*Wood and Fiber*, 9(3), 1977, pp. 191–201


# SALT DAMAGE TO NORTHERN WHITE-CEDAR AND WHITE SPRUCE

*Norman P. Kutscha,*[1] *Fay Hyland*[2]

and

*Alan R. Langille*[3]

(Received 14 March 1977)

ABSTRACT

Five-year-old transplants of northern white-cedar and white spruce were treated with tap water applied to the soil and with various concentrations of sodium chloride in distilled water, applied either to the soil or to the foliage. Observations were made on the gross morphological effects and anatomical effects of the treatments. Morphological damage included discoloration and loss of foliage. The most significant anatomical damage included fragmented cuticle, disrupted stomata, collapsed cell walls, disorganized or disintegrated protoplasts, coarsely granular cytoplasm, disintegrated chloroplasts, disintegrated nuclei and disorganized phloem. While there appeared to be no outstanding anatomical differences between the effects of soil versus foliar applications, both species did show somewhat less damage by soil-applied than by foliar-applied salt. It was not possible to conclusively assign the cause of morphological or anatomical damage to indirect effects, such as water deficiency or to ion toxicity of the salt. However, the results did suggest that northern white-cedar may be somewhat more salt-tolerant than white spruce.

*Keywords:* Salt damage, *Thuja occidentalis*, *Picea glauca*, morphology, anatomy, leaves, twigs.

## INTRODUCTION

A review of studies that deal with the effects of salt on plants indicates the widespread concern for this problem, particularly in relation to plants growing in saline environments (Poljakoff-Mayber and Gale 1975). Some study has been directed at the effects of salt on plants as a result of deicing operations along highways. Most of the literature deals with the general or physiological effects on crop plants, while limited research has been conducted on the effects of salt on woody plants, especially conifers, which, in Maine and eastern Canada, make up a significant portion of the roadside vegetation. The reported effects of salt on conifers are often contradictory or inconclusive.

Some general morphological effects of salt on woody plants have been described. Excessive accumulations of chloride within a plant may lead to leaf burn and to shoot-tip die-back (Hayward and Wadleigh 1949; Richards 1954; Bernstein 1964; Prior 1967), these symptoms being similar to those of drought injury (Westing 1966). When there is an excess of sodium within a plant, Westing (1969) stated that the first outward effect may be a deeper green color in the leaves; tips and margins die back ("leaf burn" or "scorch"), with demarcation between necrotic and healthy tissue being a sharp one; leaves develop a bronze color in some species; and leaves abscise sooner than normal. Similar plant responses were observed by Heggestad et al. (1972) who reported that accumulation of sodium or chloride in leaves caused characteristic tip or marginal leaf "burn." Waisel (1976, personal communication) observed that tip or marginal leaf "burn"

[1] Research Scientist, Weyerhaeuser Company, 3400 13th Avenue Southwest, Seattle, Washington 98134.

[2] Professor Emeritus of Botany, Department of Botany and Plant Pathology, University of Maine, Orono, Maine 04473.

[3] Associate Professor of Agronomy, Department of Plant and Soil Sciences, University of Maine, Orono, Maine 04473.

was associated with chloride toxicity symptoms while discoloration of the more inner parts of the leaf was a sodium toxicity symptom. Die-back of stems and eventual death of the plant may follow the abscission of "burned" leaves. Blue spruce (*Picea pungens* Engelm.) was reported by Heggestad and coworkers (1972) as relatively sensitive and northern white-cedar as moderately tolerant to salt, while Zelazny (1968) lists white spruce and northern white-cedar as being moderately salt-tolerant. In studying salt water injury resulting from a hurricane, Wyman (1939) noted that injured needles were bright orange, yellow, or orange-red for varying distances from the top of the tree down. In mass, conifers appeared as though damaged by fire. In contrast to the findings of Heggestad and Zelazny, however, Wyman stated that blue spruce appeared highly resistant to salt damage.

