THE EFFECTS OF DE-ICING SALT SPRAY ON HIGHWAY PLANTINGS

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ABSTRACT

THE EFFECTS OF DE-ICING SALT SPRAY ON HIGHWAY PLANTINGS: SURVEY OF INJURY ALONG MICHIGAN HIGHWAYS AND STUDIES ON THE SODIUM AND CHLORINE CONTENT OF AUSTRIAN AND WHITE PINE

By

Luther Moxley

Reports of de-icing salt spray injury to plants has increased in the past decade (45,59,78). This study was undertaken to observe salt spray injury to plants bordering selected Michigan highways in order to provide a comprehensive guide to salt spray tolerant plants for highway areas and to partially delineate the reasons for the tolerance of Austrian pine and the susceptibility of white pine to salt spray.

Results of the survey indicate that those plants with thick coatings of wax on foliage, stems, and buds were most tolerant to salt spray. Those plants with pubescent coatings on the stems, buds and foliage were also tolerant. Injury from salt spray was observed on plants as far as 250 feet from the edge of the highway and to a vertical distance of 20 feet.

Microprobe analysis results indicate that sodium and chlorine is less evenly distributed on the white pine needle surface. The results of cross section analysis indicate that

the tolerance of Austrian pine is not due to the fact that it is able to exclude sodium and chlorine from the needle cells. Tolerance of Austrian pine may be related to its ability to tolerate higher levels of sodium and chlorine in the cells or its ability to resist dessication.

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INTRODUCTION

The use of de-icing salts has increased in the last decade as man's desire to travel by automobile over great distances at high speeds has increased. Westing (95) reports that in 1968 six million tons of salt were applied to highways in the northern states; 95% being applied as NaCl and 5% as $CaCl_2$. A typical New England highway received as much as twenty tons of salt per mile per season. Westing indicates that salt use is increasing at the rate of one million tons per year. Estimates of salt use in the northern states in the 1968-69 winter have been as high as ten million tons (68).

The problem of plant injury from salts has received much attention in recent years but is a problem that has been recognized for some time. Wyman (99) notes that when *Forsythia* was brought by ship from the Orient to Europe in the 1800's, protection from salt spray was provided. In the early twentieth century calcium chloride used as a dust palliative on dirt roads was found to injure plants along these roads (85,87,88,90). In more recent years much damage has been reported from salts applied to highways as de-icers (1,22,36,39,42,50,56,74,83).

The purpose of this research is to observe de-icing salt spray injury to plants along Michigan highways and to partially delineate the reasons for the varying susceptibility of white pine (*Pinus strobus*) and Austrian pine (*Pinus nigra*). It is hoped that this work will provide a comprehensive guide to salt spray tolerances of several plant species and will aid in the understanding of the phenomenon of salt spray tolerance.

LITERATURE REVIEW

De-icing Salt

What is it?

Today, the terms "road salt" and "de-icing salt" include more than just sodium chloride or calcium chloride. De-icing salts or road salts are combinations of sodium chloride and/or calcium chloride and various additives.

The major portions of de-icing salts still consist of sodium chloride and calcium chloride; sodium chloride being more widely used because of its lower cost and greater availability. Sodium chloride is generally applied in the form of the mineral halite which is 94 to 97% sodium chloride (80). Sodium chloride (NaCl) has a molecular weight of 58.45 and is comprised of 39.34% Na and 60.66% Cl. It occurs as cubic white crystals, granules, or powder. NaCl is colorless and transparent being translucent only when in large crystals. NaCl has a density of 2.17, a melting point of 804°C, and a solubility in cold water of 35.7g/100 cc (86,92). Its eutectic temperature (lowest possible freezing point of a saturated solution) is -6°F. NaCl has a heat of solution of -1.18kC/mole. It is usually most effective as a de-icer at temperatures above 20°F (80).

Calcium chloride ($CaCl_2$) is a joint product of natural salt brines and can exist in anhydrous, mono-, di-, tetra-, and hexahydrate forms. $CaCl_2$ has a molecular weight of 110.99 and contains 36.11% Ca and 63.89% Cl. The hexahydrate form ($CaCl_2.6H_2O$) exists as deliquescent, trigonal crystals and has a melting point of 30°C. The density of $CaCl_2$ is 2.15 and its solubility in cold water is 74.5g/100cc (86,92). Calcium chloride has a eutectic temperature of -67°F and a heat of solution of 3.01kC/mole. $CaCl_2$ is sometimes used as a de-icer when temperatures fall below 10°F. It is often used in combination with NaCl. Its use is not as great as that of NaCl because of its high cost. In Wisconsin, for example, only 5% of the de-icing salt applied is $CaCl_2$ (80).

Several additives other than sodium chloride or calcium chloride may be included in de-icing mixtures. Their purpose is to impart various properties to the de-icing mixtures making them more effective. The nature and properties of these additives are characterized in Table 1.

All or some of these additives may be found in a de-icing mixture depending on the agency applying the mixture. In Wisconsin, for example, only 10% of the de-icing salt mixtures used contain sand. From 1/2 to 2/3 of the salt mixtures contain sodium ferrocyanide. A chromium base rust inhibitor was applied in de-icing mixtures in the 1955-56 winter in Michigan but its use was discontinued after that season (80).

Table 1. De-icing Salt Additives (80,86)

Additive	Chemical Comp.	Purpose	Properties
Sand	Various Minerals	Used as an Abrasive	Non-toxic
Ferric ferrocyanide (Prussian Blue)	$Fe_4[Fe(CN)_6]_3$	used as a marker	toxic properties unknown--insoluble in H_2O--does not release CN upon acidification
Sodium ferrocyanide (Yellow Prussiate of Soda)	$Na_4Fe(CN)_6 \cdot 10H_2O$	anti-caking agent (prevents salt crystals from sticking together)	releases hydrogen cyanide in sunlight--2ppm in lakes or streams toxic to fish
Banox (Calgon Inc.)	active ingredient sodium hexametaphosphate	rust and corrosion inhibitor	nutritive value of 1% P-MLD in rabbits 130 mg/kg
Carguard (Cargill Inc.)	active ingredient sodium chromate	rust and corrosion inhibitor	MLD in rabbits 243 mg/kg

There are other minerals available that can act as de-icers but are not used extensively on highways. D-110[64], used primarily on airport runways, contains 22-29% urea, 71-78% ammonium nitrate, and 2% sodium phosphate. A second runway formulation contains 75% tripotassium phosphate and 25% formamide (80).

De-icers sold primarily for home use include ammonium sulfate, ammonium nitrate, and a combination of potassium pyrophosphate plus formamide. Many of these home de-icing products have been shown by the Portland Cement Association to damage concrete. De-icers, such as these, which contain large amounts of nitrogen or phosphorus may be undesirable used on a large scale because of possible polluting effects on lakes and streams (80).

How does salt work?

It is generally understood that salt applied to highways causes ice and snow to melt. The physical and chemical processes and the factors affecting these processes are not as widely known. Coulter (28) has explained these processes.

> When salt is applied for the control of ice or snow, melting occurs because the vapor pressure of the liquid phase of the water present is reduced. Water molecules are emitted from the surface of both the solid and liquid phases. At equilibrium, the emission of molecules from the surface and condensation of molecules on a surface are at the same rate. When both ice and water are present, in time, all will pass into that phase having the lowest vapor pressure (water) since condensation of vapor will be more rapid on that phase than emission from it. The

> excess of molecules for this condensation will be obtained from the phase with the higher vapor pressure (ice or snow).
>
> In order for melting to occur the latent heat of fusion (143.6 BTU's per pound of ice) must be supplied. On a pavement the necessary heat is abstracted from the ice adjacent to the melting area, from the atmosphere, and from the pavement.... The rate of flow of heat is directly proportional to the temperature differences between the points of supply (the adjacent ice, the atmosphere, or the pavement) and demand (the melting solution).

The type of salt applied to a highway can affect the rate and effectiveness of the melting process. If ambient temperatures are seldom less than 20°F sodium chloride is used. At a temperature of 20°F, the eutectic temperature of NaCl (-6°F) will permit a temperature differential of 26°F between the melting solution and the surrounding environment thus melting will occur at an acceptable rate. At ambient temperatures of -7°F no melting will occur (28).

When temperatures fall below 10°F calcium chloride is often used alone or with an abrasive. Because of its lower eutectic temperature, $CaCl_2$ can induce melting at very low ambient temperatures. At temperatures of 10 to 20°F mixtures of NaCl and $CaCl_2$ are often used. $CaCl_2$ has an affinity for moisture and a positive heat of solution. When it is applied to ice melting begins more rapidly but NaCl, which has a greater driving force for melting, will melt more ice in a given time period. $CaCl_2$, because of its deliquescent properties, captures moisture from the atmosphere and brings it into contact with NaCl thus facilitating the melting process (80).

Miller (62) found a mixture of 1 part $CaCl_2$ to 2 parts NaCl by volume to melt ice and snow at a lower temperature than NaCl alone, and to melt ice and snow faster at all temperatures.

Grain size also affects the rate of melting. Small-sized grains will increase the rate of melting; however, the salt particle must penetrate into the ice or snow. If salt of a very fine grain size is used, little penetration will occur and a film of brine may develop on top of the ice or snow mass. This film produces a lubricating effect causing a loss in tire traction. Larger size grains are able to penetrate to the bottom of an ice or snow mass and along with lateral diffusion of the brine permit traffic action to break up the ice sheet, or, in the case of snow, produce a slushy condition which will aid in snow removal (28).

A third factor in the melting process is the amount of traffic in the salted area. Traffic movement assists in the removal of ice and snow by the application of pressure to the melting area, thus slightly lowering the melting point of the ice or snow. The heat of tire friction and the casting of loose snow or ice from the pavement by vehicular movement also aid the melting process. If the temperatures of the environment and the melting solution are at equilibrium, traffic movement will increase the rate of heat transfer to the melting solution (28).

Ambient temperatures can affect the rate of snow and ice removal by chemicals. Low air temperatures prior to salting will slow removal, whereas high temperatures prior to salting will hasten removal by causing heat to be stored in the pavement. Removal will be slow if the atmospheric humidity is low or if conditions for heat transfer are poor; wind or radiation to a clear night sky causing poor heat transfer conditions (28).

Snow density and/or water content is also a factor in ice and snow removal. Less heat is required to melt wet snow than dry snow. Snow density and water content are affected by temperature. Low temperatures and humidity favor dry, powdery snow, while higher temperatures and humidity favor wet, dense snow. Wind action can increase snow density by packing the snow (28).

The rate of application of the salt mixture is one of the most important factors affecting the melting process. A maximum rate of melting would be achieved if sufficient salt was applied to make a eutectic solution in the water-equivalent of the ice or snow that is being melted. In practice less than that amount is applied. Providing some traffic is present, removal of ice and snow is satisfactory if 40% of the weight of the salt necessary to reduce the freezing point of the equivalent water to the existing ambient temperature is applied. The rate of application is influenced by the factors previously discussed of salt type, grain size, traffic movement, temperature, and snow density and/or water content (28).

Salts in the Highway Environment

Salts in the Water Supply

De-icing salts applied to highways may enter three regions of the environment. They may splash or drift onto plant foliage, they may splash onto or run off into the soil bordering the highway, or they may be carried off in the water supply to lakes, wells, streams, and ponds.

Schraufnagel (79) reported that in some areas of Wisconsin winter roadside runoff contained up to 10,250 mg/l chloride. Surface water in the area contained 45 mg/l chloride. The summer roadside runoff contained only 16 mg/l. Hutchinson (48) found the Na+ and Cl- content of water samples taken daily during March and April from a culvert near an interstate highway in Maine to range from 70.4 to 264.9 ppm and 38.1 to 844.9 ppm respectively. Most ground-water samples taken from highways in Massachusetts showed a chloride content of almost 250 ppm which is the upper limit recommended by the United States Public Health Service for public water supplies (83). Deutsch (31) reported alleged contamination by salt storage of the Black River limestone at the Village of the Rocks in Michigan.

Pollution of several roadside wells has been reported by the Manistee County (Michigan) Sanitation Commission. In 1960 five wells in Wisconsin were reported to be affected by salts leaching from a sand-salt stockpile (79).

Increased chloride concentrations in lakes, ponds, and rivers as a result of de-icing salt runoff have also been reported (1,9,48). Bubeck _et al._ (17) reported that de-icing salts have increased the Cl^- concentration of Irondequoit Bay fivefold in the past 20 years. In 1969 and 1970 the Cl^- concentration was sufficient to prevent the complete vertical mixing of the bay in the spring and to delay the period of summer stratification by one month. Blaser _et al._ (9) doubted that de-icing salts are contaminating major waterways.

Salts in the Soil

Excess salts in the soil bordering salted highways and resultant vegetation damage have been reported by several observers (3,9,24,25,44,45,46,47,48,49,55,67,69,91,94,95,101). Holmes _et al._ (47), while noting that direct application of NaCl to the soil around trees can cause damage, doubted that injury to deciduous trees occurred when salts were applied to roads in moderate amounts during the winter only, however, they did observe that trees in low areas may be damaged. They hypothesized that any salt accumulated in the foliage of trees along the highway would be removed when the leaves abscised.

Holmes (45) in later work reaffirmed his findings. He contended that the salt dissolved in the melted snow and ran off over the frozen ground without reaching tree roots.

Holmes found that a small amount of salt did enter the top layers of the soil causing damage to the grass under the trees, but he felt that most of this salt was probably leached out of the sandy loam soil before the foliage on the trees expanded and before there was much water uptake by tree roots.

La Casse and Rich (55) found an inverse relationship between distance from the highway and salt injury symptoms. The soluble salts in the top three inches of the soil bordering salted highways decreased significantly with distance from the road. Most injury occurred within 30 to 100 feet of the highway. Soluble soil salts were greater on the lower side of the highway and injury to trees was greater on those trees below the road level or in areas receiving drainage from the highway.

Hutchinson and Olson (49) measured sodium and chloride levels in soils adjacent to highways salted for periods ranging from 0 to 18 years. Levels of both ions were found to increase; Na^+ levels increasing more than Cl^- levels. Injury was greatest at the edge of the highway and where salting was practiced the longest. Salting increased Na^+ and Cl^- levels more at a depth of 6 inches than at 18 inches. Increased sodium and chloride levels were found at distances up to 30 to 35 feet and as far as 60 feet from the highway. Baker (3) also found high sodium and chloride levels in soils bordering salted highways.

