. rubra* were subjected to soil-applied sodium chloride (NaCl) solutions of 0.0, 1.1, and 5.0 *N* NaCl once every month beginning in October and ending in April. In May, the trees were evaluated for damage, harvested and dried. Growth measurements and shoot Na and Cl content were analyzed. For all four species, plants in the November through February/March salt treatments sustained little plant damage and reduction in growth. The October application of NaCl resulted in heavy plant damage and reduced growth in each species, while April NaCl applications produced similar results in *A. rubrum* and *Q. palustris* alone. Shoot Na and Cl content were greater in plants in the October, March, and April salt treatments.

In a second experiment, actively-growing, greenhouse-grown plants of the four species were subjected to either a fertilizer solution plus 0.25 *N* NaCl at every irrigation or a single application of 1.1 *N* NaCl followed by normal irrigation thereafter. *A. platanoides* lost its resistance to soil-applied NaCl by mid summer, while *A. rubrum* and *Q. palustris* were sensitive to a high dosage of NaCl applied at this time and *Q. rubra* was resistant. In both experiments, there were significant interactions between the time of NaCl application and the periodicity of plant growth, soil temperature, precipitation, and leaching of the salt from the soil as well as genetic factors, which affected the amount the salt injury sustained by trees.

Index words. NaCl, salt, salinity, *Acer platanoides*, *Acer rubrum*, *Quercus palustris*, *Quercus rubra*

Significance to the Nursery Industry

Landscape maintenance managers should not use sodium chloride (NaCl) to deice walkways and roadways during late autumn and late winter/early spring in order to avoid salt injury to nearby vegetation. Less toxic NaCl substitutes, such as the expensive deicing agent calcium methyl acetate as well as sand and cinders, may be used during these critical times of the dormant season. Damage to trees exposed to soil-applied NaCl during the winter may be reduced through heavy irrigation in the early spring. Landscape contractors should be cautious when selecting plant material for a site that potentially may receive rocksalt during the late autumn,

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because even species of trees reported to be salt resistant may be damaged by sodium chloride applied at that time.

Introduction

In northern regions of the United States, sodium chloride (NaCl) in the form of rock salt is used extensively in winter to deice roadways and walkways. This salt, in the form of runoff or spray, injures nearby trees by reducing growth and vigor and by causing leaf chlorosis, marginal necrosis (scorch), twig and branch dieback, and if severe plant death. Salt stress is well documented as a major problem in many urban areas and in the urban-like situations along rural roadways (6, 10, 13, 15, 26, 31).

Previous investigations have shown that the kind of salt, i.e., NaCl, $CaCl_2$, etc. (4, 5, 29), the concentration of the salt (13), and the mode of application of the salt, i.e., soil- vs. aerial-applied (4, 5, 25), affect salt injury in temperate woody landscape plants. However, little work has been done to determine whether time of application of soil-applied salt during the dormant season has any effect on the injury sustained by plants. Walton (29) compared winter and late spring/early summer applications of NaCl and found that plants treated in winter accumulated less Cl and displayed less damage in the spring compared to plants treated during the growing season. Hofstra and Lumis (12) and Lumis et al. (18) found that plants exposed to winter salt spray absorbed less salt in January and February but more in March and April. There have also been investigations where actively-growing plants have been used to evaluate salt resistance (4, 5, 8, 28). However, it is questionable whether the responses of actively-growing plants to salt can predict plant landscape performance in the roadside situation where the plants are exposed to salt in the dormant season.

Soil salinity was monitored at a roadside site on the campus of Cornell University, Ithaca, N.Y. from March through May of 1988. Soil water samples were taken periodically 1 m (3.28 ft) from the curb and at a depth of 15 cm (6 in), one sample taken at the base of each of six trees on the side of each tree facing the road. These measurements indicated that the tree roots were exposed to high soil salinity (electrical conductivity (EC) ≈ 5.0 S/m^{-1}) in late winter (early March). However, the soil salinity rapidly decreased with the coming of spring (EC ≤ 0.5 S/m^{-1}) as consistent with earlier findings (22, 29). The decrease in salinity was a result of the leaching of salt out of the root zone by water from snow melting in the spring thaw and from spring rains. It was feasible that roots of trees which are dormant in this roadside situation would absorb little salt and therefore might escape salt injury. Furthermore, those species which break dormancy late in the spring might exhibit resistance to soil salt by remaining dormant until soil salinity has decreased.