Very few reports that described the anatomical effects of salt could be found. Nieman (1965) indicated that salinity suppressed cell enlargement and cell division in bean leaves. He also found that meristematic cells and cells in early stages of enlargement are particularly active in absorbing ions and that chloride greatly influences plant development. It is possible for salt ions to cause drastic structural or anatomical changes. In a treatise of the biology of halophytes, Waisel (1972) found that stems of poplar (*Populus euphratica* Oliver) and cotton (*Gossypium* sp.) showed a thicker cortex and less xylem under saline conditions. *Populus* produced a ring-porous type of wood, as did *Gossypium*. In a study of blue spruce, Monk and Wiebe (1961) found it difficult to distinguish between death of cells due to salt and that due to normal plasmolysis. In salt damage death, however, the vacuole appeared normal and the cytoplasm appeared more granular; sometimes the cytoplasm was in clumps bordering the vacuole. Levitt (1972), in observing the responses of plants to environmental stress, noted that the protoplasm pulled away from the cell wall or that cell walls pulled away from adjacent cells.

This study is an attempt to examine the morphological and anatomical effects of salt on two coniferous species, northern white-cedar (*Thuja occidentalis* L.) and white spruce [*Picea glauca* (Moench) Voss], commonly found growing along Maine highways. It was conducted in conjunction with a second study (Langille 1974) which analyzed seedling tissue and soil for salt content following various applications of salt.

## MATERIALS AND METHODS

In October, 5-year-old transplants of northern white-cedar and white spruce were carefully potted in eight-inch, round plastic pots containing an Elmwood fine sandy loam uncontaminated with salt (Langille 1974). The pots were suspended in round holes that had been cut in the plywood cover of a styrofoam-lined box and placed outdoors. Two plastic covered A-frame sections were constructed that could be placed over the plants when snow or rain was anticipated. Throughout the experiment, sufficient tap water was added to the soil in which the plants were growing, whenever it appeared dry or powdery, so hopefully water was not a limiting factor. Overwatering, which might cause leaching of the soil, was avoided.

In December, treatments were applied to the plants. Treatments included tap water applied to the soil and 0, 100, 1,000, 10,000 and 100,000 ppm sodium chloride in distilled water, applied either to the soil or to the foliage. One application method consisted of spraying the foliage with 5 ml of each concentration using a hand atomizer. The other application method consisted of applying 5 ml of each concentration directly to the soil. Weekly applications of salt solutions were continued for 15 weeks until March. No salt treatments were applied between March and June, the period when little salt is applied to roadways. Normal bud expansion and seedling development took place during this period.

In June the experiment was terminated. For morphological and anatomical analysis, one representative plant of both cedar and spruce was selected from each of the following treatments: soil-applied tap water (which was used as the control for this study) and one each of soil and foliar application of distilled water, lowest salt concentration and highest salt concentration. Thus, seven cedar and seven spruce plants were examined for this study. Observations were made on the gross morphological effects of the treatments on the representative plants. Plants were examined for presence or absence of foliage and color of foliage and twigs. Also, needles and twigs near the tip and base of the plants were examined for general appearance and coloration. Central leaders of all transplants were erect and all green lateral shoots were turgid.

Following the morphological observations, terminal portions from both the upper and lower branches of the plants were collected and brought into the laboratory. Leaves and twigs of the current season were cut into convenient sizes, placed in F.P.A. killing and fixing fluid, and aspirated (Johansen 1940). Air was removed gradually to avoid plasmolysis. After one week in F.P.A., the specimens were dehydrated by the tertiary butyl alcohol schedule of Johansen and embedded in paraffin. Sections were cut at 10 microns on a standard rotary microtome and stained with safranin and fast green. Over 3,000 sections were analyzed and photomicrographs were prepared using a Zeiss Photomicroscope.

## RESULTS

### *Morphological*

Percent morphological damage (Table 1) was judged largely on the basis of discolored or missing leaves. The leaves and twigs of the new growth of the current season, when present, appeared green and vigorous. The leaves from the growth of the preceding season, when present, were either dark green and apparently alive, or reddish brown to yellow and apparently dead. Twigs from the preceding season were usually tan or brown. It was assumed that wherever the leaves were reddish brown to yellow or missing, the twigs were either dying or dead. All the leaves and twigs on the lower branches of all treatments were somewhat discolored or dead; only the upper branches, particularly the growth of the current season, remained alive. The demarcation between the living, green upper portion and the dead, reddish brown to yellow lower portion was more distinct in spruce than in cedar.