Prior and Berthouex (67) noted that water can infiltrate frozen forest soils to a depth of 4 inches; less infiltration occurring in heavy soils. If the soil froze slowly permeability was decreased. They found high concentrations of salt at the soil surface and nearest the highway. Salt concentrations decreased with depth. Lateral movement of salt in the soil was as great as 100 feet; however, after February, lateral movement was only 25 feet. By April the salts had been leached from the soil.

Westing (95) noted significant infiltration of salt solutions into the soil even when the ground was frozen. In well-drained, sandy soils the salts did not persist beyond March, but in less well-drained soil types, the salts persisted through summer and fall. Na^+ and Cl^- concentrations increased slowly throughout the year. Westing found the direction and rate of salt movement to be influenced by: 1) whether the soil is frozen, 2) the amount and pattern of rainfall, 3) the depth of the water table, and 4) the texture, structure, chemistry, organic matter content, permeability, cation exchange capacity, and biota of the soil.

Zelazny and Blaser (101) found high concentrations of Na^+ and Cl^- to a depth of 18 inches throughout the winter in soils bordering salted highways. Maximum concentrations of salt were found at the soil surface and closest to the pavement. The salt moved downward in the winter. Concentrations increased from year to year. Higher than normal concentrations of salt were found in the soil to a distance of 75 feet from the highway.

Button and Peaslee (24) found that most plants more than 30 feet from the highway usually escaped injury, but some plants as far as 100 feet from the highway were injured. Rich (69) observed that trees within 30 feet of the highway were affected by salt most frequently and severely. Blaser *et al.* (9) also found injury to occur up to 30 feet from the highway; injury being greatest at the edge of the highway. The distance at which injury occurred increased on curves. Hofstra and Hall (44) found injury to trees up to 120 meters from the highway.

Wester and Cohen (94) found a correlation between the amount of salted snow piled within the root zone of trees and the degree of injury to the trees. The amount of precipitation in the spring was a critical factor in the severity of the damage; no damage occurring when enough rain fell in the spring to saturate the soil and provide for leaching of salts from the soil. Holmes and Baker (46) observed that the factors affecting the amount of injury to trees were: 1) the amount of salt applied, 2) the timing of the application, 3) the quality and drainage of the soil, 4) the dates of salting, 5) the depth and duration of soil freezing, 6) the depth of snow piles, and 7) the amount of runoff before the ground thaws.

Walton (91) noted that the higher the rate of application of salt the earlier the symptoms appear on Norway maple trees. The degree of phytotoxicity was found to be governed by: 1) the amount of rainfall during the growing season, 2) the amount of snow cover, and 3) the amount of rainfall in the spring. Walton found a late spring salting to be more phytotoxic than a winter salting. He hypothesized that when salt washes to the roadside it may thaw the soil around the plant to some degree forming a "sink". As a result, the plant roots may be bathed in solutions of high salt concentrations and osmotic pressures causing root injury.

Salts as Spray

De-icing salt spray churned up by moving traffic and deposited on the foliage has been reported to cause injury to roadside plants (29,45,59,75,78,84). Wells and Shunk (93) noted the importance of ocean salt spray as a factor in coastal ecology. They observed injury to plants from salt spray and were able to induce similar injury in test plants with a 3% spray of NaCl. Oosting (65) also noted the effects of salt spray on coastal vegetation as did Boyce (11). Death of and injury to pine, spruce, privet, and dogwood were observed along the New Jersey coast (77). Edwards and Holmes (33) determined salt deposited by marine winds onto trees of North Wales forests to be responsible for the observed injury to those trees. Buccianti (18) described serious damage to vegetation along the Mediterranean Coast from salt deposition by strong sea winds.

Holmes (45) noted some injury to trees by NaCl and $CaCl_2$ applied directly to the foliage. Sauer (78) observed that de-icing salts had their greatest effect on the above-ground portions of the plant. He noted that those portions of the plant protected by snow cover escaped damage, the foliage of taller plants which extended above the spray zone appeared healthy, damage occurred only on the side of the plant facing the highway, and those plants afforded some protection from salt spray appeared healthy. Damage was greater in median strips and on expressways where larger amounts of salt were used and where increased traffic density and higher speeds caused more spray and a wider spray. The type of vehicle was found to affect the extent of the injury zone; trucks causing injury higher up on trees because of their poor aerodynamic design. Factors affecting the severity of injury were: 1) the amount of NaCl applied, 2) the time of first application, 3) the distribution rate of total salts, 4) the time of last application, and 5) climate; the most important in determining injury being the amount of NaCl applied.

Salt spray damage to vegetation along New Jersey roadsides was observed (75). Symptoms of injury were noticeable within 30 feet of the highway; being more severe on plants below the road elevation. Davidson (29) noted damage to various species of pines along Michigan highways. Those plants damaged most were located nearest the highway in the salt splash or drift zone.

Smith (84) observed salt contamination of white pine adjacent to an interstate highway. Foliar Na^+ concentrations were greater than 1% on the highway side of the plants. The threshold level of Na^+ for injury was 0.5%. No abnormal Ca^{++} levels were found. Needles of south-facing trees contained more Na^+ than those of north-facing trees; the higher levels in south-facing trees being attributed to the prevailing wind patterns. Damage to white pine occurred up to 35 meters from the highway.

Lumis, Hofstra, and Hall (59) found tree injury to decrease with distance from the highway. Injury was most severe on the side facing the road. Plants on the downwind side were damaged more severely. As traffic volume increased, plant injury increased.

De-icing salts have been shown to run off into water supplies, to splash onto or runoff into soils bordering highways, and to be deposited on the foliage of plants bordering highways. Damage from salts has been reported in all of these regions of the environment. The fate of salts in the environment is depicted in Figure 1.

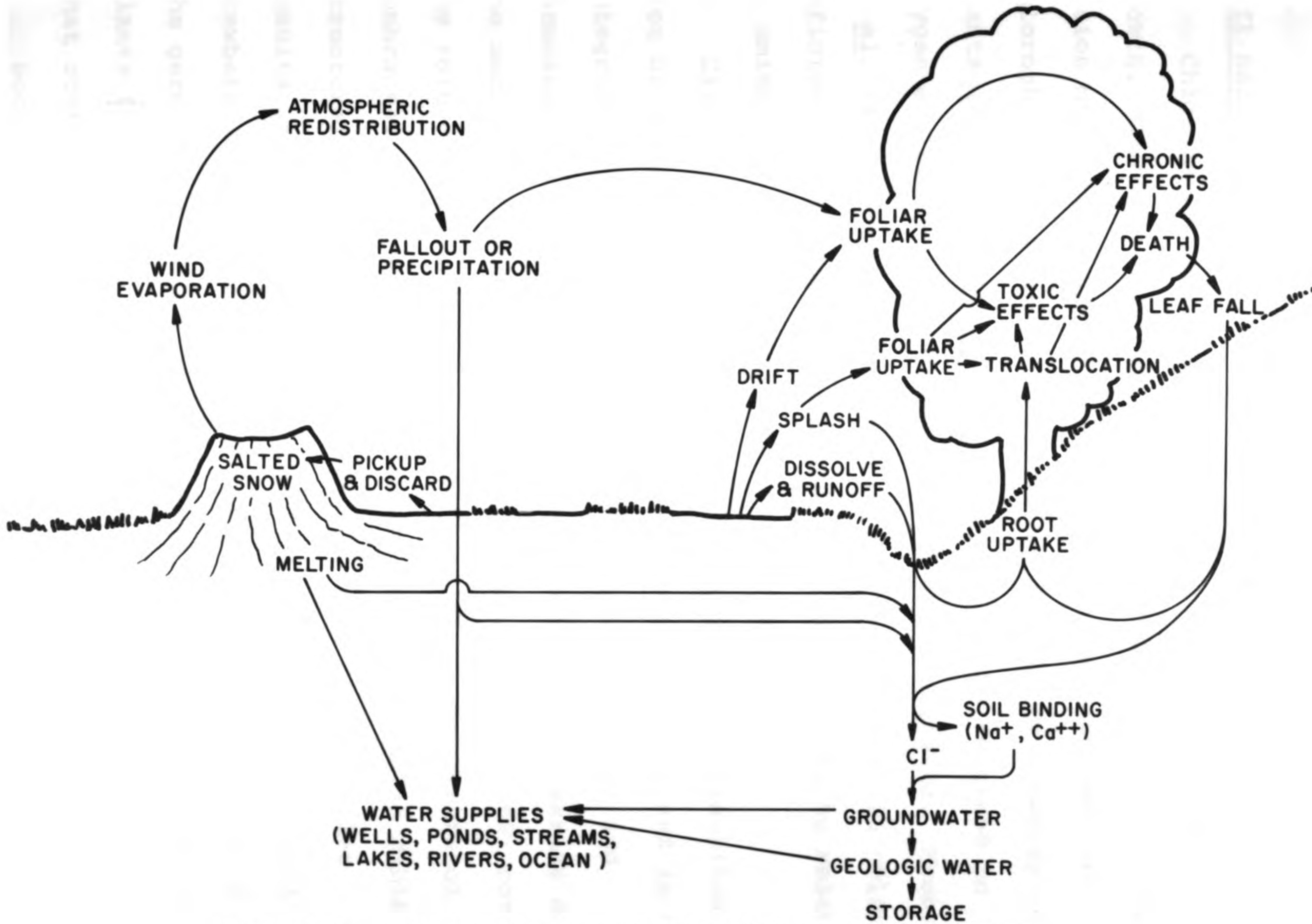

Figure 1. Fate of salts in the highway environment.

Effects of Salt on Plants

Soil Salts

Chlorine and calcium are essential elements for plant growth. Chlorine has been shown to be involved in the stimulation of certain enzymes, in carbohydrate metabolism, in chlorophyll production, and in the water-holding capacity of plants (81). Bové *et al*. (10) found Cl^- to be required in oxygen evolution by photosystem II of photosynthesis. Freney *et al*. (40) observed a build-up of free amino acids in chlorine deficient plants and hypothesized that chlorine may be related to amino acid synthesis or interconversion.

Calcium has been shown to be involved in the translocation of carbohydrates, in the development of roots, and in the integrity of cell walls (81). Ito and Fujiwara (51) and Rasmussen (68) found calcium to have an important bearing on the mechanical strength of plant tissues. Marinos (60) noted the role of calcium in the maintenance of the structure of membranes. Calcium-deficient barley shoot apex cells exhibited structureless areas. Marshner *et al*. (61) found similar results in calcium-deficient cells of barley and corn root tips. Brewbaker and Kwack (12) found calcium to be indespensable for the germination of pollen and the growth of pollen tubes in plants from several families. Rios and Pearson (72) observed that roots failed to grow in calcium-free soils.

Sodium is not generally required by green plants. Sodium has been shown to be essential for satisfactory growth and maximum yields of some plants including celery, sugar beets, swiss chard, beets, and turnips (81). Certain species, especially halophytes, require sodium. Brownell and Wood (16) and Brownell (14) showed that *Atriplex vesicaria* requires sodium as a micronutrient element. Brownell (15) observed that several other species of *Atriplex* also have a sodium requirement. Williams (96) found that *Halogeton glomeratus* has such a high salt requirement that sodium may be considered a macronutrient element for its successful growth.

Nieman (64) noted that sodium chloride stimulated growth in tolerant crop plant species and increased the succulence of the leaves of all species except onion. NaCl also increased the ratio of water to dry matter in the leaves; the greatest increase occurring in the most tolerant species. Roberts and Zybura (73) observed that 600 ppm of NaCl applied to the soil stimulated growth of several grass species.

If chlorine, calcium, sodium, or combinations of these ions are present in the soil solution or in plant tissues in excessive amounts they can cause damage to plants. Excess salts in the soil solution can affect the plant in several ways. The increased concentrations of salt in soil solutions can increase the osmotic pressure of those solutions and thus restrict the uptake of water by plant roots (7). Bernstein *et al.* (8) noted that water stress and salt damage can induce similar leaf injury in a given species. Westing (95) noted that salt damage was more severe in periods of extended drought because salts in the soil make water less available. Salts and drought reinforce each other; drought conditions resulting in less leaching of salts and the movement of water upward from lower soil layers thus concentrating the salts near the soil surface. Prior and Berthouex (67) found salts to be more harmful when soil moisture was at the wilting percentage. Zelazny and Blaser (101) measured osmotic pressures of 1.5 atmospheres in soils bordering a salted Vermont highway. Others have also hypothesized that the mechanism of salt injury is a "physiological drought" caused by the interference by salt with normal osmosis (76).

Salts in the soil solution may also be absorbed by plant roots in the form of their constituent ions, Na^+, Ca^{++}, and Cl^-. These ions may then be translocated to other plant organs such as leaves, stems, and buds and may accumulate in these organs in toxic amounts (7).

Soil salts are taken up by the roots in a largely active and partially selective process. A certain amount of salt is taken up passively by water movement into the roots. Once in the root the salt ions face several obstacles to translocation. The epidermis can be a partial barrier to some ions such as calcium. A second barrier may be the protoplasmic membranes of the cortical cells where passage of ions involves a "carrier" system and is metabolically controlled. A third barrier may be the xylem endodermis. When soil salt concentrations become very high these barriers become ineffective in stopping the flow of salts into the plant (95).

Brown *et al*. (13) concluded from a study using six varieties of stone fruit trees that the response to salinity was influenced more by specific ions than by the osmotic pressure of the solution. Button and Peaslee (24) reached a similar conclusion in work with sugar maples. Kotheimer *et al*. (53) found the chloride level of sugar maple leaves to be correlated with salt damage. Button (23) also observed this correlation in sugar maples. Chlorides accumulated in the leaves and twigs to lethal or near lethal levels; the greatest accumulation being in leaves and twigs of trees located in areas of runoff. Kotheimer (52) found the levels of Cl^- in foliage of damaged trees to be significantly higher than levels in healthy trees. Hofstra and Hall (44) found injury levels to be related to chloride levels in white pine and white cedar needles. Chloride levels in the needles in excess of 1% caused death. At similar levels of injury all pines contained similar levels of Na^+ and Cl^-. Holmes *et al*. (47) found no injury to trees on winter plots but did note higher Cl^- levels in leaves and twigs; leaf levels being highest. Wester and Cohen (94) noted that Cl^- levels in the leaves of damaged trees were three times that of normal tissue. Davison (30) observed high Na^+ and Cl^- levels in the foliage and seeds of several roadside grasses. Shortle and Rich (82) reported that uninjured roadside trees had higher Cl^- contents in the leaves than healthy trees in non-highway locations.

