308

THE EFFECT OF ANTITRANSPIRANT APPLICATION TO EASTERN WHITE PINE AND WHITE SPRUCE IN REDUCING DEICING SALT DAMAGE

BY

CHI-TI CHEN

B.Agr., College of Chinese Culture

Taipei, R.O.C., 1973

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Horticulture

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1979

Approved by

Steven M. Still

Major Professor

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

I. INTRODUCTION

During winter, ice and snow accumulation on highway obstructs traffic flow. In order to meet the demand that highways be safe and useable at all times, several mechanical and chemical methods have been used to remove ice and snow. Applying salt as a highway deicing compound has been widely accepted and is more economical than mechanical removal (24).

Sodium chloride (NaCl) and calcium chloride ($CaCl_2$) are the salts primarily used as deicing compounds, and account for the second greatest amount of salt usage in the United States (59). Rate of usage ranges from 200 to 1,000 pounds per two lane highway mile per application (27). A large amount of damage done to evergreen and deciduous woody plants along highways can be attributed to high salt application.

Damage to highway trees is caused either by salt water run off that is absorbed into the plant through the root system or by high speed traffic generating salt mist carried by wind (5,7,9,28-31,63,64). Salt drift causes more damage to evergreen trees than deciduous trees (26,29,38,39).

Construction of physical berriers, application of abrasives instead of salts, leaching of salts from the soil, application of antitranspirants, planting of trees further from highways to avoid salt spray and runoff, and selection of salt tolerant plant species have been done to protect plants from salt damage (4,9,19,45,53,54). Most protective methods are too costly, inefficient, or too late for highway trees to escape salt damage. Antitranspirants may prevent injury caused by aerial salt drift.

Eastern white pine (Pinus strobus L.) and white spruce (Picea glauca Voss) have been found to be susceptible to salt damage (3,9,5,7). The purpose of this investigation was to observe the ability of several antitranspirants to reduce damage from salt spray on over-wintering eastern white pine and white spruce.

II. LITERATURE REVIEW

A. Salt damage to roadside trees.

Deicing is the second largest use of salt in the United States, with usage ranging from 12% of total salt product in America to 21%. Average use for a ten year period (1964-1974) was approximately 15% (59). Ninety-five percent of the salt used for deicing is sodium chloride and 5% calcium chloride (59).

Generally, salt is applied at rates of 200 to 1,000 pounds per two-lane highway mile per application (27) and may be applied several times during the winter. Rich (48) reported that the 20 tons of deicing salt applied on New Hampshire highways for every two-lane mile in 1957 had increased to 30 tons ten years later (1966-1967). Thirty-five tons of NaCl per two-lane mile were applied on the Connecticut Turnpike in 1969 (56). In Maine, 22 to 30 tons of deicing salt were applied per mile of two-lane highway per year (35).

This tremendous amount of deicing salt applied in a relatively small area can be harmful to roadside vegetation (64). In 1957, the New Hampshire Highway Department (48) reported 14,000 dead trees along 3,700 miles of highway. Many of these trees were probably killed due to high salinity conditions. Davidson's (18) survey indicated that approximately 40% of 3,150 pine trees planted along the interstate highway system in Michigan during the fall of 1966 died in the next spring due to winter deicing salt application.

Salt damage symptoms on roadside deciduous trees are: marginal leaf scorch, leaf curl, dying branches in the crown, stunted leaves, premature foliar coloration, defoliation, failure to break bud, and gradual reduction of vigor (30,32,49, 62,63). These symptoms often are not evident until spring growth begins and occasionally not until stress conditions occur in late spring or summer (32,33,49,62,63).

Salt damage symptoms on evergreens are a bluish-green foliage followed by needle tip browning that gradually work its way to the leaf base, resulting in defoliated branches, a lack of vigor and/or eventual death (44,49). These injuries on evergreens become apparent during late winter or early spring during warmer weather (26,38,49).

High concentrations of sodium and chloride ions have been found in injured plant tissue (foliage, root, and twig) and in the soil surrounding the trees (26,28,35,43,45,49,51,52). Lacasse and Rich (34) suggested that the primary injury to roadside maple trees occurred from runoff of deicing salt taken up by the root system. They also observed that hemlock needles turned brown, probably as a direct result of salt spray from passing vehicles in the winter. A report in 1965 (32) using greenhouse experiments concluded that eastern white pine could be injured by salt applied to the foliage or roots.

Wester and Cohen (63) reported that salted snow piled by snowplows over the roots of plants caused more damage to the plants than saltless snow piled over the root zone. The accumulation of salt in the soil apparently plasmolyzed the root tissue, thus preventing proper water absorption resulting in poor foliage and shoot development.