TABLE 1. *Percent morphological damage*

| | Northern White-Cedar | | White Spruce | |
|---|---|---|---|---|
| Treatment | Soil Application | Foliar Application | Soil Application | Foliar Application |
| Tap water (control) | 10% | — | 0% | — |
| Distilled water | 50% | 75% | 80% | 67% |
| 100 ppm NaCl | 40% | 90% | 60% | 75% |
| 100,000 ppm NaCl | 90% | 100% | 100% | 100% |
| Average of 100 and 100,000 ppm | 65% | 95% | 80% | 87% |

Results of the morphological analysis are summarized in Table 1. The control cedar plants were yellow on the lower 10%, whereas the spruce plants remained essentially green under control conditions. The soil-applied distilled water caused 50–80% damage while the foliar-applied caused 67–75% damage. The soil-applied low salt concentration caused 40–60% damage and the foliar-applied 75–90% damage. All plants receiving the high salt concentration died. The high concentration in cedar resulted in a yellow coloration for soil-applied and a more reddish-yellow coloration for foliar-applied salt. The high concentration in spruce resulted in a reddish coloration for soil-applied and a deep reddish color for foliar-applied salt.

### *Anatomical*

The anatomical effects on leaves and twigs were more difficult to evaluate than the morphological, because of the larger number of possible features that could be affected. Results are summarized below for leaves and twigs of both species, for both soil and foliar applications including samples taken from upper and lower branches from the tap water (control), distilled water, low-salt concentration and high-salt concentration treatments. Complete results are detailed in a report by Langille (1974). Photomicrographs presented illustrate cross sections of portions of the organs indicated taken from the upper portion of the plants. "Control" indicates treatment with tap water and "salt treated" indicates treatment with 100,000 ppm NaCl, both soil applied.

## *Leaves*

### 1. *Cuticle*

The cuticle appeared normal (smooth) in the upper needles of both cedar (Fig. 1) and spruce in the control. In cedar, at both low- (100 ppm) and high- (100,000 ppm) salt concentrations, however, the cuticle varied from being somewhat to much fragmented (broken up and rough) (Fig. 2), whereas the cuticle of white spruce needles evidenced no damage except on the needles from the lower branches where it showed some fragmentation.

### 2. *Stomata*

In the upper needles of both species, the stomata appeared for the most part normal and intact (Fig. 1) except at the high-concentration treatments where the guard cell protoplasts were disrupted (distorted or partially collapsed) or disintegrated (broken into fragments or nonexistent). In general the stomata of the lower needles of cedar were disintegrated in all treatments, whereas those of white spruce appeared normal except at high concentrations, where they appeared generally disrupted.

### 3. *Chlorenchyma*

*Cell Walls*—The cell walls were not disrupted or only slightly wavy in the controls and low-concentration treatments of both species. The cell walls of the needles from the lower portions of the cedar varied from wavy and slightly disrupted to completely collapsed (fallen or shrunken together), whereas at the high concentration they were either wavy or collapsed. Spruce upper needles appeared unaffected by any except the high-concentration treatments, where the cell walls were wavy and slightly disrupted.

*Protoplasts*—The protoplasts ranged from intact or slightly separated (even in the controls) (Fig. 3) to completely collapsed in both spruce (Fig. 4) and cedar. However, the spruce appeared less drastically affected.

*Cytoplasm*—The cytoplasm varied from clear to coarsely granular with the different treatments. It appeared clear in the uppermost needles of spruce except at the high concentration, where it was finely or coarsely granular. In cedar, the cytoplasm appeared finely granular in all treatments of the upper needles except for the soil-applied high-salt concentration and the control, where it appeared coarsely granular. It appeared coarsely granular in the needles of the lowermost parts of both species.

*Chloroplasts*—The chloroplasts appeared distinct (green, rounded structures) to indistinct (discolored, lacked rounded outline) in all treatments of the upper leaves of cedar (Fig. 2), whereas the chloroplasts of spruce were distinct except in the high-concentration treatments.

*Nuclei*—Except at the high concentration, where the nuclei were partially or

→

FIG. 1. Northern white-cedar needle. Control. 810×. a) normal intact cuticle, b) normal stoma, c) chlorenchyma cell with distinct nucleus.