This study examined the effect of time of application of soil-applied NaCl in the dormant season on the amount of damage sustained by trees during the following spring. In addition, a followup experiment examined the salt resistance of actively-growing plants.

Materials and Methods

Experiment 1: Dormant plants. The following four species were tested: *Acer platanoides* L. (Norway Maple)—early to break dormancy, reportedly NaCl resistant; *A. rubrum* L. (Red Maple)—early to break dormancy, NaCl sensitive; *Quercus palustris* Muenchh. (Pin Oak)—late to break dormancy, NaCl sensitive; and *Q. rubra* L. (Northern Red Oak)—late to break dormancy, NaCl resistant (1, 2, 3, 9, 24, 32).

In spring 1987, one-year-old seedlings of these species were potted into two-gallon (7.6 l) containers using a soil : peat : perlite (2:1:1 by vol) mixture amended with 1.14 kg/cu m (1.14 oz/cu ft) treble superphosphate, 0.6 kg/cu m (0.6 oz/cu ft calcium nitrate), and 3.5 kg/cu m (3.5 oz/cu ft) dolomitic limestone. For the mix, bulk density = 0.56 kg/l (4.7 lb/gal) aeration porosity = 30.3%, pH = 6.2, and cation exchange capacity = 0.31 mol/kg. Plants were fertilized weekly with Peter's Peatlite Special fertilizer (20 N–4.3 P–16.6 K) plus trace elements at a rate of 200 ppm N : 42 ppm P : 166 ppm K and were allowed to become established in the containers for one growing season. In September, each plant was pruned to one unbranched stem, 80–100 cm (2.6–3.3 ft) for *A. platanoides* and 30–40 cm (1.0–1.3 ft) for the other species.

In early October, the bottom of each container was removed and the pots were sunk into the ground to the rim over a 5-cm (2 in) layer of gravel. The soil mix was recessed 7.5 cm (3 in) from the container rim to prevent run-off of precipitation from the soil mix surface and to allow for strict containment of applied solutions. The trees were exposed to ambient precipitation as well as air and soil temperatures. A pre-emergence herbicide, Rout (2% oxyfluorfen : 1% oxyzalin), was broadcasted at a rate of 10.8 g A.I./sq m (10.8 oz/sq ft) for weed control.

Three concentrations of NaCl were used: 1.1 *N* NaCl (8.6 oz/gal) the concentration of Cl found along a roadway recently deiced with rocksalt (25); 5.0 *N* NaCl (38.0 oz/gal) the concentration of a saturated solution of NaCl at 0°C; and tapwater.

The experiment was arranged as a three-way factorial of 4 species exposed to 3 concentrations of NaCl solutions across 7 monthly application (October, November, December, January, February, March, and April) by 6 replicates of each treatment ($4 \times 3 \times 7 \times 6 = 504$ plants or experimental units) in a randomized complete block (RCB) design. A given plant received one 500-ml (0.13-gal) application of one solution at only one of the seven application times.

Average daily soil temperature was monitored in four containers using thermistors inserted to a depth of 10 cm (4 in) into the soil mix in each of four containers and the temperature data recorded using a datalogger. Relative root growth activity was monitored using rhizotrons. Four rhizotrons [1.2 m × 0.2 m × 0.3 m (3.4 ft × 0.66 ft × 0.98 ft)] were constructed of wood and plexiglass and six plants of a given species were planted into each with a portion of their root systems positioned against the plexiglass, afterwhich the rhizotrons were sunk into the ground at the experimental plot. The rhizotrons were lifted every 1–2 weeks through the course of the experiment and the growth of 5 roots per plant was rated on a scale, where: 1 = no visible change in root length since the last observation; 2 = elongation up to 1 cm (0.39 in) per root; 3 = elongation between 1 and 2 cm (0.39–0.78 in); and 4 = elongation greater than 2 cm (0.78 in). Also noted were the dates of important phenological events of the shoot (bud enlargement and break, leaf expansion and abscission) in relation to relative root growth activity over the duration of the experiment. Precipitation was monitored at a weather station 1 km (0.62 mile) away from the experimental site. Soil salinity was determined from soil water extracted with soil water samplers implanted to a depth of 15 cm (6 in) into bottomless, two-gallon, soil mix-filled containers. With the exception of the no salt control, each pot received one 500-ml (0.132 gal) application of 5.0 *N* NaCl at one of the seven application times. Water samples were withdrawn on the first and fourteenth of each month from November 14 1987 to June 1 1988 except for the period from January 1 to March 26 1988 when soil temperatures made obtaining samples impossible. Electrical conductivity (EC) was measured for the water samples using a Solu-Bridge electrical conductivity meter.