Holmes (30,31) thought that deicing salt increased NaCl concentration in the soil, causing roadside tree damage. His seven years of data indicated little damage occurred on deciduous trees due to the elimination of the salt with leaf abscission in the fall.

Lumis et al. (38,39) observed that plants on the down wind side of the road were damaged to a greater extent than similar plants on the opposite side. They observed that pine branches covered by snow during the winter season were green while higher branches on the same tree were brown. Increased traffic volume and speed were correlated with plant salt damage. The aerial salt spray created by traffic possibly contributes greater damage than salts remaining in the soil (26,28,56).

Although research data have indicated that deicing salt is harmful to roadside vegetation; it is unrealistic to stop its use. However, researchers have proposed various protective methods (4,9,19,45,48,53,54) to reduce salt damage to plants:

1. Mix sand with salt to reduce the amount of salt used.
2. Use abrasives in place of salt.
3. Construct ditches between the edge of the highway and trees so runoff does not come in contact with the root zone.
4. Improve planting soil structure by application of

gypsum ($CaSO_4$).

5. Add activated carbon or charcoal to the soil to neutralize the deicing salt.
6. Leach salt from the root zone on small scale plantings.
7. Protect plant specimens by physical barriers (plywood, burlap, plastic film, etc.).
8. Select tolerant tree species and plant at proper sites.
9. Use antitranspirant to provent salt injury from aerial drift.

Many of these methods are costly and thus only used on small scale plantings; or, are implemented too late to prevent or reduce salt damage on existing roadside trees. Antitranspirant have been promoted as a means for protection of trees against aerial salt drift created by highway traffic.

B. Antitranspirant.

An antitranspirant or antidesiccant is any material applied to plants for retarding transpiration. Three type of antitranspirants have been reported in the literature (14,16,25):

1. Compounds that form a film over the stomata.
2. Chemicals that prevent complete stomatal opening.
3. Materials that reflect incoming radiation from the leaf.

The first type of antitranspirant provides a physical barrier over the leaf. The second tyoe works by affecting the guard cells around the stomata openings. The third type simply reflects the radiation energy from the sun, thereby reducing leaf temperature.

Most commercially available antitranspirants are the film-forming type. They consist of colorless plastics, silicone oils and low viscosity waxes (16,25). Application of antitranspirants has been recommended for several horticultural crop to increase fruit size (15,17), prevent winter desiccation (3,53,55), reduce transplanting shock (12,47,58), increase keeping qualities of cut flowers (40), and protect against aerial salt drift (11,53,54).

Since film-forming antitranspirants provide a physical barrier for the plant, they may act as a protectant against salt spray injury as well as winter desiccation. Bartlett (3) sprayed an antitranspirant on hemlock to reduce the needle injury and needle drop caused by dry winter wind and salt spray. He concluded that evergreen trees and shrubs grown along ocean shorelines would benefit from application of antitranspirants.

C. Eastern white pine and white spruce.

Eastern white pine and white spruce are relatively easy trees to grow and maintain and are used in many landscape plantings (22). Eastern white pine is classified as a salt sensitive plant (5,38,39) while white spruce is reported as having greater tolerance to salt spray than eastern white pine (38,39). Carpenter (7) has classified white spruce as moderately tolerant to salt contaminated soil. Heavy application of deicing salt to highways has caused extensive damage to roadside eastern white pine and white spruce as a result of salt spray injury to the needles (28,38,46,56).

D. Objective.

Since aerial salt drift is created by highway traffic, it eventually becomes a major problem to susceptible evergreen trees along major highways. Film-forming antitranspirants may provide a physical barrier to provent direct salt contact to plant tissue. This study was designed to observe the effectiveness of several antitranspirants in reducing NaCl penetration into plant tissue of eastern white pine and white spruce.

III. MATERIALS AND METHODS

Four-year-old eastern white pine (Pinus strobus L.) and white spruce (Picea glauca Voss.) seedlings were planted during April 1977 into 4 liter plastic containers filled with a growing medium of soil:peat:perlite 1:1:1. Plants were fertilized with 6.3 g/pot Osmocote (18:6:12) at planting, placed outdoors and watered as needed. Supplemental fertilizer, 300 ppm N solution of 20:20:20 Perters solution, was applied weekly.

A. Treatments.

1. Antitranspirant.

Three film-forming antitranspirants Wit Pruf NCF, Vapor Gard, and Exhalt 4-10 at recommended level (1X) and twice (2X) the recommended level were sprayed on 96 eastern white pine and 72 white spruce on November 26, 1977 (Table 1). There were 16 nonsprayed eastern white pine and 12 nonsprayed white spruce. On December 15, 1977, 56 eastern white pine and 42 white spruce (half the study) were transferred to a cold chamber for laboratory studies. An equal number of plants were left outside for comparison. The cold chember (4-8°C) was equipped with fluorescent lighting to provide an illumintion at plant height of 100 ft-candles. Relative humidity was kept at 60-100%.