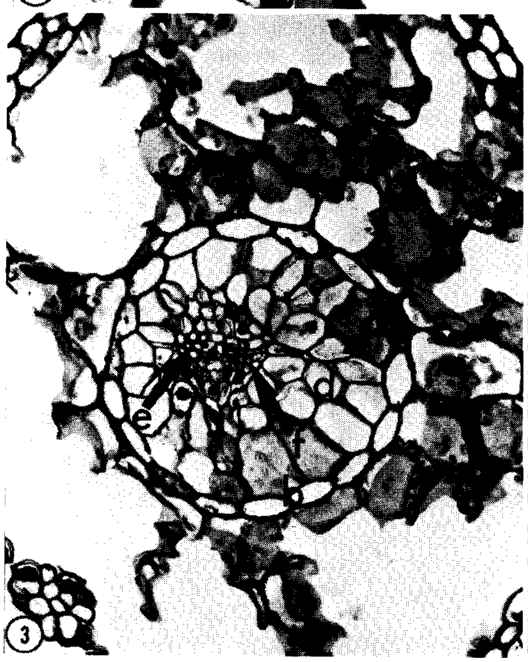



FIG. 2. Northern white-cedar needle. Salt-treated. 710×. a) fragmented cuticle, b) chloroplasts indistinct.

FIG. 3. White spruce needle. Control. 270×. a) chlorenchyma cell protoplasts intact or only slightly separated from the cell walls, b) stele with normal endodermis, c) endodermal cell with clear cytoplasm, d) normal transfusion tissue, e) phloem appearing normal or nearly so, f) normal xylem.

FIG. 4. White spruce needle. Salt-treated. 700×. a) chlorenchyma protoplasts completely collapsed, b) chlorenchyma cell with disintegrated nucleus, c) endodermis of stele with shrunken protoplasts, d) disrupted xylem.

completely disintegrated (Fig. 4), the nuclei were in general distinct and appeared normal (Fig. 1).

4. *Stele*

The stele was not evident as such in northern white-cedar needles.

*Endodermal Protoplasts*—In spruce, the endodermis appeared normal in the upper needles of all treatments (Fig. 3), except at the high-concentration treatments, and also in the lower needles of the control. In all other cases, the protoplasts appeared shrunken or distorted (Fig. 4).

*Endodermal Cytoplasm*—The cytoplasm of the cells in all the upper needles was clear in all treatments (Fig. 3) except for the two high-concentration ones, in which the cytoplasm appeared coarsely granular. The lower needles of the control had clear cytoplasm and in all other treatments the cytoplasm was either slightly or coarsely granular.

*Transfusion Tissue*—The transfusion tissue appeared normal (Fig. 3) in the control, the upper needles of the distilled-water treatments, the lower needles of the soil-applied low-concentration treatments, and the upper needles of the foliar-applied low-concentration treatments. In all other treatments, the transfusion tissue appeared distorted with shrunken contents.

5. *Vascular bundles*

Photomicrographs of vascular bundles in white spruce demonstrate the effects observed in both species.

*Phloem*—The phloem in general appeared normal or nearly so in the upper portions of the plants of both species (Fig. 3). The effects of the different treatments on the lower portions of the plants varied greatly, but in general showed moderately to drastically disrupted protoplasts in both species.

*Xylem*—The xylem appeared generally normal in both species (Fig. 3) except at the high concentration, where the cell walls appeared disrupted or irregular (Fig. 4).

## *Twigs*

1. *Cuticle*

Much variation was observed in the effects of the treatments on the cuticle and few clear-cut conclusions could be drawn. However, fragmentation of the cuticle occurred to a greater extent in spruce than in cedar at high-concentration treatments.

2. *Cortex*

*Cell Walls*—The cell walls of the upper twigs of cedar in all treatments appeared normal (Fig. 5), with a few exceptions (Fig. 6). Generally, the cell walls of the lower twigs in all treatments were slightly disrupted. The effects of the treatments on spruce were similar except in the two high-concentration treatments, where cell walls ranged from slightly disrupted to collapsed (Figs. 7 and 8).

*Cytoplasm*—In the uppermost twigs, the cytoplasm was finely granular in both cedar and spruce (Figs. 5 and 7) except at the high concentration where it appeared coarsely granular (Figs. 6 and 8). With some exceptions, the cytoplasm appeared coarsely granular in all other treatments.

*Nuclei*—Similar to the protoplasts, the nuclei exhibited marked variation. Some control plants had distinct nuclei (Figs. 5 and 7) while others did not. At the high concentration in spruce, all of the nuclei were completely disintegrated, i.e., not visible (Fig. 8), whereas in cedar some were distinct and some were disintegrated (Fig. 6).