On June 1 1988, the dormant season experiment was terminated and plant condition was evaluated using a visual rating scale, where: 1 = stems necrotic or stems not necrotic but no bud break; 2 = bud break and/or very small leaves ($\leq$ 2 cm or 0.78 in) present; 3 = leaves small ($\leq$ 75% of normal size for a given species); and 4 = leaves normal size.

The plants were then harvested, washed, separated into roots, old and current season's shoot growth, and dried at 60°C (140°F) for five days. Relative shoot growth was calculated, where relative shoot growth = DW new shoot growth ÷ (DW roots + DW old shoot growth).

Because Na and Cl absorbed by the roots from soil-applied NaCl tend to accumulate in the shoot (7, 28), only the shoot material was saved for analysis of these elements. Shoot material was first ground in a Wiley mill equipped with a 40 mesh screen. The chloride assay method used was adapted from the one developed by LaCroix et al. (16). One half gram (0.018 oz) of dry sample was shakened for 15 min with 50 ml (0.013 gal) of 0.125 *N* HNO_3 and allowed to settle for 1 h. A 10-ml (0.003 gal) aliquot of the extract was removed from each sample to be used for sodium analysis. Sodium analysis was performed using an inductively-coupled argon plasma atomic emission spectophotometer. The remaining 40 ml (0.012 gal) of extract was neutralized with 10 ml (0.003 gal) 0.5 *N* KOH and titrated with 7.05×10^{-3} *N* $AgNO_3$ in 0.1 *N* HNO_3 + 0.1 *N* KOH. The endpoint of the chloride titration was determined using an ion meter equipped with a chloride ion specific electrode and a double junction reference electrode.

Experiment 2: Actively-growing plants. One-year-old seedlings of the same four species were potted up into two-gallon (7.6 l) containers, irrigated, and fertilized as above and grown for one season then overwintered in an unheated greenhouse. In mid July the plants were placed in a 23°C (73°F) day/18°C (64°F) night greenhouse and grown under 18 hr daylength.

Three salt treatments were examined in this study: 1) a no salt control where a given plant was irrigated with a solution of Peter's Acid Special fertilizer (21 N–3.01 P–5.81 K) with trace elements at a rate of 200 ppm N : 29 ppm P : 58 ppm K; 2) a low, continuous exposure to salt treatment where a given plant was irrigated with the same fertilizer + 0.25 *N* NaCl solution at every irrigation; 3) a high, single application of salt in the form of a one 500-ml (0.132 gal) 1.1 *N* NaCl application at the beginning of the experiment, followed by irrigation with fertilizer solution every 2 days beginning one day after treatment. At every irrigation, all containers were leached first with 1 l (0.26 gal) tapwater.

The experiment was a two-way factorial of 4 species receiving 3 salt treatments with 6 replicates per treatment ($4 \times 3 \times 6 = 72$ plants or experimental units) arranged in a complete randomized (CR) design. Plant condition was evaluated weekly throughout the experiment and at its conclusion using a pretransformed scale, where: 1 = leaves completely necrotic; 2 = leaves $\geq$ 2/3 necrotic; 3 = leaves 1/3–2/3 necrotic; 4 = leaves $\leq$ 1/3 necrotic; 5 = leaves not necrotic. After 8 weeks the condition of the plants stabilized, at which time the experiment was terminated.

Statistical analysis. An analysis of variance (ANOVA) was performed on the final visual rating, relative shoot growth, shoot Na and Cl data from the two experiments. The Waller-Duncan k-ratio t-test at $\alpha = 0.05$ was used to compare means between application times within each species by salt level treatment combination.