Baker (3) observed that while Na levels in the leaf were abnormally high, leaf scorch symptoms were not associated with Na^+ levels. Levels of 1% Cl^- in the leaves were responsible for leaf scorch. Zelazny and Blaser (101) found the greatest Cl^- increase in leaves and the greatest Na^+ increase in the stem.

Verghese _et al_. (89) found a close relationship between application rates of salt and the amounts of Na^+ and Cl^- absorbed by grasses. Ehlig and Bernstein (34) observed that the salt concentration influenced the rate of foliar accumulation of salts but did not affect the level at which injury occurred. The effects of Na^+ and Cl^- did not appear to be additive since injury occurred at the same leaf content of Na^+ or Cl^- alone as when both were present. Chloride accumulated equally from NaCl and $CaCl_2$. Kotheimer _et al_. (53) indicated that $CaCl_2$-NaCl mixtures may be less harmful than NaCl alone. Brown _et al_. (13) noted that $CaCl_2$ was more toxic than NaCl because Ca^{++} facilitates the entry of Cl^-. Strong (87) noted that white pine was injured by lower soil concentrations of NaCl than $CaCl_2$.

An excess of one particular ion may influence the absorption of other ions essential for plant growth (7). This phenomenon may be especially significant in soils found along highways which are often low in fertility (89). Parups et al. (66) observed that increased amounts of Cl^- depressed the absorption of K^+. Kotheimer (52) reported greater Cl^- uptake when higher levels of K^+ were present in the soil. Leggett (58) contended that K^+ uptake and Cl^- uptake were associated. Walton (91) reported similar rate-limiting steps for K^+ and Cl^- absorption.

Holmes (45) thought NaCl to be more damaging than $CaCl_2$ due to the ion antagonism between Na^+ and K^+. Button and Peaslee (24) observed an antagonism between Na^+ and K^+ or Ca^{++}; however, Baker (3) found that Ca^{++}, Mg^{++}, and K^+ levels in leaf tissue were not affected by Na^+ levels. Davison (30) observed that K^+ concentrations in grass clippings decreased in relation to increases in the concentration of Na^+. The alteration of the K^+/Na^+ balance affected competition between these grasses and other flora. Verghese et al. (89) noted that increased rates of K^+ decreased the uptake of Na^+ by certain grasses.

Sulphate, phosphate, and nitrate ions applied as sodium salts decreased Cl^- uptake but not Na^+ uptake. Phosphate ions were most effective; an inverse relationship occurring between phosphate and Cl^- ion contents. Ca^{++} and K^+ salts also decreased Na^+ and Cl^- uptake; K^+ salts being more effective (89). Button and Peaslee (24) observed an antagonism between Cl^- and certain organic acids. Hayward and Bernstein (43) proposed that NaCl and $CaCl_2$ may inhibit nitrogen uptake.

Lastly, an excess of sodium ions in the soil may have a detrimental effect on soil structure (71). Westing (95) reports that if sodium reaches 15% of the cation exchange capacity the soil structure deteriorates. The sodium ions cause the clay particles of the soil to disperse thus decreasing the permeability and water-holding capacity of the soil. Roberts and Zybura (73) reported that 24,000 lb of NaCl applied per mile of four lane highway in two successive winters affected median and foreslope soil structure and prevented satisfactory establishment of a grass cover.

Carpenter (25) noted that excess salts caused stunting of all plant parts and reduced yield and quality. Bernstein et al. (8) hypothesized that NaCl interferes with normal stomatal closure under high evaporative conditions causing excess water loss. Strong (87) noted that $CaCl_2$ killed cell protoplasm by plasmolysis. Carter and Myers (26) indicated that NaCl and $CaCl_2$ added to irrigation water significantly increased light reflectance from the upper leaf surfaces of grapefruit. NaCl and $CaCl_2$ also decreased chlorophyll contents of the leaves. Metabolic activity was reduced. Carter and Myers hypothesized that leaf structural changes may be involved in plant responses to excess salts.

Damage from excess soil salts expresses itself as stunted growth, marginal leaf scorch, foliage thinning, and preseasonal defoliation. Sodium toxicity symptoms are: 1) deeper green leaves at first, 2) margin or tip burn with a sharp line between burned and unburned areas, 3) bronze coloration of the leaves after burning, and 4) premature leaf drop. Chloride toxicity symptoms are: 1) margin or tip burn of the leaves, and 2) shoot tip dieback (81).

Bernstein and Hayward (7) observed that seasonal effects may modify salinity expression. Holmes (45) noted less injury at low temperatures. Prior and Berthouex (67) observed less salt uptake at low temperatures. Bernstein (6) found high temperatures to intensify leaf burn injury.

Holmes and Baker (46) noted that salt may affect the susceptibility of trees to other injury and other agents may affect the severity of salt injury. Symptoms from such indirect effects as impaired aeration, water deficiency, nutrient imbalance, and other biotic and abiotic agents may be observed. Wester and Cohen (94) noted that salt damage exposes the bark and branches of leaders to sun scald.

Salt Spray

Wells and Shunk (93) hypothesized that injury from salt spray was due to excessive water loss from young tissues resulting from the osmotic action of high salt concentrations on unprotected surfaces. Boyce (11) noted that injury to leaf cuticles by wind facilitated the entry of Cl^- into leaves. Subjecting leaves to wind prior to salt application resulted in increased injury from salt and increased Cl^- ion penetration. Cl^- accumulated in young leaves in detrimental amounts before older leaves were injured. Cl^- was concentrated at the tip of the leaf first. Regardless of where the Cl^- entered the leaf it was translocated to the tip. Cl^- deposited on the windward side of the plant was not translocated to the leeward side.

Bukovac and Wittwer (19) noted that foliar-applied Cl^- was readily absorbed. A high percentage of the chlorine was transported to other plant parts, especially the stem. They hypothesized that transport of Cl^- in the phloem may be the limiting factor in its absorption and mobility.

Woolley *et al.* (98) observed that radio-chlorine applied to the leaves of tomatoes and sugar beets reached all plant parts in some quantity. More translocation of Cl^- was observed 8 days after application than one day after application. Younger plant structures obtained radio-chlorine at the expense of older leaves. Retranslocation of Cl^- from regions of high Cl^- concentration to regions of low Cl^- concentration was observed concurrent with a decrease in Cl^- concentration in all plant parts.

Wittwer and Tuebner (97) also found Cl^- to be readily absorbed by plant foliage. Patterns of Cl^- absorption were similar to those of P^{32}. Cl^- uptake was found to be light dependent. The action spectrum for Cl^- absorption was similar to that for the chlorophyll system. Absorption of Cl^- of *Vallesneria* was inhibited by cyanide, arsenate, and uranyl-nitrate.

Laties (57) found the salt absorption process to be a rapid initial uptake followed by a slower, more prolonged uptake. The initial uptake is physical in nature while the more prolonged uptake is dependent on respiration.

Franke (38) noted that halogen ions being small (10Å) were able to penetrate intermicellar spaces. Buschbom (20) noted that after autumn leaf fall Cl^- ions penetrated through the buds into the inner shoot tissues.

Symptoms of salt spray injury have been described by several authors (11,29,59,77,93). Wells and Shunk (93) noted that the young growth of loblolly pine was killed by salt spray. Symptoms appeared first on the tips of the leaves, then on the leaves, and finally on the branches. There was a lag in appearance of the symptoms from the time of application. Boyce (11) noted that Cl^- caused hypertrophy of mesophyll cells on the windward side of plants. Deciduous plants exhibited a "sympodial" branching habit. Plants damaged by salt along the New Jersey coast were found to be killed or stag-headed. Dogwoods failed to bloom (77). Davidson (29) noted that pines exhibited needle dessication on the highway side only.

Lumis, Hofstra, and Hall (59) noted and described the symptoms of de-icing salt spray injury in much detail on both evergreen and deciduous species. Their findings were as follows:

General injury patterns:

1 - injury more severe on side facing the road, plants one-sided due to branch die-back
2 - damage more pronounced on downwind side of highway
3 - plants further from road injured less
4 - branches covered by snow not injured
5 - injury to evergreens apparent in late winter, injury to deciduous plants not evident until spring
6 - branches above the spray-drift zone not injured or injured less
7 - damage increased with volume and speed of traffic and amount of salt applied to highway
8 - plants damaged over several years lack vigor and soon begin to die
9 - less winter-hardy plants injured more severely
10 - salt spray penetrates only a short distance into dense plants
11 - plants in sheltered locations lack injury symptoms.

Symptoms specific to evergreens:

1 - needle browning moderate to extreme, beginning at the tip
2 - needle browning and twig dieback on the side facing the road but none or very little on the back side
3 - no needle browning or dieback on branches near the ground under continuous snow cover
4 - needle browning and twig dieback less severe further from the road
5 - browning usually first evident in late February or early March and becoming more extensive throughout spring and summer.

Symptoms specific to deciduous plants:

1 - leaf buds on the terminal part of branches facing the road very slow to open or do not open
2 - new growth arises from the basal section of branches facing the road, resulting in a tufted appearance
3 - flower buds on the side facing the road do not open but flowering normal on back side.

Salt Tolerance, Avoidance, and Alleviation of Injury

Soil Salts

Tolerance to salts may be measured in several ways: 1) the ability of a plant to survive on saline soils, 2) the yield of a crop on saline soils, and 3) the yield of a crop on saline soils as compared to yield on non-saline soils (81). Salt tolerance of ornamentals may be measured by the severity of injury symptoms.

Holmes (45) observed that soil salt tolerance may be the result of the tendency of the roots of salt tolerant plants not to take up chlorine and/or the tolerance of plant tissues to high levels of chlorine. The choice of rootstock influenced the amount of chlorine accumulated by avocado trees. Holmes further hypothesized that the depth of roots may be a factor in escaping damage. Hayward and Bernstein (43) also noted the significance of depth of rooting in escaping salt damage as did Ruge and Stack (74).

Hofstra and Hall (44) thought it probable that more resistant pines accumulate lower concentrations of salts. LaCasse and Rich (55) noted that Na^+ was more readily transported by maples than by other species. Kotheimer (52) observed that Norway maples tolerated higher levels of Cl^- and also naturally accumulated more Cl^- than did sugar maples. Rich and LaCasse (70) noted that white birch and white ash failed to translocate Na^+ to the leaves and were salt tolerant.

Shortle and Rich (82) found that red oak, white oak, red cedar, and black cherry did not accumulate Cl^-.

Epstein and Jeffries (37) noted that salt tolerance involves aspects of tolerance and transport. Some species were able to exclude ions from the intracellular centers of metabolism. The possibility of true cytoplasmic tolerance to a solute was also noted. Epstein and Jeffries indicated it was possible to breed for salt tolerance. Baker (3) noted a genetic difference in the ability of sugar maples to translocate Na^+ to Cl^- ions.

Westing (95) theorized that early-age saline conditions may adapt plants to higher soil salt levels at later ages. Hanes et al. (41) noted that certain plant species increase in tolerance to salt with growth and development. Redbuds (Cercis canadensis) were damaged less by salts when they were older and/or growing rapidly.

Carpenter (25) observed that salt damage could be alleviated by leaching salts from the soil, by washing the foliage, or by applying gypsum. Verghese et al. (89) hypothesized that the use of KH_2PO_4 with de-icing compounds may minimize salt injury; however, Walton (91) found that the use of K_2SO_4 to counter K^+ deficiencies in early spring increased salt damage. K^+ and Cl^- were both absorbed.

El Damaty et al. (35) found that soybean plants and seedlings from wheat kernels soaked in CCC (2-chloroethyl trimethylammonium chloride) were more tolerant to salt. Amo-1618

(4-hydroxy-5 isopropyl-2 methylphenyltrimethylammonium chloride, l-piperidine carboxylate) and phosfon (2,4-dichlorobenzyltributylphosphonium chloride) had the same effect on soybeans. The CCC treated plants were healthier, more turgid, and contained more chlorophyll. The osmotic pressure of the sap was higher for treated plants. Similar results were reported in Utah (2). Bernstein and Hayward (7) noted that the short/root ratio was an important factor in severity of salt injury. Plants with excessive top growth exhibited severe injury.

Hvass (50) recommended the use of $CaNO_3$, urea, and ammonium sulfate for road clearance. Blaser et al. (9) saw the need for improved methods of storing, handling, and applying salt. Salt should be considered during highway design; especially in the design of drainage systems. Design of roadside plantings to minimize injury is also important.

Salt Spray

Oosting (65) noted that those plants with the toughest leaves and heaviest cuticles were most resistant to salt spray. Those plants with enrolled leaves had a smaller surface for salt spray to adhere to. Rhizomes were a means of survival for some plants. Seeds were little affected by salt spray.

Boyce (11) studied the deposition of salt upon plant surfaces. The total concentration of salt deposited as spray was influenced by the physical factors of impact deposition. An increase in wind velocity increased the deposition efficiency of droplets smaller than twenty microns, the deposition efficiency of droplets 5μ in size being 10%, while that of 10μ droplets being 95%. The efficiency of deposition was greater on margins of a glass slide than in the center.

The size of salt spray droplets collected varied with the size and position of the collecting surface (leaves or twigs); the efficiency being greater on leaves of a smaller size. Pines and small-needled plants accumulated more salt per unit area because they are more efficient collectors of small droplets. Salt was deposited uniformly on moving leaves. Smith (84) noted a differential impaction of airborne material. Those plants with a high surface/volume ratio exhibited more injury.

Boyce (11) further observed that plants with a broad, uniform canopy exhibited a low deposition of salt on leaves just below the canopy level and on the upper leaves of the canopy. Any young shoot or leaf which projected above the canopy level was a very efficient collector and was killed by high salt concentrations. Leeward and interior portions of the plant received the lowest salt concentrations. Those plants with a lower canopy angle had a higher salt spray intensity. Wells and Shunk (93) noted that slightly depressed shoots on certain plants escaped damage because of the suction factor of the wind.

Buschbom (20) in studies on 240 deciduous and evergreen species noted marked interspecific differences in tolerance to NaCl and $CaCl_2$. He noted that while the constitutional resistance is of considerable significance in some species, the degree of resistance of the protoplasts is generally more important and is often the deciding factor governing lethal effects. In further work, Buschbom (21) noted that resistance of the protoplasts in the stem tissue of broadleaved woody species alters considerably during the course of the year. Resistance is higher during winter dormancy than in summer growth and is lowest during spring flush. Younger shoots appear to be less resistant than older ones.

Lumis, Hofstra, and Hall (59) noted that increased amounts of wax or bloom on spruce resulted in added protection from salt spray; the bluer the spruce the more resistance to salt spray. Deciduous trees or shrubs with resinous or submerged buds were more resistant to spray. Resistant evergreens or dense deciduous shrubs could be used as screens to trap spray.