3. *Vascular tissue*

*Phloem*—The phloem cell walls appeared either normal or wavy in most of the upper

→

FIG. 5. Northern white-cedar twig. Control. 280×. a) cell walls of cortex normal, b) cytoplasm finely granular, c) nucleus distinct, d) phloem cell walls normal, e) xylem normal, f) pith cell walls not collapsed.

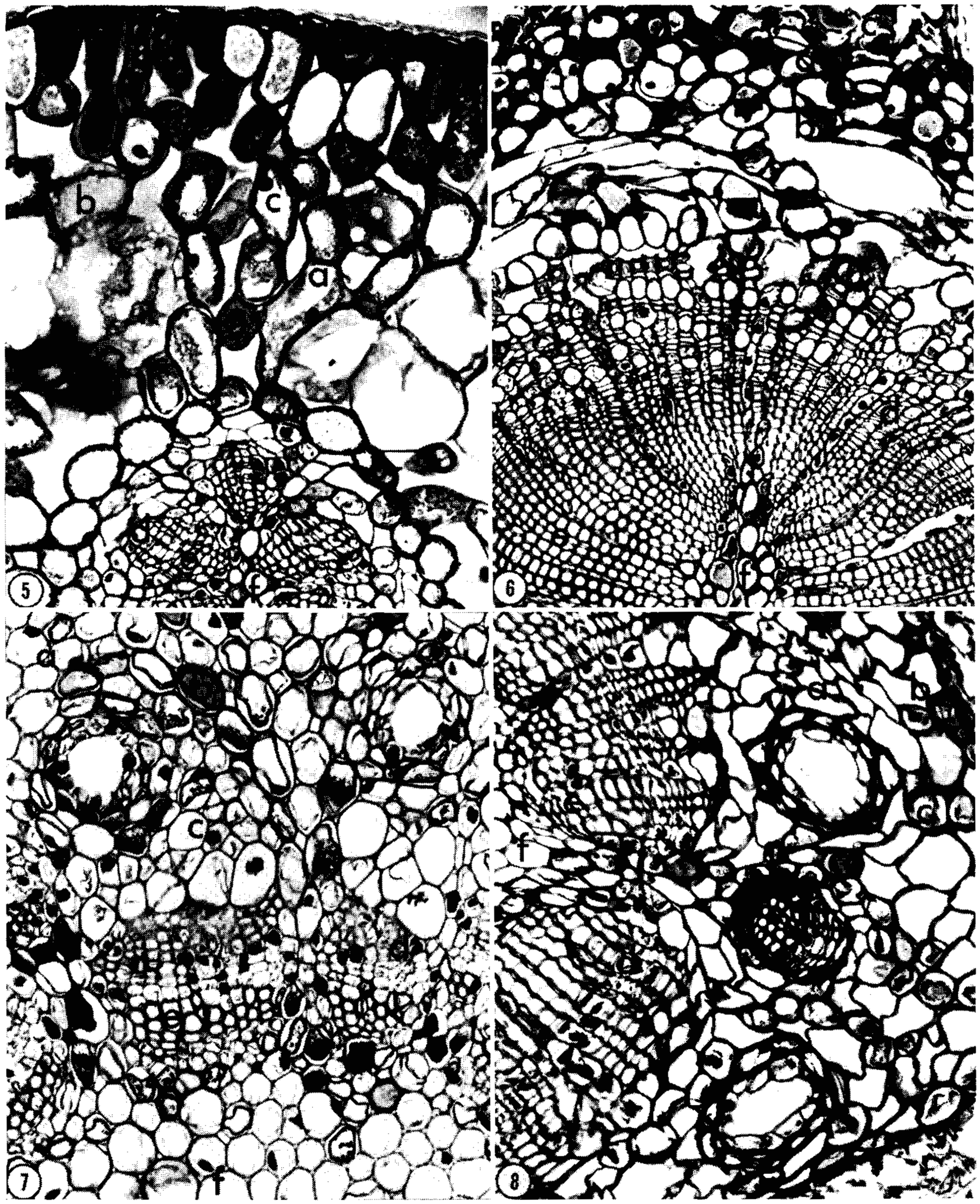


FIG. 6. Northern white-cedar twig. Salt-treated. 180×. a) cortex cells with disrupted walls and damaged protoplasts, b) cytoplasm coarsely granular, c) nuclei, some distinct and some disintegrated, d) phloem cell walls normal or collapsed, e) xylem normal, f) pith cell walls not collapsed.