Results and Discussion

Experiment 1: Dormant plants-Soil salt levels. When salt was applied in October, the EC and the concentrations of Na, and Cl in the soil water extract were very high (EC = 5.3, Na = 10,000 ppm, Cl = 12,000) in mid November but rapidly decreased to control levels (EC $\leq$ 0.2 S/m, Na $\leq$ 250 ppm, Cl $\leq$ 350 ppm) by late March (Fig. 1). The maximal EC of the soil water after treatment with 5.0 *N* NaCl was comparable with the EC of soil water from the streetside sites monitored on the Cornell campus. For the November treatment, soil salinity (EC = 5.2 S/m, Na =

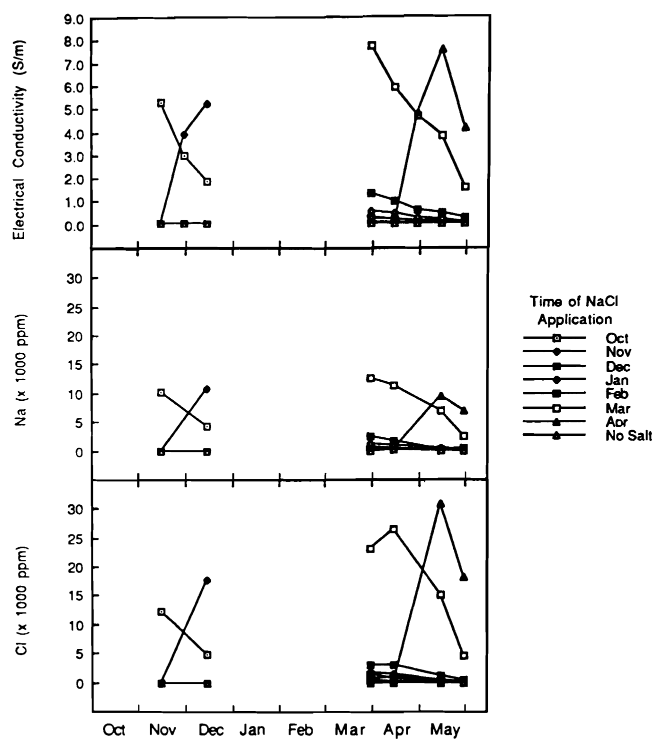

Fig. 1. Soil salinity monitored from October 1987 to May 1988 for Experiment 1. No soil water samples were obtainable from January 1 to March 26. Levels for the no salt control did not exceed 0.1 S/m for EC, 50 ppm for Na and 80 ppm for Cl over the course of the experiment.

11,000 ppm, Cl = 18,000 ppm) was elevated by mid December but like the October treatment, had returned to near background levels by March, when measurements of soil salinity resumed. Similar results were seen following measurements of soil salinity resumed. Similar results were seen following the December, January, and February treatments. For both the March and April treatments, salinity levels rose rapidly after each of the respective treatments were made (EC = 7.7 & 7.6 S/m, Na = 12,500 & 9,500 ppm, Cl = 26,000 & 31,000 ppm, respectively), then decreased precipitously with leaching by spring rains. Generally, Cl was leached from the soil faster than Na. The rainfall for the period was: Oct—3.7 cm (1.45 in); Nov—4.5 (1.77); Dec—5.3 (2.09); Jan—3.1 (1.22); Feb—5.4 (2.13); Mar—4.6 (1.81); Apr—6.6 (2.60); May—8.8 (3.46). Over the entire period, precipitation totaled 42 cm (16.5 in), 15% below average. A high degree of leaching of salt from the soil had occurred sometime during the period between late December through late March. During this period, the liquid equivalent of approximately 20 cm (7.87 in) of precipitation had fallen.

Tissue salt levels. Final shoot Na (Fig. 2) and Cl (Fig. 3) data followed nearly identical trends, where shoot Cl was generally higher than shoot Na. The shoot Na and Cl contents of all plants in the no salt treatment were less than 300 and 250 ppm, respectively. In the low salt treatment, plants of *A. platanoides* treated in October had significantly higher amounts of shoot Na and Cl (5,000 ppm and 7,000 ppm) compared to plants treated at other application times (700–1000 ppm Na and 1,000–3,500 ppm Cl). For *A. rubrum*, only plants in the April application time had significantly higher shoot Na and Cl (7,000 and 11,000 ppm) compared to plants in the other application time treatments (1,000–2,500 ppm and 500–3,500 ppm). Shoot Na content of *Q. palustris* was elevated for the October and April treatments (3,900 and 2,800 ppm). Plants in the April treatment had the highest levels of shoot Cl (4,500 ppm). For *Q. rubra*, the shoot Na and Cl content (1,500 and 3,000 ppm) for the October group was just significantly higher than that of the other application times with the exception of the April application time for shoot Cl. Although nearly all the plants of all species regardless of the application time were killed in the high salt treatment, shoot Na and Cl levels still followed the same general trends seen with the low salt treatment. Shoot Na and Cl levels ranged from 2,000–19,000 ppm and 2,500–28,000 ppm, respectively, with the highest levels found in the October, March and April treatments.