Observations of salt spray damage along the New Jersey coast indicated that feeding, watering, and mulching plants helped in their recovery from injury. Rinsing plants with water immediately after salt deposition decreased the amount of injury (77). Bartlett (4) noted that spraying the foliage of plants with anti-dessicants effectively prevented injury from salt spray. Sauer (78) observed that plants in good soil exhibited less injury presumably because of their better regeneration ability. Buccianti (18) found that an automatic installation that wets the foliage when the wind reaches 40km per hour aided in protection of plants along the Mediterranean coast.

The salt tolerances of various woody and herbaceous plants are listed in the appendix. These tolerances were compiled from a review of the available literature on salt tolerance.

MATERIALS AND METHODS

Preliminary Survey

On January 28, 1972, a preliminary survey of highway tree and shrub conditions was conducted in the Lansing-East Lansing area. Its purposes were 1) to determine the extent of de-icing salt spray injury to trees and shrubs bordering the highways in the Lansing-East Lansing area, 2) to become familiar with and observe de-icing salt spray injury symptoms, and 3) to search out areas for future, more intensive study.

The preliminary survey was conducted along the following highways (Figure 2):

1) M-78 from the junction of M-78 and M-43 northeast to the junction of M-78 and M-52. Plants along this highway are primarily evergreen species of varying maturity; most trees being in a mature state. The plants are located at distances from the highway of 10 to 100 feet. Plants are located below, at, or above the road level; those at or below road level being predominant. Traffic on the highway is heavy and travels at an average speed of 65 miles per hour.
2) M-52 from the junction of M-52 and M-78 south to the junction of M-52 and M-43. Plants along this highway consist of mature red pine (*Pinus resinosa*) at a

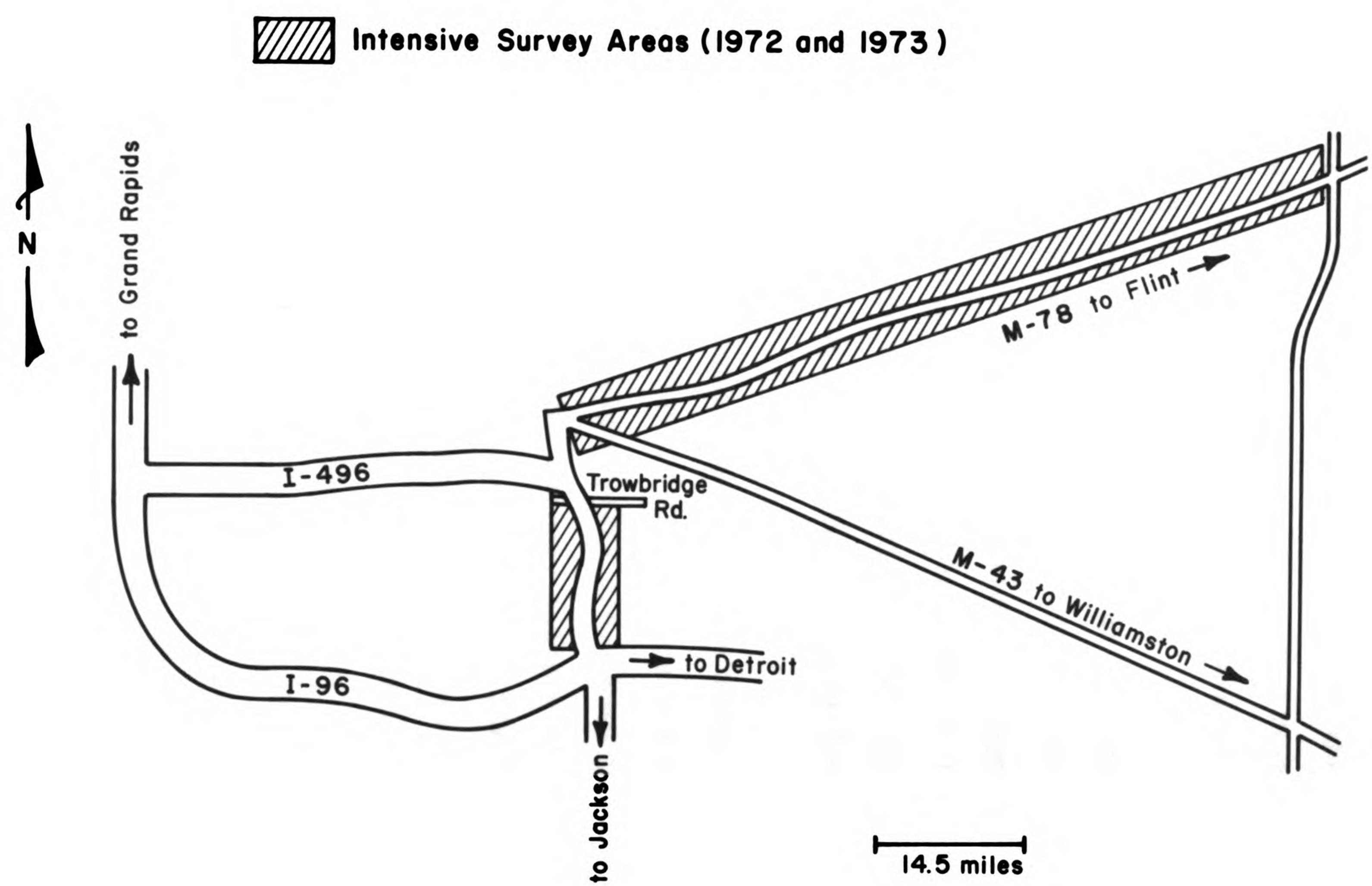

Figure 2. Salt injury survey areas in the Lansing-East Lansing vicinity.

distance of approximately 30 feet from the edge of the pavement. Plants are at road level. Traffic on the highway is moderate; the average speed of the traffic being 55 to 60 miles per hour.

3) M-43 from the junction of M-43 and M-52 northwest to the junction of M-43 and M-78. Plants along this highway consist mainly of mature evergreen species at distances of 20 to 80 feet from the edge of the pavement. Most plants are at road level. Traffic on this road is heavy; travelling at speeds ranging from 25 to 50 miles per hour.

4) I-496 from the Trowbridge Road exit south to the junction of I-496 and I-96. Plantings along this highway are approximately eight years old. Most plants are above the level of the highway and are at distances of 10 to 60 feet from the highway. The plantings consist of both evergreen and deciduous species. Traffic on this highway is moderate to heavy and travels at an average speed of 70 miles per hour.

5) I-96 from the easterly junction of I-96 and I-496 west and north of the westerly junction of I-96 and I-496. Plantings along this highway are approximately six years old and consist of deciduous and evergreen species. Most plants are at or slightly above road level. Traffic is moderate on this highway and travels

at an average speed of 70 miles per hour. The plants are at distances of 10 to 50 feet from the edge of the pavement.

6) I-496 from the westerly junction of I-496 and I-96 east to the Trowbridge Road exit. Plantings in this area are one to two years old and consist of deciduous and evergreen species. The plants are above the road level and are 20 to 40 feet from the edge of the pavement. Traffic on this highway is heavy and travels at an average speed of 70 miles per hour.

Plants bordering these highways were observed for any de-icing salt spray injury symptoms. Symptoms of de-icing salt spray injury as described by Lumis, Hofstra, and Hall (59) were used to determine salt injury. Injury to various plant species was recorded.

I-96 Survey

An additional survey of the plants bordering I-96 from the easterly junction of I-96 and I-496 west and north of the westerly junction of I-96 and I-496 was conducted in May of 1972 after the deciduous trees had begun to leaf out and the current year's symptoms began to be expressed on evergreens. Injury symptoms were observed and recorded on both evergreen and deciduous species on the north and south sides of the highway. Plant injury was rated on a scale of 1 to 5 as follows:

1 - no symptoms of salt injury

2 - minor symptoms of salt injury

3 - moderate symptoms of salt injury

4 - severe symptoms of salt injury

5 - very severe symptoms of salt injury or death of the plant.

M-78 Survey

On March 21, 1973, a more detailed survey of salt injury to plants bordering M-78 from the junction of M-78 and M-43 northeast to the junction of M-78 and M-52 was made (Figure 2). Symptoms of de-icing salt injury were observed and recorded on both deciduous and evergreen plants. The plants were rated for injury on a scale of 1 to 5 as previously discussed. In addition to the injury rating, the distance from the edge of the pavement to the plant was estimated and recorded.

I-496 Survey

In April and May of 1972 and in late April of 1973 surveys of tree and shrub conditions on I-496 from the Trowbridge Road exit south to the junction of I-96 and I-496 were conducted (Figure 2). Plants were observed for salt spray injury symptoms, were rated for salt injury on a scale of 1 to 5, and their distances from the edge of the highway were noted and recorded.

Michigan Arboretum Survey

In April and May of 1972 and in late April of 1973 surveys of tree and shrub conditions were conducted at the Ford Motor Company's Michigan Arboretum in Dearborn, Michigan. The arboretum is directly adjacent to the Southfield expressway and consists of 95 species of native Michigan shrubs and trees (Figure 3). The plants are from 9 to 13 years old and are located at distances of 40 to 100 yards from the expressway. The arboretum is located on the east side of the expressway and the prevailing winds are from the southwest.

Symptoms of salt spray injury were observed and recorded for the various species. The distances from the highway of each of the plant species were estimated and recorded.

Microprobe Analysis of White and Austrian Pine Needle Surfaces

Needles of white (*Pinus strobus*) and Austrian (*Pinus nigra*) pine were collected from trees growing along M-78 in the salt spray zone and from trees growing on the Michigan State University campus where no salt spray could reach the needles. The needles were cut into one centimeter sections beginning at the tip. These centimeter sections were then mounted with television tube koat onto carbon discs taking care to preserve the proper orientation (tip to base) of the needle sections. The sections were then coated with carbon to a thickness of 100 Å.

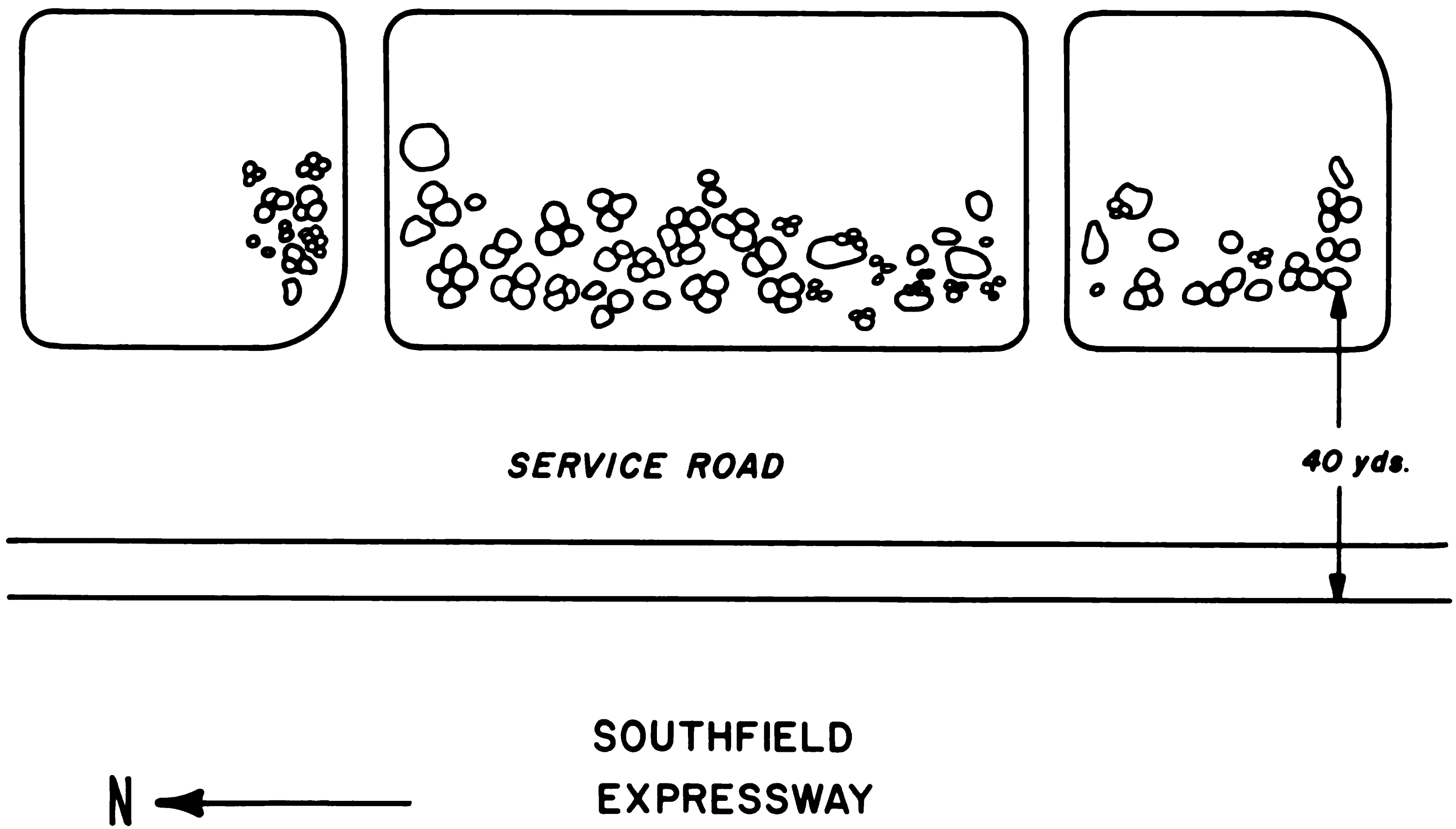

Figure 3. Salt injury survey area--Ford Motor Company's Michigan Arboretum.

Horizontal line profiles for sodium and chlorine were then made on the EMX-SM electron microprobe of the surface of each section closest to the tip. A distance of 480 microns was scanned on each section. Operating conditions for the microprobe were 15 KV and 0.02 microamps of current. Magnification was 500X.

Microprobe Analysis of White and Austrian Pine Needle Cross Sections

Needles of white and Austrian pine were collected from the highway and nonhighway sides of trees growing along M-78 in the salt spray zone and from trees growing on the Michigan State University campus where no salt spray could reach the needles. The needles were embedded in O.C.T. and sectioned on a cryostat to a thickness of 8 micrometers. Randomly chosen sections were mounted on carbon discs; O.C.T. being used as a mounting material. The sections were then coated with carbon to a thickness of 100 Å.