FIG. 7. White spruce twig. Control. 280×. a) cell walls of cortex normal, b) cytoplasm finely granular, c) nucleus distinct, d) phloem cell walls normal or wavy, e) xylem normal, f) pith cell walls not collapsed.

FIG. 8. White spruce twig. Salt-treated. 280×. a) cell walls of cortex disrupted or collapsed, b) cytoplasm coarsely granular, c) nucleus completely disintegrated, d) phloem cells disorganized, e) xylem normal, f) pith cell walls not collapsed.

twigs of both cedar (Fig. 5) and spruce (Fig. 7), but some completely collapsed protoplasts were observed in those receiving the salt treatments. In general, with all the other treatments, the phloem cell walls varied from normal to disorganized (disrupted). Both high-concentration treatments in spruce showed disorganized phloem in upper twigs (Fig. 8); in cedar both normal and collapsed protoplasts were observed in the upper twigs (Fig. 6). In only those treatments with salt were completely collapsed protoplasts observed.

*Xylem*—The xylem appeared least affected of any tissue in the plant. It appeared normal with all treatments on both upper and lower twigs in both species (Figs. 5, 6, 7, 8).

4. *Pith*

*Cell Walls*—No collapsed cells were observed in any of the treatments (Figs. 5, 6, 7, 8). However, partially disrupted cells occurred in some of the treatments, particularly in spruce.

*Protoplasts*—The protoplasts were separated from the cell walls (even in the control) in the pith of cedar with most treatments and were collapsed in some of the high-salt concentration treatments. In spruce, the protoplasts of the cells varied widely from intact to completely collapsed; those in the control were usually completely collapsed.

The most significant anatomical damage due to salt (or dehydration) on comparing the upper portion of the highest-concentration plants with the upper portion of the control plants is shown in Table 2.

## DISCUSSION AND CONCLUSIONS

Morphological observations are summarized in Table 1. On comparing the tap water (control) and distilled water treatments, it is possible that the unexpectedly high percent of damage resulting from distilled water was due to an osmotic imbalance. The low concentration (100 ppm NaCl) applied to the soil appeared to have a beneficial effect on growth, as compared with distilled water, possibly due to a better osmotic balance. The low concentration applied to the leaves, however, yielded more damage than the distilled water treatment, possibly due to disruption of the epidermis and stomata. The high-concentration treatment caused more damage than the low-concentration treatment for both soil and foliar application. This agrees with the work of Mercado (1970) who determined that while low concentrations may be harmful or beneficial, high concentrations impaired the growth of all plants tested. For both low and high concentrations, the soil application usually caused less damage than the foliar application for both species, possibly due to salt retention by the soil, salt accumulating in the roots and not affecting the rest of the plant, and the foliar application disrupting epidermis and stomata. When averaging the percent damage for low and high concentrations with soil application, cedar showed slightly less damage than spruce, 65% versus 80%. Foliar application produced about the same amount of damage in both cedar and spruce, 95% versus 87%.

Analysis of the anatomical observations was considerably more complex than that of the morphological observations. While morphologically the needles and twigs of any new growth of the current season appeared green and vigorous, anatomical observation revealed that the cells were drastically divergent from the normal, resulting from the treatments and/or desiccation. It must be kept in mind that the distinction between salt tolerance and drought tolerance is sometimes difficult, since the effects on the plant, both macroscopically and microscopically, appear similar and that studies of plant tissue at the cellular level fail to reveal a clear-cut distinction between salt damage and normal plasmolysis. In this study, some of the anatomical features examined in the control plants exhibited deleterious effects similar to those receiving salt treatments, possibly as a result of desiccation. In some cases,

TABLE 2. *Anatomical damage from salt or dehydration in upper portion of plants receiving highest salt concentration*