2. Salt spray.

Twenty-eight eastern white pine and 21 white spruce in cold storage and an equal number of outside were sprayed daily with a

TABLE 1. Antitranspirants, salt treatments, and number of plants used during the experiment.

Treatment			Number of plants	
NaCl	Antitranspirant	Rate	Eastern white pine	White spruce
0	Control	-	8	6
0	Wilt Pruf NCF[a]	1X[d]	8	6
0	Wilt Pruf NCF	2X	8	6
0	Vapor Gard[b]	1X[e]	8	6
0	Vapor Gard	2X	8	6
0	Exhalt 4-10[c]	1X	8	6
0	Exhalt 4-10	2X	8	6
0.25N	Wilt Pruf NCF	1X	8	6
0.25N	Wilt Pruf NCF	2X	8	6
0.25N	Vapor Gard	1X	8	6
0.25N	Vapor Gard	2X	8	6
0.25N	Exhalt 4-10	1X	8	6
0.25N	Exhalt 4-10	2X	8	6
0.25N	No antitranspirant	-	8	6
TOTAL			112	84

[a]Nursery Specialty Products, Inc., P.O. Box 4280, Greenwich, Connecticut 68030; recommended dilution for winter protection 1:5.

[b]Miller Chemical and Fertilizer Co., P.O. Box 333, Hanover, Pennsylvania 17331; recommended dilution for winter protection 1:20.

[c]Kay-fries Chemicals, Inc., Stony Point, N.Y. 10980; recommended dilution for winter protection 1:4.

[d]Label recommended rate for winter protection.

[e]Double the label recommended rate for winter protection.

0.25N NaCl solution for 30 days starting on December 25, 1977. The soil of the sprayed plants was covered to prevent soil contamination. Plants in cold storage were sprayed in a closed cardboard box to avoid drift onto the non-treated plants. Following the 30 days salt spray period, the cold storage tempertture was raised to 18°C for 9 days and then the plants were transferred to the greenhouse on February 3, 1978. Percent needle injury was evaluated every 5th day beginning on February 5. Under greenhouse conditions, the relative humidity varied from 40 to 100% and most often was below 70%; temperature was above 20°C, with high light intensity (3,000-4,000 ft/candle) on a cloudy day. Outside plants were sprayed on the downwind side, 10 feet away from the other plants, and were evaluated for percent needles injury every 25th day starting on January 30, 1978.

B. Determination.

1. Sample collection and determination of amount of salt on the needle surface.

Plant needles, except the new growth, were harvested when the nonsalt sprayed plants all showed new growth. Needles were washed twice for 10 seconds, with 500 ml of deionized distilled water. The salt concentration of the collected 1,000 ml volume was determined with a Solu-Bridge. The needles were again leached with 500 ml deionized distilled water to leach out any remaining salt.

The needles from each eastern white pine were stored 1 plant per bag. However, because of the small amount of white spruce needles, the needles from 3 plants given the same anti-transpirant treatment were placed in a bag. All needles were oven dried at 85°C for 24 hr, and ground though a 40 mesh screen in a Wiley Mill (28).

2. Chloride determination.

Percent chloride was determined by shaking a 0.5 g needle sample in 100 ml of dilute nitric acid (5 ml of fuming nitric acid per 1,000 ml of water) (6,28). After standing 8 hr, the chloride concentration was measured with an Orion solid state chloride electrode (Orion 94-17) and a double junction reference electrode (Orion 90-02) (8,28). Chloride concentration was then converted to percent dry weight of the needle sample.

C. Data Collection.

A randomized complete block design with 2 blocks for eastern white pine and 3 blocks for white spruce on each area (cold storage and outside) was used.

Eastern white pine:

2 plants/treatment x 14 treatment/block
x 2 block = 56 plants/region.

White spruce:

1 plant/treatment x 14 treatment/block
x 3 block = 42 plants/region.

Data for (1) visual rating of percent injury per plant

(0-completely green, 100-completely brown), (2) chloride concentration in the needles, (3) visual rank of salt accumulated on the salt sprayed plants (0-no salt, 4-most salt), and (4) the total salt concentration on the needle surface were recorded.

Analysis of variance and correlation coefficiency were performed using Statistical Analysis System (SAS computer program) (1).