Horizontal line profiles for sodium and chlorine were made on the EMX-SM microprobe of randomly selected portions of each section. The portions of the sections scanned were 200 micrometers in length. Operating conditions for the microprobe were 15KV and 0.02 microamps of current. Magnification was 500X.

RESULTS AND DISCUSSION

Preliminary Survey

De-icing salt spray injury was observed along highways in the Lansing-East Lansing area. The symptoms of salt spray injury on evergreens were observed to be similar to those described by Lumis, Hofstra, and Hall (59). Needle browning was observed on the highway side of susceptible plants. On the highway side of older plants bud necrosis, in addition to needle browning, was observed. The needle browning began at the tips of the needles and progressed toward the base. Symptoms were evident on the highway side of the plant only. Plant portions above or beyond the spray or drift zone exhibited no injury symptoms. Symptoms were observed to be less severe further from the road.

De-icing salt spray injury was observed on some species in all areas surveyed. White pine (*Pinus strobus*) was severely injured. This species exhibited severe needle browning on the highway side. Many white pines exhibited bud necrosis. Several young white pines were dead. Norway spruce (*Picea abies*) exhibited slight needle browning as did Douglas fir (*Pseudotsuga taxifolia*). Scotch pine (*Pinus sylvestris*), arborvitae (*Thuja occidentalis*), red pine (*Pinus resinosa*), and juniper (Juniperus spp.) exhibited moderate salt spray injury. Needle browning was evident on the highway side of the plants but there was very little bud necrosis. Austrian pine (Pinus nigra) and Colorado spruce (Picea pungens) exhibited no injury symptoms.

I-96 Survey

Soil conditions were very poor at this site. The soil was very hard and extremely dry. Symptoms observed on evergreens were similar to those observed on evergreens in the preliminary survey. Injury from saw fly was noted on Scotch pine (Pinus sylvestris). Symptoms of salt spray injury on deciduous species were observed to be similar to those described by Lumis, Hofstra, and Hall (59). Those branches on the highway side of the plant exhibited tip necrosis; those injured for more than one year exhibiting a "tufted" branching habit (Figure 4). Flowering was severely reduced on the highway side of the plant. Injury from tent worms was observed on Malus spp., Crataegus crusgalli, and Crataegus oxyacantha. Injury ratings for the various species observed are presented in Table 2, on page 47.

M-78 Survey

Sumptoms of de-icing salt spray injury were observed on plants located on both the north and south sides of M-78. There was no apparent difference in the amount of plant injury

Figure 4. Tufting of the branches of bur oak (Quercus macrocarpa).

Table 2. Average salt spray injury ratings of plants bordering I-96--May 1972.

Species	Average Injury Rating
Acer campestre	2.0
Acer ginnala	2.0
Acer platanoides	1.5
Acer rubrum	2.0
Acer saccharum	4.0
Crataegus crusgalli	2.5
Crataegus monogyna	2.5
Crataegus oxyacantha	3.5
Euonymus europaeus	4.0
Elaeagnus angustifolia	1.5
Fraxinus pensylvanica lanceolata	1.5
Gleditsia triacanthos	3.0
Malus floribunda	4.0
Pinus nigra	1.5
Pinus strobus	4.0
Pinus sylvestris	3.0
Platanus occidentalis	4.0
Populus deltoides	1.0
Quercus alba	1.5
Quercus palustris	2.5
Quercus robur	4.0
Quercus rubra	4.0
Rhus typhina	1.0

between the north and south sides of the highway. Injury expressed as needle browning and bud necrosis was observed on both the highway and non-highway sides of white pine (Pinus strobus). Injury symptoms were observed to a vertical distance of 30 feet with most injury occurring at a height of 20 feet or below. American Beech (Fagus grandifolia) located on the north side of M-78 at a distance of 20 feet from the highway exhibited slight "tufting" of the branches on the highway side of the trees. White oak (Quercus alba) 18 feet from the highway exhibited moderate tufting on the highway side. Green ash (Fraxinus pensylvanica lanceolata) and red maple (Acer rubrum) exhibited no injury symptoms at distances of 10 and 30 feet from the highway. Shagbark hickory (Carya ovata) exhibited no injury symptoms at a distance of 15 feet from the highway. Pin oaks (Quercus palustris) located 20 feet from the highway exhibited bud and tip necrosis on the highway side. Average injury ratings of evergreens observed on M-78 are presented in Table 3, on the following page.

I-496 Survey

Injury symptoms similar to those observed in other areas on both deciduous and evergreen species were noted. Injury occurred on some species at distances of 60 feet from the highway. Average injury ratings of those species observed are presented in Table 4, on page 50.

Table 3. Average salt spray injury ratings of evergreens observed on M-78--March 1973.

Species	Average Injury Rating
Juniperus spp.	2.5
Picea abies	1.5
Picea glauca	1.5
Picea pungens	1.0
Pinus banksiana	4.0
Pinus nigra	1.0
Pinus resinosa	2.5
Pinus strobus	4.0
Pinus sylvestris	1.5
Pseudotsuga taxifolia	2.0
Taxus spp.	1.0

Table 4. Average salt spray injury ratings of plants observed on I-496--April 1972 and April 1973.

Species	Average Injury Rating
Acer ginnala	3.0
Acer platanoides	2.0
Acer rubrum	3.0
Acer saccharinum	2.0
Acer saccharum	4.0
Cornus stolonifera	3.0
Crateagus crus-galli	1.5
Crataegus oxyacantha	3.0
Euonymus alatus	1.0
Gleditsia triacanthos	1.5
Ligustrum spp.	2.5
Malus spp.	4.0
Pinus nigra	1.5
Pinus strobus	4.5
Pinus sylvestris	2.5
Populus deltoides	2.0
Pseudotsuga taxifolia	1.0
Quercus coccinea	3.5
Quercus palustris	2.5
Rhamnus spp.	2.0
Rhodotypos scandens	1.0
Salix spp.	3.0
Spiraea vanhouttei	1.0
Thuja occidentalis	3.5
Ulmis pumila	1.0
Viburnum dentatum	3.0

Michigan Arboretum Survey

Injury to many deciduous and evergreen species was noted. Injury was very severe on certain species. Many deciduous trees exhibited severe "tufting" of the branches and many evergreen species exhibited browning of the needles. Injury occurred on trees as far as 250 feet from the highway. Average injury ratings for the species observed are presented in Table 5, on the following page.

Microprobe Analysis of White and Austrian Pine Needle Surfaces

Representative relative X-ray intensities for sodium and chlorine of white and Austrian pine needle surfaces from highway and non-highway trees indicate that there is a greater amount of sodium and chlorine on the surface of both white and Austrian pine needles from highway trees (Figures 5 and 6). The X-ray graphs indicate further that the sodium and chlorine on the surface of the Austrian pine needles from the highway area is more evenly distributed along the needle than the sodium and chlorine on the surface of the white pine needle from the highway area. Most of the sodium and chlorine on the white pine needle was concentrated on the upper (tip) one-third of the needle.

Table 5. Average de-icing salt spray injury ratings of plants at the Michigan Arboretum--1972 and 1973.

Species	Average Injury Rating
Acer saccharum	2.5
Acer saccharum nigrum	3.0
Acer rubrum	3.5
Aesculus glabra	1.0
Amelanchier canadensis	1.5
Cercis canadensis	4.0
Cornus racemosa	2.5
Hamamelis virginiana	2.5
Ilex verticillata	1.5
Larix laricina	1.5
Liriodendron tulipifera	4.0
Morus rubra	1.5
Nyssa sylvatica	3.0
Picea canadensis	3.5
Picea mariana	3.5
Pinus banksiana	3.0
Pinus nigra	2.0
Pinus resinosa	3.5
Pinus strobus	4.5
Platanus occidentalis	3.0
Prunus americana	3.5
Quercus alba	4.5
Quercus bicolor	4.0
Quercus coccinea	3.5
Quercus imbricaria	1.5
Quercus macrocarpa	4.0
Quercus palustris	3.5
Quercus prinus	4.0

Continued

Table 5--Continued

Species	Average Injury Rating
Quercus rubra	3.0
Quercus velutina	4.0
Rhus glabra	1.5
Rhus typhina	1.5
Salix nigra	1.5
Sassafras variifolium	3.5
Viburnum americanum	1.5
Viburnum lentago	2.5

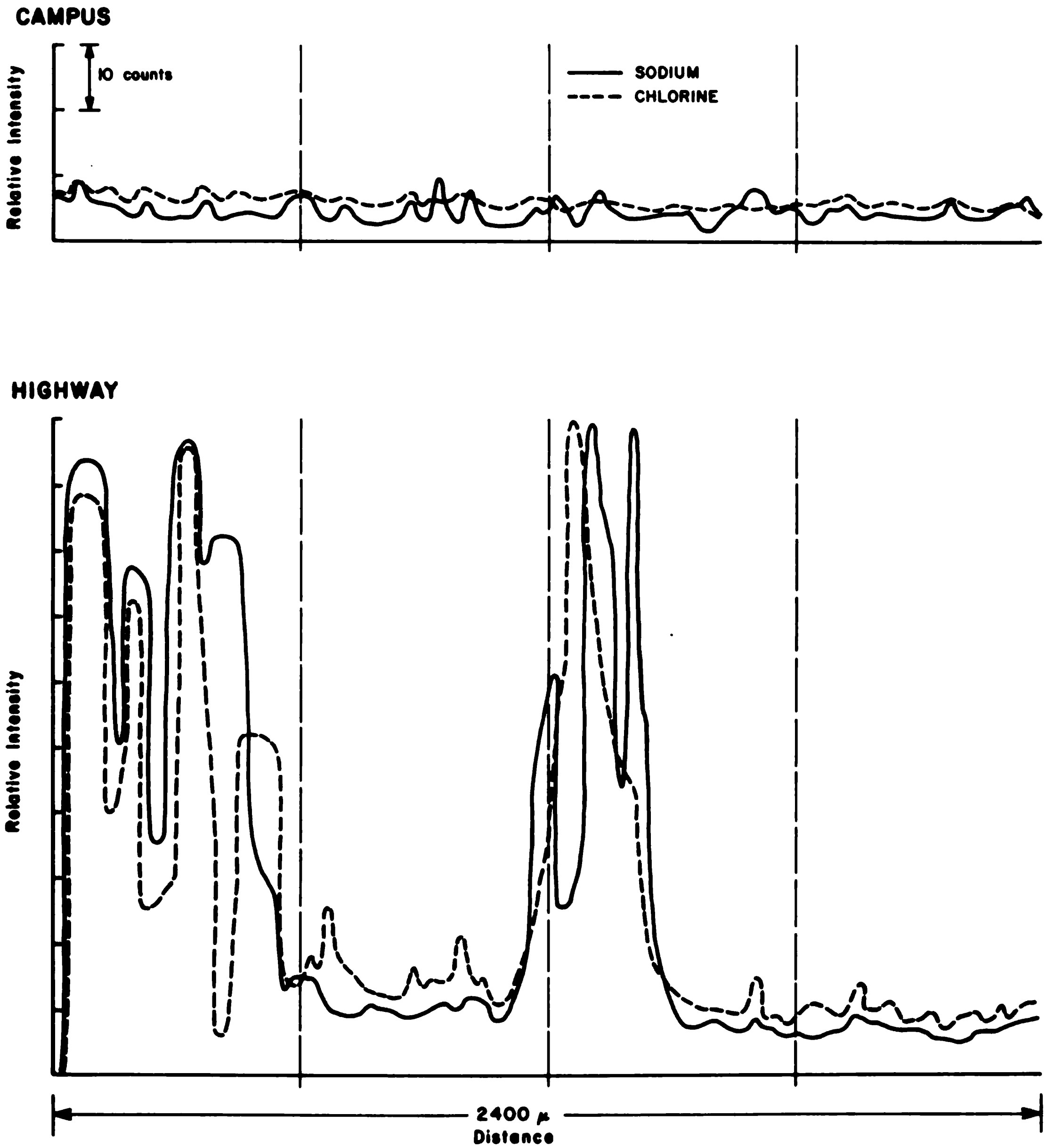

Figure 5. Representative relative X-ray intensities of sodium and chlorine on white pine needle surfaces. (Background equals 1.5 counts/sec. for Cl^- and 1.6 counts/sec. for Na^+.) Vertical hash marks indicate divisions between needle sections.

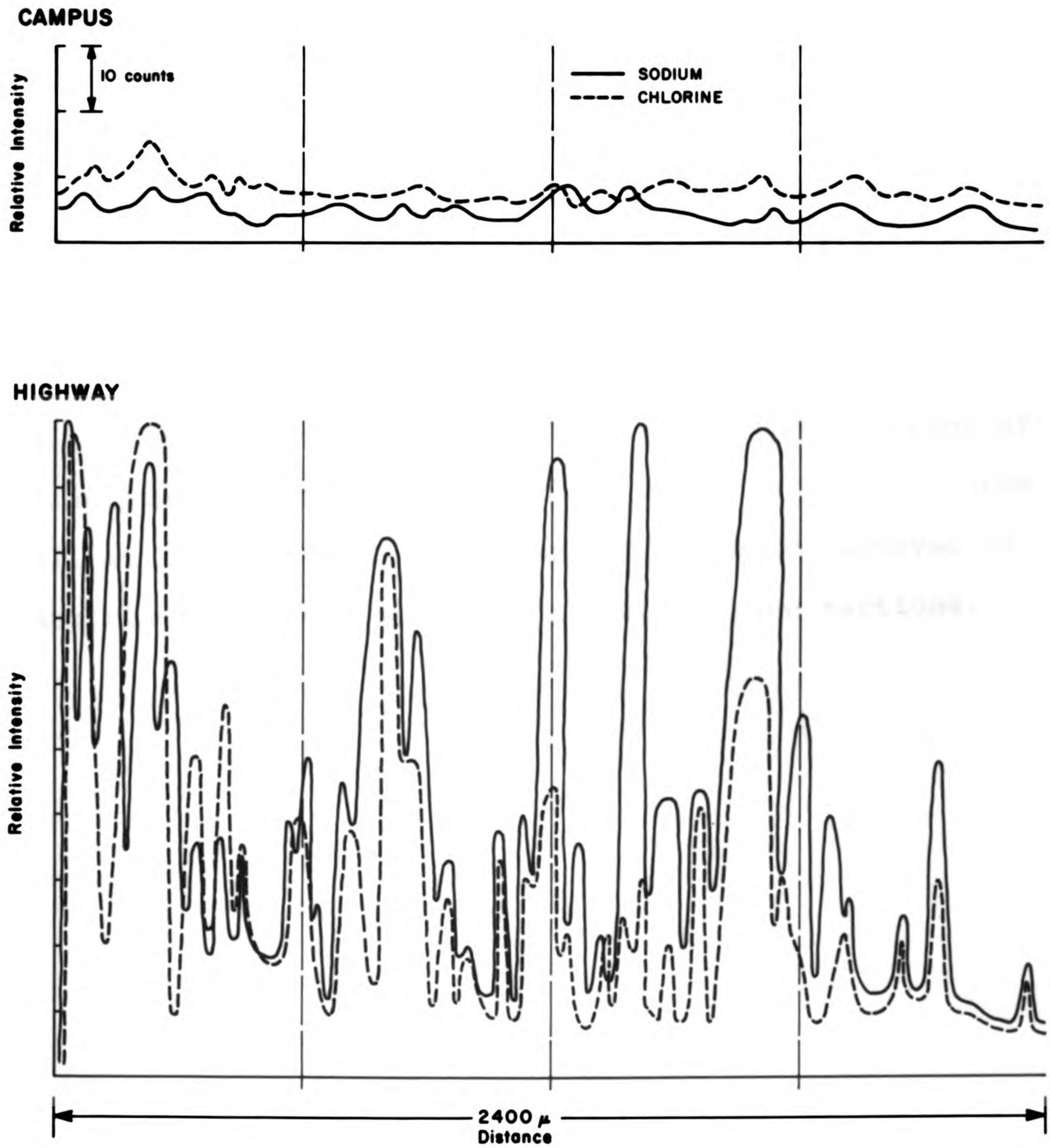

Figure 6. Representative relative X-ray intensities of sodium and chlorine on Austrian pine needle surfaces. (Background equals 2.5 counts/sec. for Cl^{-} and 1.9 counts/sec. for Na^{+}.) Vertical hash marks indicate divisions between needle sections.