| Damage | Treatment | Tissue | Species* |
|---|---|---|---|
| 1. Cuticle fragmented | Soil | Leaf | NWC |
| | Foliar, soil | Twig | WS |
| 2. Stomata disrupted or disorganized | Foliar, soil | Leaf | NWC |
| | Foliar, soil | Leaf | WS |
| 3. Cell walls wavy in chlorenchyma | Foliar, soil | Leaf | WS |
| 4. Cortex cells disrupted | Foliar, soil | Twig | WS |
| 5. Protoplasts separated in cortex cells | Foliar, soil | Twig | NWC |
| 6. Cytoplasm coarsely granular in chlorenchyma, stele cells, or cortex cells | Foliar | Leaf | WS |
| | Foliar, soil | Stele** | WS |
| | Foliar, soil | Twig | NWC |
| | Foliar, soil | Twig | WS |
| 7. Chloroplasts indistinct in chlorenchyma | Foliar, soil | Leaf | WS |
| 8. Nuclei indistinct in chlorenchyma or cortex cells | Foliar, soil | Leaf | NWC |
| | Foliar, soil | Leaf | WS |
| | Foliar | Twig | NWC |
| | Foliar, soil | Twig | WS |
| 9. Cell walls distorted in endodermal cells | Foliar, soil | Stele** | WS |
| 10. Transfusion tissue distorted | Foliar, soil | Stele** | WS |
| 11. Phloem disorganized | Foliar, soil | Leaf | NWC |
| | Foliar, soil | Leaf | WS |
| | Foliar, soil | Twig | WS |
| 12. Xylem disrupted | Foliar, soil | Leaf | WS |

* NWC—Northern White-Cedar, WS—White Spruce.
** Leaf Tissue.

the ill effects of the application of distilled water equaled or surpassed those of the low-salt concentration treatment. For this reason it was decided to scrutinize most closely the most significant anatomical damage due to salt (or dehydration) on comparing the upper portion of the high-concentration plants (severely damaged) with the upper portion of the control plants (no damage), the results of which are shown in Table 2. Features listed were present in the upper portion of plants receiving the highest salt concentration but were absent in the upper portion of the control plants.

The most significant anatomical damage included fragmented cuticle, disrupted stomata, collapsed cell walls, disorganized or disintegrated protoplasts, coarsely granular cytoplasm, disintegrated chloroplasts, disintegrated nuclei and disorganized phloem. Sometimes damage to needles and twigs was similar, particularly in the case of coarsely granular cytoplasm and indistinct nuclei. Features 5, 8, and 11 (Table 2) were found in the upper twigs (appeared normal morphologically) of the species indicated that had received the low-concentration, soil-applied treatment but were not found in the upper twigs (appeared normal morphologically) of the control plants that had received the tap water, soil-applied treatment, and therefore may be a direct result of the salt treatment. While there appeared to be no outstanding anatomical differences between the effects of soil versus foliar applications, both species did show somewhat less damage by soil-applied than by foliar-applied salt. While morphologically the cedar appeared somewhat more salt-tolerant than spruce, it also demonstrated slightly less anatomical damage to its internal tissue than spruce, although no quantitative comparisons were made.

A comparison of the morphological and anatomical data obtained in this study with the results of tissue and soil analyses obtained on the same samples by Langille (1974) using a Baird Atomic Emission spectrograph indicates a general agreement on certain points. Langille indicated that trees receiving foliar application had more sodium in both needles (most sodium) and stems (somewhat less) than those receiving soil application, while morphological data indicated that foliar application caused more damage than soil application in both species. Likewise, Langille indicated that sodium content of needles and stems increased with increasing salt concentration for both species while both morphological and anatomical data indicated that most damage occurred at the highest concentration for both species. Both these points of agreement assume that excess sodium is detrimental. Also, Langille indicated that chloride content was species dependent, being much higher in spruce, and if one again assumes that an excess of chloride is detrimental, both morphological and anatomical data indicated slightly more damage to spruce than to cedar. Likewise, for foliar application of labeled sodium it appeared that the sodium tended to accumulate in the needles and stem tissue of spruce, more so than in cedar, and that there was more movement into the root region of cedar than spruce (Langille 1974). Accumulation of salt in the roots has been substantiated by Lumis (1973). Thus one might expect more foliar damage to spruce than cedar, which seemed to be the case, both morphologically and anatomically.

In general, it appeared that the cedar was somewhat more salt-tolerant than the spruce, possibly because the numerous scalelike leaves of cedar enclose the twigs, protecting the innermost tissues from damage, or possibly because the twig cuticle of cedar is more highly resistant to salt damage. However, the specific effect of salt on plant organs is poorly understood.