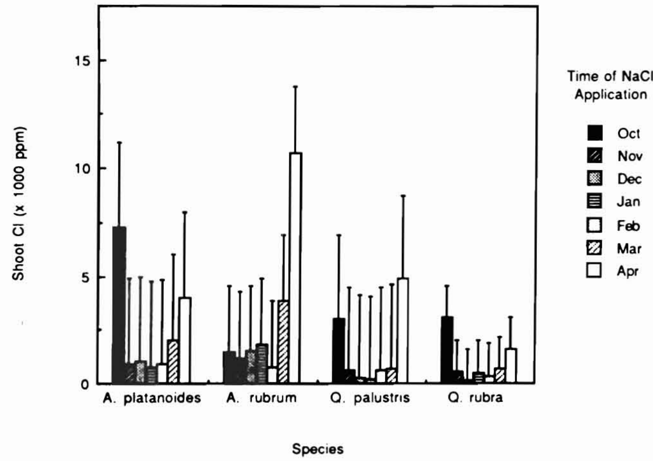

Fig. 3. Shoot Cl data for Experiment 1 for trees that received the low salt treatment (1.1 *N* NaCl) in the preceding dormant season. Bars represent LSD, 0.05.

Final visual rating and relative shoot growth. The final visual rating data (Fig. 4) and the relative shoot growth data (Fig. 5) followed similar trends. The 5.0 *N* NaCl treatment caused the death or severe reduction in leaf size of all plants regardless of time of salt application. Significant differences in condition and growth between application times were seen only in response to the 1.1 *N* NaCl treatment and therefore only data for the low salt treatment are provided. Plants of all four species in the control treatment showed no damage, with relative shoot growth in the range of 0.3–0.5. For *A. platanoides*, plants treated with salt in October showed significant reduction in leaf size and shoot growth, ≤ 25% of the control. Plants of *A. rubrum* treated in October as well

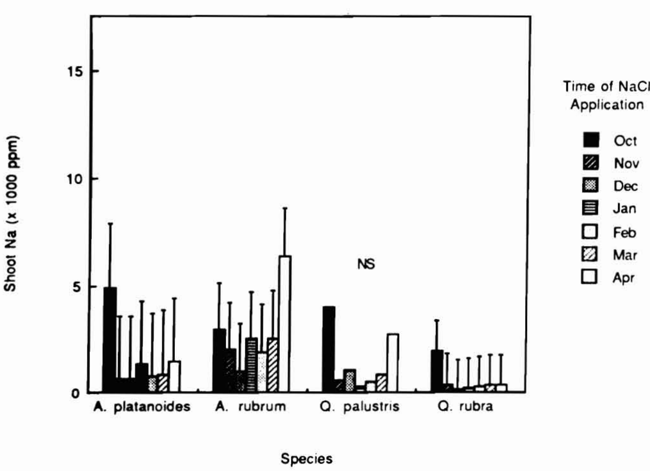

Fig. 2. Shoot Na data for Experiment 1 for trees that received the low salt treatment (1.1 *N* NaCl) in the preceding dormant season. Bars represent LSD, 0.05.

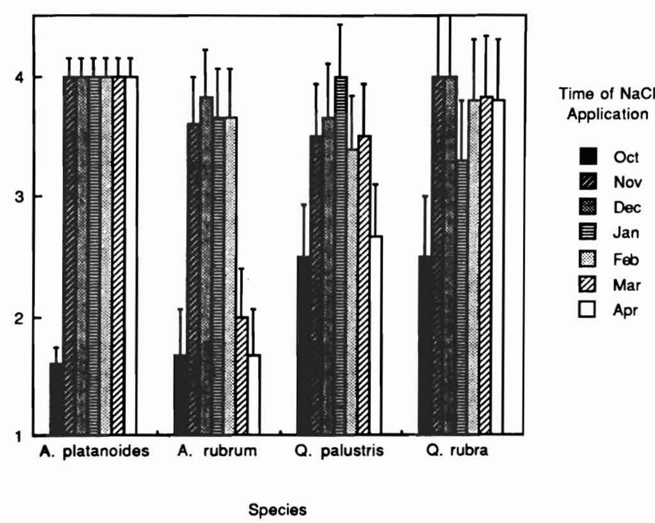

Fig. 4. Final visual rating (FVR) data for Experiment 1 obtained on June 1 1988 on trees that received the low salt treatment (1.1 *N* NaCl) in the preceding dormant season. FVR: 1 = no bud break, stems necrotic; 4 = leaves normal size. Bars represent LSD, 0.05.