Microprobe Analysis of White and Austrian Pine Needle Cross Sections

Representative X-ray intensities for sodium and chlorine of white and Austrian pine needle cross sections indicate that the needle sections from the highway side of both Austrian and white pine contain more sodium and chlorine than do sections of needles from the non-highway side of the same trees or needles from the campus trees (Figures 7 and 8). There is a slight increase in X-ray intensity of sodium and chlorine in non-highway needle sections as compared to campus needle sections. When the intensities of the highway side sections of Austrian pine are compared with those of white pine (Figures 7 and 8), at least as much sodium and chlorine is observed in the Austrian pine sections as in the white pine sections.

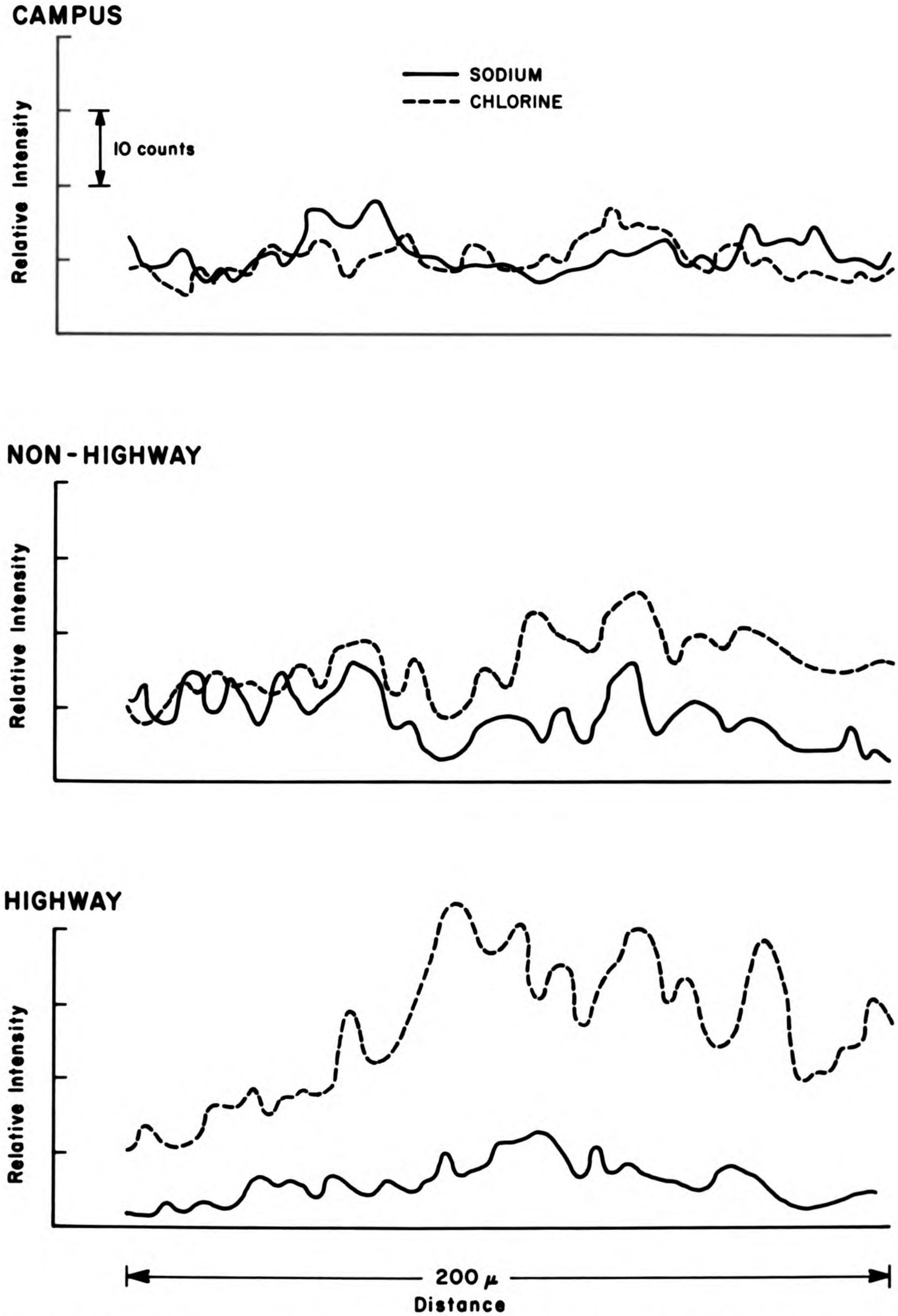

Figure 7. Representative relative X-ray intensities of sodium and chlorine in white pine needle cross sections (Background equals 1.8 counts/sec. for Cl^- and 1.8 counts/sec. for Na^+).

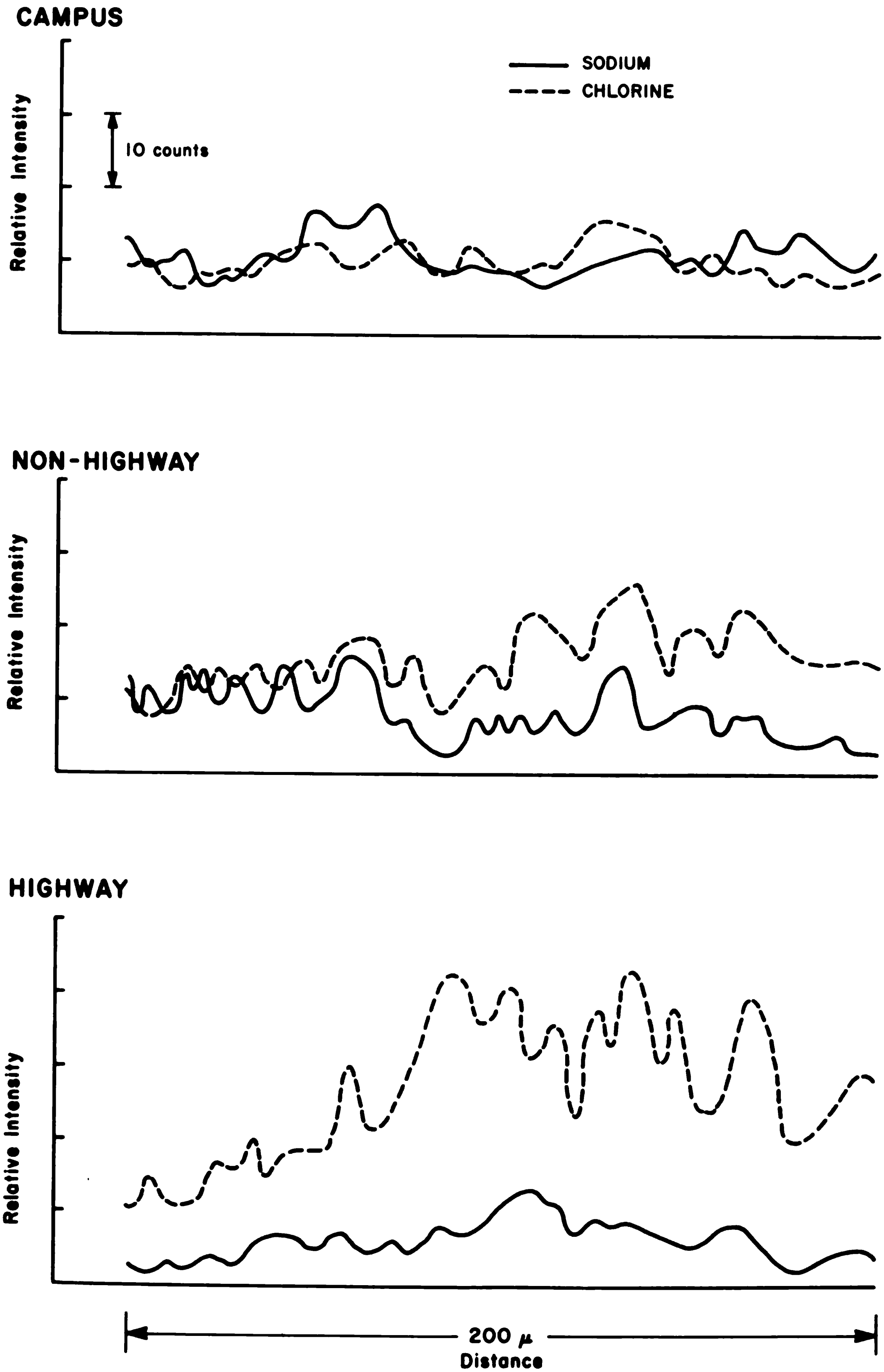

Figure 8. Representative relative X-ray intensities of sodium and chlorine in Austrian pine needle cross sections. (Background equals 1.7 counts/sec. for Cl^- and 1.3 counts/sec. for Na^+).

SUMMARY AND CONCLUSIONS

Symptoms of salt spray injury were observed on both deciduous and evergreen species growing along highways in the Lansing-East Lansing area and at the Michigan Arboretum in Dearborn, Michigan. Symptoms of salt spray injury on evergreen species were observed to be 1) browning of the needles from the tip to the base, 2) injury evident on the highway side of the plant only, 3) plant portions above or beyond the spray or drift zone were uninjured, and 4) symptoms were less severe further from the road. Symptoms of salt spray injury on deciduous species were observed to be 1) tufting of the branches due to death of the apical bud, 2) lack of flowering on the highway side of the plant, 3) plant portions above or beyond the spray or drift zone were uninjured, 4) symptoms were less severe further from the road.

Injury was observed on plants at distances as far as 250 feet from the highway and to a vertical distance of up to 20 feet. Wind seemed to be a factor in carrying the spray drift to greater distances. Also the type of vehicle and speed of the vehicle were observed to be factors in determining the extent of the spray drift.

Average salt spray injury ratings and tolerances of all plants observed along Michigan highways are listed in Table 6.

Table 6. Average salt spray injury ratings and tolerances of plants bordering selected Michigan highways.

Botanical Name	Common Name	Average Injury Rating	Tolerance*
Acer campestre	Hedge maple	2.0	T
Acer ginnala	Amur maple	3.0	MT
Acer platanoides	Norway maple	2.0	T
Acer rubrum	Red maple	2.5	MT
Acer saccharinum	Silver maple	2.0	T
Acer saccharum	Sugar maple	3.5	S
Acer saccharum nigrum	Black maple	3.0	MT
Aesculus glabra	Ohio buckeye	1.0	VT
Amelanchier canadensis	Juneberry	2.0	T
Cercis canadensis	Redbud	4.0	S
Cornus racemosa	Gray dogwood	2.5	MT
Cornus stolonifera	Redosier dogwood	3.0	MT
Crataegus crusgalli	Cockspur hawthorn	2.0	T
Crataegus monogyna	Singleseed hawthorn	2.5	MT
Crataegus oxyacantha	English hawthorn	3.5	S
Elaeagnus angustifolia	Russian olive	1.5	T
Euonymus alata	Winged euonymus	1.0	VT
Euonymus europaeus	European euonymus	4.0	S
Fraxinus pensylvanica lanceolata	Green Ash	1.5	T
Gleditsia triacanthos	Common honeylocust	2.5	MT
Hamamelis virginiana	Common witch-hazel	2.5	MT
Ilex verticillata	Michigan holly	1.5	T
Juniperus spp.	Juniper	2.5	MT
Larix laricina	Tamarack	1.5	T

Continued

*VT=very tolerant; T=tolerant, MT=moderately tolerant; S=sensitive, and VS=very sensitive.

Table 6--Continued

Botanical Name	Common Name	Average Injury Rating	Tolerance
Ligustrum spp.	Privet	3.0	MT
Liriodendron tulipifera	Tulip tree	4.0	S
Malus spp.	Crabapple	4.0	S
Morus rubra	Red mulberry	1.5	T
Nyssa syvatica	Black gum	3.0	MT
Picea abies	Norway spruce	1.5	T
Picea glauca	White spruce	2.5	MT
Picea mariana	Black spruce	3.5	S
Picea pungens	Colorado spruce	1.0	VT
Pinus banksiana	Jack pine	3.0	MT
Pinus nigra	Austrian pine	1.5	T
Pinus resinosa	Red pine	2.5	MT
Pinus strobus	Eastern white pine	4.0	S
Pinus sylvestris	Scotch pine	2.0	T
Platanus occidentalis	American sycamore	3.5	S
Populus deltoides	Cottonwood	1.5	T
Prunus americana	American plum	3.5	S
Pseudotsuga taxifolia	Douglas fir	2.0	T
Quercus alba	White oak	3.5	S
Quercus bicolor	Swamp white oak	4.0	S
Quercus coccinea	Scarlet oak	3.5	S
Quercus imbricaria	Shingle oak	1.5	T
Quercus palustris	Pin oak	3.0	MT
Quercus prinus	Chestnut oak	4.0	S
Quercus robur	English oak	4.0	S
Quercus rubra	Red oak	3.5	S
Quercus velutina	Yellow oak	4.0	S

Continued

Table 6--Continued

Botanical Name	Common Name	Average Injury Rating	Tolerance
Rhamnus spp.	Buckthorn	2.0	T
Rhodotypos scandens	Black jetbead	1.0	VT
Rhus glabra	Smooth sumac	1.5	T
Rhus typhina	Staghorn sumac	1.5	T
Salix spp.	Willow	2.5	MT
Sassafras variifolium	Silky sassafras	3.5	S
Spiraea vanhouttei	Van houtte Spirea	1.0	VT
Taxus spp.	Yew	1.0	VT
Thuja occidentalis	American arborvitae	4.0	S
Ulmus pumila	Siberian elm	1.0	VT
Viburnum americanum	American cranberry bush	1.5	T
Viburnum dentatum	Arrow wood	3.0	MT
Viburnam lentago	Nannyberry	2.5	MT

Tolerance ratings were based on average injury ratings. Injury ratings were averaged over time, location, and distance from the edge of the highway.