Among the ways salt may exert its deleterious effects on plants are (1) indirectly and (2) by toxicity of the salt ions. Indirect effects might include impaired root aeration, water deficiency, and nutrient imbalance (Westing 1969). Bernstein et al. (1972) found that salt tolerance was not well correlated with injury by Cl or Na, although many species exhibited leaf burn; nor was survival under highly saline conditions necessarily a good index of salt tolerance. Leaves with symptoms like those of Cl or Na injury but containing very few of these ions were frequently observed in landscape plantings of a number of shrub species. The injury was attributed to inadequate watering. It was suggested that Cl or Na accumulation in leaves or shrubs may cause injury by interfering with normal stomatal closure, causing excessive water loss and leaf injury symptoms like those of drought. While Strogonov (1962) concluded that the mechanism of sodium toxicity and chloride toxicity is unknown, Bernstein (1976, personal communication) has indicated that it is the woody plants that are generally sensitive to Na and Cl, and develop toxicity symptoms.

In this study, it was not possible to conclusively assign the cause of the damage to indirect effects, such as water deficiency, or to ion toxicity of the salt. However, it is felt that at least some of the morphological and anatomical effects observed were due to the salt applied. More study will be necessary to identify specific features of damage that can be related directly to salt. This study does suggest that northern white-cedar might be somewhat better than white spruce for planting along roadways where salt is used for deicing purposes.

## REFERENCES

BERNSTEIN, L. 1964. Salt tolerance of plants. USDA, Agric. Inf. Bull. No. 283.

BERNSTEIN, L., L. E. FRANCOIS, AND R. A. CLARK. 1972. Salt tolerance of ornamental shrubs and ground covers. J. Am. Soc. Hortic. Sci. 97(4):550–556.

HAYWARD, H. E., AND C. H. WADLEIGH. 1949. Plant growth on saline and alkali soils. Adv. Agron. 2:1–38.

HEGGESTAD, H., F. SANTAMOUR, AND L. BERNSTEIN. 1972. Plants that will withstand pollution and reduce it. *In* Landscape for living—the yearbook of agriculture. House Document No. 229, Supt. of Documents, Washington, D.C.

JOHANSEN, D. A. 1940. Plant microtechnique. McGraw-Hill Book Co., Inc., New York.

LANGILLE, A. R. 1974. Salt toxicity of conifers, final report. Maine Dep. Transportation Materials and Research Technical Paper 74-5.

LEVITT, J. 1972. Responses of plants to environmental stresses. Academic Press, New York.

LUMIS, G. P. 1973. Absorption and translocation of highway deicing salt by white pine (*Pinus strobus* L.). Abstract, 70th Annual Meeting, Am. Soc. Hortic. Sci. 8(3) sec. 2: 272–273.

MERCADO, B. T. 1970. On the NaCl resistance of *Beta vulgaris* and *Zea mays*. Protoplasma, 69(2):151–170.

MONK, R. W., AND H. H. WIEBE. 1961. Salt tolerance and protoplasmic salt hardiness of various woody and herbaceous ornamental plants. Plant Physiol. 36(4):478–482.

NIEMAN, R. H. 1965. Expansion of bean leaves and its suppression by salinity. Plant Physiol. 40(1):156–161.

POLJAKOFF-MAYBER, A., AND J. GALE (EDS.). 1975. Plants in saline environments. Springer-Verlag, New York.

PRIOR, G. A. 1967. A study of salt pollution of soil by highway salting. *In* Highway Research Record Report No. 193 on Environmental Considerations in Use of Deicing Chemicals. Highway Research Board, National Research Council, National Academy of Sciences, Washington, D.C. Pp. 8–12.

RICHARDS, L. A. (ED.). 1954. Diagnosis and improvement of saline and alkali soils. USDA Handb. No. 60.

STROGONOV, B. P. 1962. Physiological basis of salt tolerance of plants as affected by various types of salinity. (In Russian with English translation.) Akademia Nauk USSR (Moscow).

WAISEL, Y. 1972. Biology of halophytes. Academic Press, New York.

WESTING, A. H. 1966. Sugar maple decline: an evaluation. Econ. Bot. 20(2):196–212.

WESTING, A. H. 1969. Plants and salt in the roadside environment. Phytopathology, 59 (9):1174–1181.

WYMAN, D. 1939. Salt water injury of woody plants resulting from the hurricane of September 20, 1938. Arnold Arbor., Bull. Popular Information, IV(7):45–52.

ZELAZNY, L. W. 1968. Salt tolerance of roadside vegetation. *In* Proceedings of the symposium: pollutants in the roadside environment. Univ. of Connecticut, Storrs. Pp. 50–56.