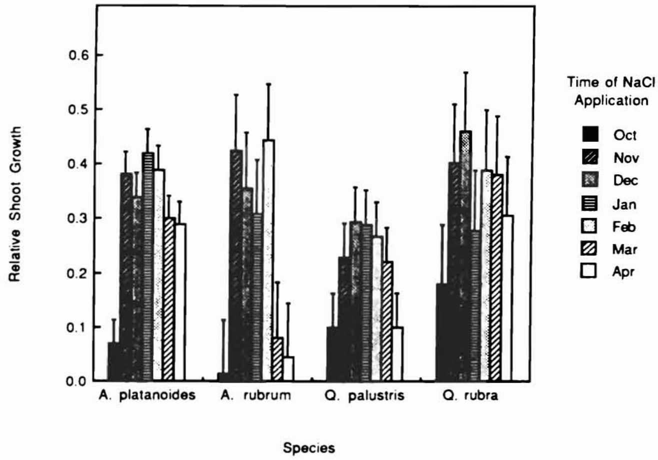

Fig. 5. Relative shoot growth (RSG) data for Experiment 1 for trees that received the low salt treatment (1.1 *N* NaCl) in the preceding dormant season. RSG = (DW new SG)/(DW roots + DW old SG). Bars represent LSD, 0.05.

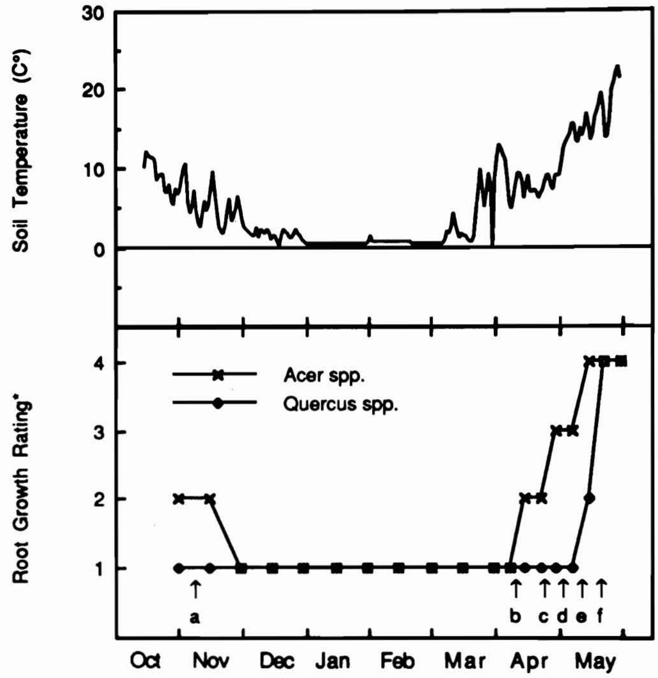

Fig. 6. Average daily soil temperature and periodic root growth data for Oct 1987 to May 1988 for Experiment 1. The root growth rating (RGR) data were obtained through observation using rhizotrons. RGR: 1 = no growth; 4 = high growth. Note: a = *Acer* and *Quercus* leaf abscission; b = *Acer* buds enlarging; c = *Acer* buds breaking; d = *Acer* shoots lengthening and *Quercus* buds enlarging; *e* = *Quercus* shoots lengthening.

as in March and April showed significantly more shoot damage and less shoot growth (<10–20% of the control) than when salt was applied at other dates. For *Q. palustris*, plants treated in October and April displayed the most damage and the least growth (30–50% of the control). For plants of *Q. rubra*, the October application of NaCl produced the most severe damage and reduction in shoot growth (50% reduction relative to the control).

During the winter months from November to February/March, woody plants experience deep dormancy and cold temperatures. These factors probably accounted for trees being less affected by salt applied during this time. The uptake of ions by mass flow requires transpiring leaves and hence would be neglible during the dormant season. Active transport of ions requires moderate temperatures and likewise would be restricted by frigid temperatures in this period (19). The March and April salt applications also produced high levels of soil salinity and species reported to be salt sensitive (*A. rubrum* and *Q. palustris*) sustained substantial damage, while species reported to be salt resistant (*A. platanoides* and *Q. rubra*) sustained little. These data suggest that both a seasonal effect as well as a genetic component appear to be determining the extent of salt injury and resistance observed in these species.