The plants observed to be most tolerant to salt spray were those with heavy coatings of wax on the foliage, stems, or buds (Pinus nigra, Aesculus glabra, Rhus glabra, Fraxinus pensylvanica lanceolata, and Picea pungens). Those plants with pubescent coatings on the stems, buds, or foliage were also observed to be very tolerant (Amelanchier canadensis, Rhus typhina, and Elaeagnus angustifolia). Other characteristics observed to be factors in salt spray tolerance were submerged buds (Larix laricina) and persistence of the foliage (Quercus imbricaria).

Those plants that were observed to be sensitive to salt spray had exposed buds without a thick waxy coating. Some of these sensitive species were very fine textured and thus had a high surface to volume ratio (Pinus strobus).

Results of the microprobe analysis indicate that the sodium and chlorine on the surface of the Austrian pine needles was more evenly distributed than the sodium and chlorine on the surface of the white pine needle. This may be due in part to the coalescence of the white pine needles upon becoming wet.

Results of microprobe analysis of cross sections indicate that the tolerance of Austrian pine is not due to its ability to exclude sodium or chlorine from the interior of the needle. The contents of sodium or chlorine in the Austrian pine needle sections were just as great as those of the white pine needle sections. Hofstra and Hall (44) found similar injury symptoms at similar sodium and chlorine needle levels and hypothesized that resistance was due to the fact that resistant species accumulated less salt. White pine exhibited severe injury symptoms whereas Austrian pine exhibited no injury symptoms.

The tolerance of Austrian pine to de-icing salt spray may stem from two sources: (a) the ability of Austrian pine needle cells to tolerate high concentrations of sodium and chlorine or (b) the ability of the Austrian pine needle to restrict water loss resulting from the osmotic action of high salt concentrations on the needle surface. Buschbom (20) found the degree of resistance of the protoplasts to be more important than constitutional resistance and thought it to be the governing factor in lethal effects. In further work Buschbom (20) noted interspecific differences in the protoplasmic resistance of broadleaved woody species. This resistance was lowest at spring flush when most salt injury symptoms appear.

Several researchers have determined the cause of salt spray injury to be an osmotic effect rather than a specific ion effect (56, 87, 93). Oosting (65) observed that plants with heavily cutinized leaves showed no salt injury symptoms.

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APPENDIX

SALT TOLERANCES OF VARIOUS WOODY AND HERBACEOUS PLANTS

The following is a list of the salt tolerances of various woody and herbaceous plant species compiled from a review of the available literature on salt tolerance. Salt tolerance is divided into three categories:

1) General salt tolerance--tolerance to both soil salts and salt spray.

2) Soil salt tolerance--salt tolerance as determined by application of salts directly to the soil or by observations of salt damage in areas where soil salts but not salt spray were a factor.

3) Salt spray tolerance--salt tolerance as determined by application of salts directly to the foliage or by observations of salt damage in areas where soil salts were not a factor.

The salt tolerances of the various species were rated as follows:

VT--very tolerant
T--tolerant
MT--moderately tolerant
S--sensitive
VS--very sensitive

Ratings were based on injury symptoms and varied slightly with the researcher.

This table is designed to indicate relative salt tolerances and is not based on any specific levels of salt either in the soil or on the foliage. It can be used primarily as a guide when selecting plants for areas where salt is a factor. Local conditions should also be considered.

SALT TOLERANCES OF VARIOUS WOODY AND HERBACEOUS PLANTS

		Salt Tolerance					
Botanical Name	Common Name	Gen.	Ref.	Soil	Ref.	Spray	Ref.
	CONIFERS AND EVERGREEN TREES						
Abies balsamea	Balsam fir	VS	9	MT	12		
Chamaecyparis pisifera	Sawara false cypress					S	2
Ilex aquifolium	English holly					VS	2
Juniperus spp.	Juniper					MT	7
Juniperus virginiana	Eastern red cedar	T	11	MT,MT	8,12		
Larix decidua	European larch			VS	12	T	2
L. laricina	Tamarack					T	7
L. leptolepis	Japanese larch					T	2
Metasequoia glyptostroboides	Dawn redwood					VS	2
Picea abies	Norway spruce			S	6	VS,MT	2,7
P. Glauca	White spruce	VS	9	MT	12	VS	7
P. Pungens	Blue spruce			VS,MT	8,12	VT	7
Pinus cembra	Swiss stone pine					VS	2
P. divaricata	Jack pine					T	7
P. Mugo	Mugo pine					T	7
P. nigra	Austrian pine					T	7
P. ponderosa	Ponderosa pine			MT,MT	8,12		
P. resinosa	Red pine	VS	11			VS	7
P. strobus	E. white pine	VS	11	S	6	VS	7
P. sylvestris	Scotch pine					VS,VS	2,7
Pseudotsuga menziesii	Douglas-fir			VS,MT	8.12	MT	2
Taxus spp.	Yew					S	7
T. baccata	English yew					VS	2
Thuja occidentalis	American arborvitae			MT	12	S	7
Tsuga canadensis	Canada hemlock	VS,VS	9,11	VS	6	VS	7
T. heterophylla	Western hemlock					MT	2

continued

Botanical Name	Common Name	Gen.	Ref.	Salt Tolerance Soil	Ref.	Spray	Ref.
	DECIDUOUS TREES						
Acacia spp.	Acacia			T	12		
Acer campestre	Hedge maple					VT,MT	2,10
A. carpinifolia	Hornbeam maple					S	2
A. davidii	David maple					S	2
A. ginnala	Amur maple					VS	2
A. grosseri v. hersii	Grosser's maple					S	2
A. mono	Mono maple					T	2
A. monspessulanum	Montpelier maple					S	2
A. negundo	Box-Elder			MT	12	MT,VS	2,7
A. palmatum	Japanese maple					VS	2
A. platanoides	Norway maple					VT,VT,T	2,7,10
A. pseudoplatanus	Sycamore maple	S	9	VS	12		
A. rubrum	Red maple	VS	11	VS	12	MT	7
A. saccharinum	Silver maple					MT,T	2,7
A. saccharum	Sugar maple	VS,VS	9,11	MT,MT	6,12	T	7
A. sieboldianum	Siebold maple					MT	2
A. spicatum	Mountain maple					VS	2
A. tataricum	Tatarian maple					VS	2
A. vetlutinum	Velvet maple					VT	2
Aesculus hippocastanum	White horsechestnut					VT,VT	2,7
Ailanthus altissima	Tree of heaven					VT	7
Alnus glutinosa	European alder					T,MT	2,10
A. hirsuta	Manchurian alder					T	2
A. incana	Speckled alder			VS	12	MT	2
Amelanchier asiatica	Asian serficeberry					VS	2
A. grandiflora	Apple serviceberry					VS	2
A. laevis	Allegany serviceberry					VS	7
A. ovalis	Garden serviceberry					T	2
A. spicata	Dwarf serviceberry					S	2
Betula spp.	Birch	VS	9	MT	12		

continued

APPENDIX--Continued

Botanical Name	Common Name	Gen.	Ref.	Salt Tolerance Soil	Ref.	Spray	Ref.
DECIDUOUS TREES--continued							
B. alleghaniensis	Yellow birch	T	11				
B. ermannii	Ermans birch					MT	2
B. humilis	--- ---					S	2
B. lenta	Black birch	T	11				
B. papyrifera	Canoe birch	T	11			MT	7
B. pendula	European birch			MT	6	MT	2
B. populifolia	Gray birch	T	11			MT	7
Betula pubescens	--- ---					VS	2
B. schmidtii	Schmidts birch					VS	2
Carpinus betulus	European hornbeam	VS	9	VS	12	VS,S	2,10
Carpinus betulus quercifolia	Oakleaf hornbeam					S	2
Carpinus caroliniana	American hornbeam	VS	11				
Carya ovata	Shagbark hickory	VS	11			T	7
Castanea dentata	American chestnut					S	2
Catalpa speciosa	Catalpa					MT	7
Celtis australis	European hackberry					VS	2
C. caucasica	Caucasian hackberry					VS	2
C. occidentalis	Hackberry					VS	2
Cercis canadensis	Eastern redbud			MT	6		
Cornus mas	Cornelian cherry					VS	2
Corylus avellana	Filbert			VS	12	VS,S	2,10
C. colurnoides	Colurnoid filbert					VS	2
C. cornuta	Beaked filbert					VS	2
Crataegus spp.	Hawthorn			T	12	S	7
C. coccinoides	Kansas hawthorn					S	2
C. crus-galli	Cockspur thorn					VS	2
C. grignonensis	--- ---					VS	2
C. lavallei	Lavalle hawthorn					S	2
C. monogyna	Singleseed hawthorn					S,S	2,10
C. oxyacantha	English hawthorn					S,S	2,10
C. prunifolia	Plumleaf hawthorn					VS	2

continued

APPENDIX--Continued

Botanical Name	Common Name	Gen.	Ref.	Salt Tolerance Soil	Ref.	Spray	Ref.
DECIDUOUS TREES--continued							
C. punctata	Dotted hawthorn					S	2
C. sanguinea	Redhaw hawthorn					S	2
C. sorbifolia	Sorvus hawthorn					VS	2
Cydonia oblonga	Quince					MT	7
Fagus grandifolia	American beech	VS	9	MT	12	MT,VS	2,7
F. orientalis	Oriental beech					VS	2
F. silvatica	European beech			VS	12	VS,S	2,10
F. silvatica laciniata	Cutleaf Eur. beech					VS	2
F. s. quericifolia	Oakleaf Eur. beech					VS	2
Fraxinus americana	White ash	T	11			T	7
F. angustifolia	Narrowleaf ash					MT	2
F. excelsior	European ash					T,T	2,10
F. holotricha						S	2
F. ornus	Flowering ash					VT	2
F. pensylvanica lanceolata	Green ash	VT	9	S,MT,MT	6,12,8		
Gleditsia japonica	Japanese honeylocust					VT	2
G. triacanthos	Common honeylocust					S,T	2,7
G. triacanthos inermis	Thornless honeylocust			T,VT,VT	6,8,12		
Hippophae rhamnoides	Common sea-buckthorn					MT,T	2,10
Juglans nigra	Eastern black walnut			VS,VS	8,12	T	7
J. regia	English walnut					T	7
Laburnum anagyroides	Golden chain					VS	2
Liriodendron tulipifera	Tulip tree			VS	6		
Malus spp.	Apple					S	7
M. spp.	Crabapple	S	9			MT	7
M. baccata	Siberian crabapple			MT	12		
M. silvestris	Apple			T	6		
Morus spp.	Mulberry	VT	9	T	12		
M. alba	White mulberry					VS,VS	2,7

continued

APPENDIX--Continued

Botanical Name	Common Name	Salt Tolerance Gen.	Ref.	Soil	Ref.	Spray	Ref.
DECIDUOUS TREES--continued							
Ostrya japonica	Japanese hopbornbeam					MT	2
Platanus acerifolia	London plane tree					S	2
Populus spp.	Poplar	S	9	MT	12	T	7
P. alba	White poplar			T	12	T	2
P. alba 'nivea'	Silver poplar	VT	9	T	12	T	2
P. canadensis	Caroline poplar					VT	2
P. canescens	Gray poplar	VT	9	T	12	VT	2
P. deltoides	Cottonwood			MT	12	VT	7
P. grandidentata	Largetooth aspen	T	11			MT	7
P. nigra	Black poplar					T	2
P. nigra 'Italica'	Lombardy poplar			VS	12	MT	7
P. tremuloides	Quaking aspen	S,T	9,11			MT,MT	2,7
Prunus armeniaca	Common apricot	VT	9	T	12		
P. avium	Mazzard cherry					MT	2
P. mahaleb	Mahaleb cherry					VS	2
P. padus	European bird cherry					T	2
P. serotina	Black cherry	T	11			VS,S	2,10
P. virginiana	Chokecherry					T	7
Pyrus spp.	Pear					MT	7
Quercus alba	White oak	VT,VT	9,11	T	12	VS	2
Q. bicolor	Swamp white oak					S	2
Q. cerris	Turkey oak					S	2
Q. heterophylla	Bartram oak					S	2
Q. libani	Lebanon oak					VS	2
Q. macranthera						MT	2
Q. macrocarpa	Bur oak	T	9			MT,S	2,7
Q. muehlenbergii	Yellow chestnut oak					VS	2
Q. palustris	Pin oak					S	2
Q. petraea	Durmast oak					VS	2

continued

APPENDIX--Continued

Botanical Name	Common Name	Gen.	Ref.	Salt Tolerance Soil	Ref.	Spray	Ref.
DECIDUOUS TREES--continued							
Q. pyrenaica	Pyrenees oak					VS	2
Q. robur	English Oak	VT	9	T	12	S	2
Q. rubra	Swamp oak	VT,T	9,11	T	12	S,T	2,7
Rhamnus davurica	Dahurian buckthorn					T	2
Robinia pseudoacacia	Black locust	VT,T	9,11	T	12	VT,VT	2,7
R. p. 'Pyramidalis'	Pyramid locust					VT	2
Salix alba	White willow					T	2
S. a. 'Tristis'	Golden willow					MT	7
Salix alba 'Vittelina'	Yellowstem willow			T,MT	8,12	VS	2
S. amygdalina	Peach-leaf willow					T	2
S. aurita	Roundear willow					MT	2
S. caprea	Goat willow					MT,MT	2,10
S. daphnoides	Daphne willow					T	2
S. fragilis	Brittle willow					T	2
S. nigra	Black willow					T	7
S. pentandra	Laurel willow					MT	2
S. purpurea	Osier willow			T	12		
S. p. nana	Blue willow			VS,VS	8,12		
S. p. lambertiana	Lambert purpleosier W.					T	2
Sophora japonica	Japanese pagoda tree					VS	2
Sorbus spp.	Mountain ash					T	7
S. aria	White beam mntn ash					T	2
S. aucuparia	European mntn. ash					VS	2
S. commixta	Korean mountain ash					MT	2
S. decora	Showy mntn. ash					T	2
S. hydrida	Oakleaf mountain ash					S	2
S. intermedia	Swedish mountain ash					VS	2
S. japonica	Japanese mountain ash					T	2
S. koehneana	Koehnes mountain ash					VS	2