There is a high negative relationship between the final visual rating and relative growth data (Fig. 4 and 5) with shoot Na and Cl data (Fig. 2 and 3). A noteworthy exception is *A. rubrum* where the October application of 1.0 *N* NaCl severely damaged or killed the treated plants with little accumulation of Na or Cl in the shoot. Perhaps the salt solution quickly damaged and killed the root system, resulting in little salt uptake. A more plausible explanation is that after the plants were treated with NaCl in October most of the Cl in the shoot was deposited in the leaves (8, 28) which then abscised, leaving little Cl behind in the stem.

Root growth periodicity. Both *Acer* spp. showed some root growth in October and November, which then ceased after the soil temperature fell below 4–5°C (39–41°F) in December (Fig. 6). Root growth of the *Acer* spp. resumed at about the time of bud break in early April and increased rapidly in late April and early May, when the soil temperature remained above 8–10°C (46–50°F). For the two *Quercus* spp., no root growth was observed from October until bud break in mid May. Sudden and rapid root growth was then observed in the second half of May, when soil temperatures reached 10–15°C (50–59°F). These root growth periodicity data are consistent with Morrow (21) for *Acer* and with Lyr and Hoffmann (20) for *Quercus*.

Salt injury and inhibition of relative growth were better correlated with soil temperature than with root growth in the autumn and winter. Contrary to the hypothesis that late-breaking species would have an advantage over early-breaking species by escaping exposure of their roots to dormant season-applied salt, the early breaking *A. platanoides* and the late-breaking *Q. rubra* sustained less injury while the early-breaking *A. rubrum* and the late-breaking *Q. palustris* sustained more. Thus, time of breaking of dormancy made little difference in plant resistance to soil-applied salt. Rather, soil temperature and genetic factors seem more likely indicators of potential salt injury.

Experiment 2: Actively-growing plants. When actively-growing plants of the four species were exposed to soil-applied NaCl, the two *Acer* spp. performed well after prolonged exposure to 0.25 *N* NaCl, sustaining only moderate injury (visual rating = 3.7–3.8). The two *Quercus* spp. were damaged more severely (visual rating = 2.2–2.5) (Fig. 7). The single application of salt treatment of 1.1 *N* NaCl severely damaged plants of *A. platanoides*, *A. rubrum*, and *Q. palustris* (visual rating = 0.3–0.7). Plants of *Q. rubra* under the same treatment sustained only moderate injury (visual rating = 3.0).

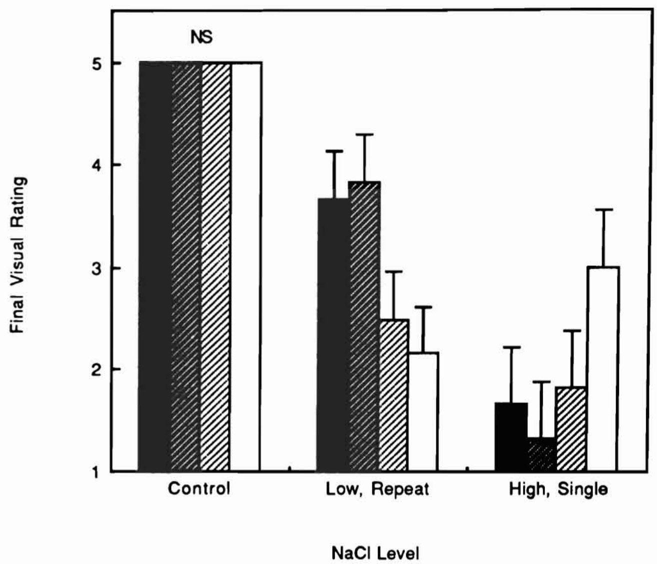

Fig. 7. Final visual rating (FVR) of plant conditon for Experiment 2 for plants exposed to NaCl while in active growth. FVR: 1 = leaves completely necrotic; 5 = leaves not necrotic. Bars represent LSD, 0.05.

The final visual rating and relative shoot growth data (Fig. 4 and 5) and the results of the followup study (Fig. 7) support the conclusion that there are seasonal changes in sensitivity to salt in three tree species. Plants of *A. platanoides* given a single dose of 1.1 *N* NaCl treatment in July (the same salt concentration used in the low salt treatments in the dormant season experiment), were severely damaged. Apparently, *A. platanoides* possesses resistance to soil-applied NaCl in winter/early spring but then loses it after leafing out by mid summer. The loss in resistance may be linked to increased salt uptake due to elevated transpiration rates. In contrast, actively-growing plants of *Q. rubra* were resistant to a single application of NaCl. This species' resistance to sudden salt exposure persists into the summer, but it too loses it by autumn. Both species clearly regain their resistance to salt over the winter, possibly as a result of the plant making adjustments to its metabolism when going into full dormancy, such as undergoing osmotic adjustment during cold acclimation (30). *A. rubrum* and *Q. palustris* apparently do not undergo this transition or go through this transition in the winter then revert back. It is interesting to note that the actively-growing plants of *A. rubrum* in this experiment demonstrated very good resistance to repeated exposure to low amounts of NaCl. *A. rubrum* is listed as being highly sensitive to NaCl (3, 32), but these data indicate an exception to this claim. However, these results do demonstrate that *A. rubrum* is sensitive to saline shock. Sudden exposure to salt may produce osmotic disruption or result in an immediate increase in ions in its system, inducing specific ion toxicity. Resistance to saline shock is an important trait in street trees because in the street-side situation a tree may be suddenly exposed to high doses of salt when the street is deiced with rocksalt. The results from this study indicate it is difficult to estimate the salt resistance of trees in the dormant season based on experimentation on actively-growing plants.

There are a number of explanations why there is a wide range of plant responses between the different times of application of soil-applied NaCl in the dormant season. In the period between November and March, plants of all four species avoid salt damage probably by not taking up salt during this period. Leaching of the salt from the root zone may then occur before resumption of growth in spring. As previously mentioned, processes that are involved in salt uptake, such as mass flow and active transport, are temperature dependent and are slowed or curtailed during this period, thereby resulting in less water and ion (including Na^+ and Cl^- ion) uptake. Also, basipetal lignification and suberization of cell walls of cortex and root cap that occurs as plants go dormant can restrict water and ion uptake by roots (14). Less salt uptake should lead to less salt injury. Another reason for salt resistance during the period of November through March may be that plants are in a physiological state that make them qualitatively less sensitive to salt, due to osmotic adjustment occurring for the establishment of cold hardiness.

In October, however, trees of all four species were damaged by salt applied at this time, while in April trees of *A. rubrum* and *Q. palustris*, but not *A. platanoides* and *Q. rubra*, were heavily damaged by salt (Fig. 4 and 5). Salt uptake more closely followed soil temperature (Fig. 6) and increased with higher transpiration rates brought on with presence of expanding leaves (in April and May) and existing leaves (in October) along with higher air temperatures. In the case of *A. platanoides* and *Q. rubra*, salt taken in at this time may simply reduce cold hardiness. Sucoff and Hong (27) found that elevated NaCl levels in tissues reduce cold hardiness in *Malus* and *Syringa*. Salt may lead to reduced hardiness by altering membranes (23), increasing succulence (17), or conversely by intensifying the dehydration of the protoplasm in response to freezing temperatures (17).

The two species which displayed good salt resistance in April, *A. platanoides* and *Q. rubra*, accumulated less Na and Cl in their shoots (Figs. 2 and 3). This salt resistance might be based upon the ability to prevent ions from entering their roots and/or shoots and/or the ability to dilute the concentration of Na and Cl through growth.

Not only may time of application of salt from a roadway affect injury in roadside trees, but the amount, intensity (concentration), and duration of exposure to salt may also affect the severity of tree injury. These conditions in turn may vary greatly depending on several more factors, such as the amount of salt applied to the roadway, roadside topography, and the distance the trees are from the roadway (11, 22, 31). In addition, meterorological (i.e., temperature and precipitation) and edaphic factors (i.e., texture, compaction, drainage characteristics, and CEC) can directly affect the rate at which salt is leached from the root zone.

The results from this study suggest that time of application of NaCl affects the amount of injury sustained by trees. This reason may justify the alteration of roadway and walkway deicing practices in an effort to reduce salt injury in street trees. In the critical times of the dormant season less toxic alternatives such as sand or cinders may be used. Furthermore, screening actively-growing trees for salt resistance may have little relation on their performance in the field.

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