continued

APPENDIX--Continued

Botanical Name	Common Name	Gen.	Ref.	Salt Tolerance Soil	Ref.	Spray	Ref.
DECIDUOUS TREES--continued							
S. latifolia	--- ---					S	2
S. pohuashanensis	--- ---					VS	2
S. rufo-ferruginea	Flameberry Mountain A.					VS	2
S. sambucifolia	Siberian mountain ash					VS	2
S. serotina	--- ---					T	2
S. torminalis	Wild service tree					S	2
S. vilmorinii	Vilmorin mntn. ash					VS	2
Tilia americana	Basswood	VS	11			MT	7
T. cordata	Little-leaf linden			VS,VS	8,12	T	2
T. euchlora	Crimean linden					S	2
T. platyphylla	Big-leaf linden					T	2
Ulmus americana	American elm	VS	11			T	7
U. campestris	Scotch elm	VT	9	T	12		
U. carpinifolia	Smooth-leaved elm					S,MT	2,10
U. glabra	Scotch elm					T,T	2.10
U. laevis	Russian elm					MT	2
U. pumila	Siberian elm					T	7
U. p. arborea	Narrow siberian elm					VS	2
	SHRUBS						
Alnus rugosa	Speckled alder	S	11			MT	7
Arctostaphylos uva-ursi	Bearberry	T	5				
Artemisia abrotanum 'Nana'	Dwarf southernwood	T	5				
Berberis aggregata	Salmon barberry					S	2
B. beaniana	Beans barberry					T	2
B. bretschneideri	Purpleberry barberry					VS	2
B. dictyophylla	Chalkleaf barberry					VS	2
B. dielsiana 'Compacta'	Dwarf diels barberry					VS	2

continued

APPENDIX--Continued

Botanical Name	Common Name	Gen.	Ref.	Salt Tolerance Soil	Ref.	Spray	Ref.
SHRUBS--continued							
B. fendleri	Colorado barberry					MT	2
B. gagnepaini	Black barberry					VS	2
B. giraldii	Girald barberry					VS	2
B. hookeri	Hookers barberry					VS	2
B. julianae	Wintergreen barberry					VS	2
B. koreana	Korean barberry					MT	2
B. oblonga	Bigflower barberry					MT	2
B. thibetica	Thibetan barberry					VS	2
B. thunbergii	Japanese barberry			VS,VS	8,12	VS	2
B. t. atropurpurea	Redleaf Japanese Brbry					T	7
B. tischleri	Tischler barberry					VS	2
B. vulgaris	Common barberry					S	2
Buxus sempervirens	Common box	S	9	VS	12		
Callistemon lanceolatus	Bottle brush			T	12		
Caragana arborescens	Silberian pea-tree					VT,VT,T	2,7,10
Chaenomeles lagenaria	Flowering quince					S	7
Colutea arborescens	Bladder-senna					T	2
Comptonia peregrina	Sweetfern	T	5				
Cornus alba	Tararian dogwood					S	2
C. alba 'Kesselringii'	Purpletwig dogwood					VS	2
C. alba 'Sibirica'	Siberian dogwood					VS	2
C. alba 'Spaethii'	Yellowedge dogwood					VS	2
C. amomum	Silky dogwood					VS	2
C. racemosa	Gray dogwood					S	7
C. sanguinea	Bloodtwig dogwood					VS,S	2,10
C. stolonifera	Red osier dogwood					VS,S	2,7
Corylus americana	American filbert					VS	2
Corylus sieboldiana	Japanese filbert					VS	2
Cotoneaster integerrimus	European cotoneaster					VS	2

continued

APPENDIX--Continued

Botanical Name	Common Name	Gen.	Ref.	Salt Tolerance Soil	Ref.	Spray	Ref.
SHRUBS--continued							
Crataegus intricata	Thicket hawthorn					VS	2
Elaeagnus angustifolia	Russian olive	VT	9	T,T	8,12	T,T,T	2,7,10
E. commutata	Silverberry					VT	2
E. ebbingei	--- ---					VS	2
E. multiflora	Cherry elaeagnus					MT	2
E. pungens reflexa	--- ---					VS	2
E. p. simoni	--- ---					VS	2
E. umbellata	Autumn elaeagnus					VS	2
Euonymus alatus	Burningbush			VS,VS	8,12	T	7
E. europaeus	Spindle tree					S	2
E. latifolius	Broadleaf euonymus					S	2
E. pauciflorus	--- ---					VS	2
E. verrucosus	Wartybark Euonymus					VS	2
Feijoa sellowiana	Pineapple guava			VS	12		
Forsythia intermedia	Border forsythia					MT	7
F. i. 'Spectabilis'	Spring glory forsythia			MT	6		
Halimodendron halodendron	Siberian salttree					T	2
Ilex verticillata	Winterberry			VS	12		
Juniperus chinensis 'Pfitzeriana'	Pfitzer juniper			T	6		
J. horizontalis	Creeping juniper	T	5				
J. h. plumosa	Andorra creeping juniper			MT,MT	6,12		
Kolkwitzia amabilis	Beauty bush					S	7
Lantana camera	Lantana			MT	12		
Ligustrum spp.	Privet					MT	7
L. amurense	Amur privet			T	6		
L. texanum	Texas privet			MT	12		
L. vulgare	Common privet					MT,S	2,10

continued

Botanical Name	Common Name	Gen.	Ref.	Salt Tolerance Soil	Ref.	Spray	Ref.
SHRUBS--continued							
Lonicera spp.	Honeysuckle					T	7
L. amoena 'Alba'	White gotha honeysuckle					S	2
L. caprofolium	Sweet honeysuckle					S	2
L. coerulea	Sweetberry honeysuckle					S	2
L. involucrata	Bearberry honeysuckle					VS	2
L. japonica	Japanese honeysuckle			MT,MT	8,12		
L. ledebourii	Ledebour honeysuckle					S	2
L. Maackii	Amur honeysuckle					S	2
L. morrowii	Morrow honeysuckle					S	2
L. nigra	--- ---					MT	2
L. periclymenum	Wood bine					T	2
L. purpusii	Purpus honeysuckle					VS	2
L. syringantha	Lilac honeysuckle					VS	2
L. tatarica	Tatarian honeysuckle			T	6	VS	2
L. xylosteum	European fly honeysuckle					MT,T	2,10
Mespilus germanica	Medlar					VS	2
Myrica pennsylvanica	Bayberry	T	5				
Nerium oleander	Oleander			T	12		
Philadelphus spp.	Mock orange					T	7
P. coronarius	Sweet mock-orange					T	2
Pittosporum spp.	Pittosporum			MT	12		
Prunus spinosa	Blackthorn					S	2
Pyracantha atalantoides	Gibbs firethorn					VS	2
P. coccinea	Scarlet firethorn			MT	12	VS	2
P. crenatoserrata	Chinese firethorn					VS	2
Rhamnus catharticus	European buckthorn					MT,VT	2,7
R. crenatus	Oriental buckthorn					MT	2
R. frangula	Alder buckthorn					MT,MT	2,7
R. infectorius	Persianberry buckthorn					S	2
R. utilis	Chinese buckthorn					VS	2

continued

Botanical Name	Common Name	Gen.	Ref.	Salt Tolerance Soil	Ref.	Spray	Ref.
SHRUBS--continued							
Rhus aromatica	Fragrant sumac	T	5				
R. glabra	Smooth sumac	T	5				
R. trilobata	Squawbush			T,T	8.12		
R. typhina	Staghorn sumac				T	7	
Ribes alpinum	Alpine currant					T,T	2,10
R. americanum	American black currant					MT	2
R. aureum	Golden currant					T	2
R. diacanthum	Siberian currant					T	2
R. divaricatum	Straggly gooseberry					MT	2
R. giraldii	--- ---					VS	2
R. gordonianum	Gordon currant					T	2
R. magdalenae	--- ---					T	2
R. nigrum	European black currant					VS	2
R. niveum	Snow gooseberry					T	2
R. sanguineum	Winter currant					S	2
Rosa canina	Dog rose					S,S	2.10
R. multiflora	Japanese rose			S,S,VS	6,8,12		
R. rubiginosa	Sweetbriar					VS	2
R. rugosa	Rugosa rose					S,T	2,10
Rubus fruticossus	European blackberry					S	10
Sambucus canadensis	American elder					S	2
S. nigra	European elder					S	2
S. racemosa	Red-berried elder					S,S	2.10
Shepherdia argentea	Buffalo berry			T	8		
Spiraea x bumalda	Bumalda spirea					S	7
S. vanhouttei	Vanhoutte spirea			S,S,VS	6,8,12		
Stewartia serrata						S	2
Symphoricarpus albus	Snowberry	T	5			MT,T	2,10

continued

Botanical Name	Common Name	Gen.	Ref.	Salt Tolerance Soil	Ref.	Spray	Ref.
SHRUBS--continued							
S. chenaultii	Chenault coralberry					VS	2
S. orbiculatus	Coralberry					VS	2
Syringa amurensis japonica	Japanese tree lilac					T	7
S. vulgaris	Common lilac					VS,T	2,7
Tamarix gallica	Tamarix			T,T	8,12		
T. hispida	Kashgar tamarix	VT	9				
T. pallassii	--- ---	VT	9				
T. pentandra	Five-stamen tamarix					T	2
Vaccinium vitis-idaea	Cowberry	T	5				
Viburnum spp.	Viburnum			VS	12		
V. lantana	Wayfaringtree viburnum					S	2
V. molle	Kentucky viburnum					S	2
V. opulus	European cranberrybush					S,T	2,7
Weigela 'Eva Rathke'	Eva Rathke W.			MT	6		
Xylosma congestum	Xylosma			MT	12		
Yucca filamentosa	Adams needle			MT	6		
	GRASSES, GROUND COVERS AND VINES						
Agropyron elongatum	Tall wheatgrass			T	1		
A. smithi	Western wheatgrass			T	1		
Agrostis spp.	Bentgrass					S	4
Alepocurus pratensis	Meadow foxtail			S	1		
Alyssum saxatile	Yellow Alyssum			S	8		
Arrhenatherum elatius	Tall meadow oat grass			MT	1		
Astragalus cicer	Mikvetch	T	5				
A. falcatus	Sicklepod milkvetch	T	5				
Avena sativa	Oats			MT	1		

continued

Botanical Name	Common Name	Salt Tolerance Gen.	Ref.	Soil	Ref.	Spray	Ref.
GRASSES, GROUND COVERS AND VINES--continued							
Boutelona gracilis	Blue grama			MT	1		
Bromus catharticus	Rescue grass			T	1		
B. inermis	Smooth brome			MT	1		
B. marginatus	Mountain brome			MT	1		
Celosia argentea	Celosia			S	8		
Chloris gayana	Rhodes grass			T	1		
Clematis vitalba	Traveler's joy					VS	2
Cynodon dactylon	Bermuda grass			T	1		
Dactylis glomerata	Orchard grass			MT	1		
Dianthus barbatus	Sweet William			S	8		
Distichlis stricta	Saltgrass			T	1		
Elymus canadensis	Canada wild rye			T	1		
E. triticoides	Beardless wild rye			MT	1		
Festuca elatior	Meadow fescue			MT	1		
F. e. arundinacea	Tall fescue			T	1		
F. E. a. 'Kentucky 31'	Kentucky 21 fescue					T	4
F. rubra	Creeping red fescue					S	4
Hedera helix	English ivy					VS	2
Hemerocallis fulva	Tawny day lily	T	5				
Hordeum vulgare	Barley			T	1		
Kochia scoparia	Kochia			T	8		
Lolium perenne	Perennial ryegrass			MT	1		
L. p. 'Norlea'	Norlea perenn. Rye					T	4
Lotus corniculatus	Birdsfoot trifoil	T	5	T	1		
L. illiginosis	Big trefoil			MT	1		
Lycium chinense	Chinese wolfberry					T	2
L. halimifolium	Matrimony vine					T	2
L. ruthenicum						T	2

continued

Botanical Name	Common Name	Gen.	Ref.	Salt Tolerance Soil	Ref.	Spray	Ref.
GRASSES, GROUND COVERS AND VINES--continued							
Medicago carstiensis	Carstien alfalfa	T	5				
M. falcata	Sicklepod alfalfa	T	5				
M. pironae	Pirone alfalfa	T	5				
M. sativa	Prostrate alfalfa	T	5	MT	1		
Melilotus alba	White sweet clover			MT	1		
M. a. annua	Hubam clover			MT	1		
M. indica	Sour clover			MT	1		
M. officinalis	Yellow sweet clover			MT	1		
Parthenocissus quinquefolia	Virginia creeper	T	5			VT	2
Paspalum dilatatum	Dallis grass			MT	1		
Petunia hybrida	Petunia			T	8		
Phalaris arundinacia	Reed canary			MT	1		
P. tuberosa stenoptera	Harding grass			MT	1		
Poa annua	Annual bluegrass					S	4
P. distans	Alkaligrass	T	3				
P. pratensis	Kentucky bluegrass					MT	4
Polygonum reynoutria	Reynoutria fleece flwr.	T	5				
Portulaca grandiflora	Moss rose			T	8		
Potentilla tridentata	Wineleaf cinguefoil	T	5				
Puccinellia nuttaliana	Nuttall alkaligrass			T	1		
Sanguisorba minor	Burnet			S	1		
Secale cereale	Rye			MT	1		
Sorghum vulgare sudanense	Sudan grass			MT	1		
Sporobulus airoides	Alkali sacaton			T	1		
Trifolium arvense	Rabbitfoot clover	T	5				
T. fragiferum	Strawberry clover			MT	1		
T. hydridum	Alsike clover	S	5	S	1		
T. pratense	Red clover	S	5	S	1		
T. repens	White clover	S	5	S	1		
T. r. forma giganteum	Ladino clover			S	1		
Triticum aestivum	Wheat			MT	1		

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