IV. RESULTS AND DISCUSSION

A. Foliage injury.

1. Cold storage-greenhouse plants.

No significant damage occurred on eastern white pine and white spruce treated with antitranspirants without salt treatment except that a low level leaf damage appeared on 2X rate Wilt Pruf treated eastern white pine (Table 2,3) after one week in the greenhouse. The needles of these plants were shriveled, a dull green color, and easily pulled from the plants (Fig. 1). These plants died in the greenhouse. The foliar and plant damage was caused by excess Wilt Pruf application. The heavy antitranspirant film may have completely covered the leaf surface preventing O_2/CO_2 exchange and reducing transpirantion. When the plants were placed under greenhouse conditions the damage to the needles was accelerated. This acceleration may have been due to increased needle temperature from high greenhouse temperature, low humidity (Fig. 2), and a high light intensity. Under greenhouse conditions, nonsalt sprayed plants showed new growth on white spruce at 7 days and on eastern white pine at 12 days.

Eastern white pine and white spruce sprayed with 0.25N NaCl had no visible damage while they were in cold storage. Damage appeared when the plants were placed in the greenhouse (Table 4,5,6). Significant differences were soon observed between treatments for foliar damage and got worse as greenhouse

TABLE 2. Percent injury appearing across time in the greenhouse on eastern white pine sprayed with antitranspirant but not salt before storage and after 50 days of storage. Plants were placed in the greenhouse on February 3, 1978.

Treatment		Time							
Antitranspirant	Rate	12/22/77	1/25/78	2/5/78	2/10/78	2/15/78	2/20/78	2/25/78	3/1/78
Control	-	1.7	2.5	6.0	9.5	15.0	14.5	9.7	11.2b[x]
Wilt Pruf NCF	1X	1.2	4.0	4.5	5.0	13.7	8.2	12.2	11.2b
Wilt Pruf NCF	2X	2.0	5.3	6.3	10.3	26.3	13.8	22.5	22.5a
Vapor Gard	1X	2.0	4.0	3.8	7.0	17.5	8.0	7.3	8.8b
Vapor Gard	2X	2.2	2.5	4.5	4.0	12.7	7.2	6.0	6.2
Exhalt 4-10	1X	2.7	4.5	7.2	8.5	13.5	7.7	13.0	9.2b
Exhalt 4-10	2X	2.2	3.2	6.2	11.7	15.7	13.0	14.0	11.0b

[x]Mean separation within colcuns by Duncan's New Multiple Range test, 5% level.

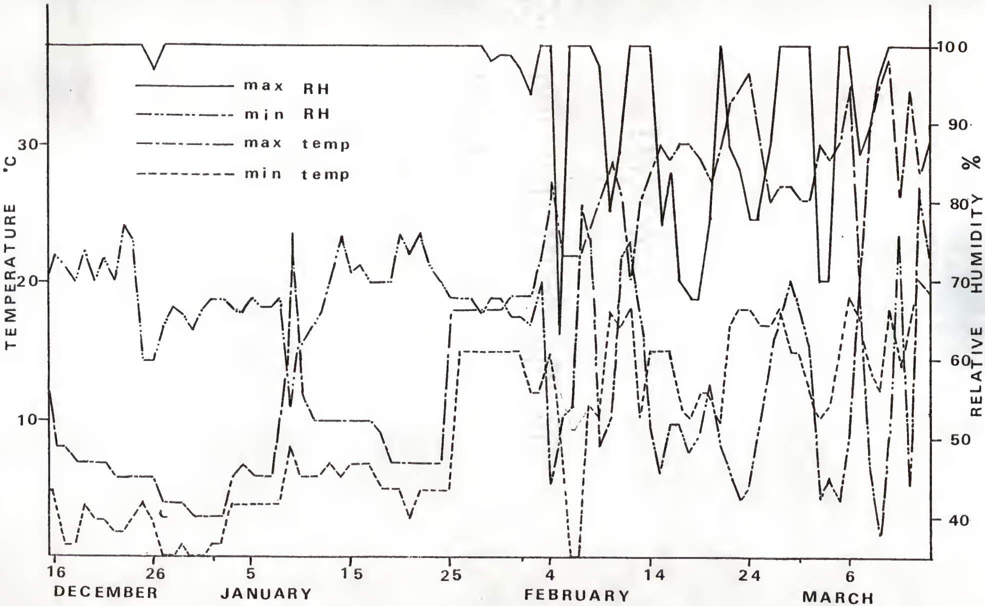
TABLE 3. Percent injury appearing across time in the greenhouse on white spruce sprayed with antitranspirant but not salt before storage and after 50 days of storage. Plants were placed in the greenhouse on February 3, 1978.

Treatment		Time							
Antitranspirant	Rate	12/22/77	1/25/78	2/5/78	2/10/78	2/15/78	2/20/78	2/25/78	3/1/78
Control	-	5.0[x]	5.0	3.3	4.0	5.0	4.7	6.7	5.0
Wilt Pruf NCF	1X	5.7	13.4	9.0	8.7	11.7	9.4	13.4	6.7
Wilt Pruf NCF	2X	4.7	5.0	9.4	4.7	11.7	6.7	8.4	5.0
Vapor Gard	1X	6.3	5.0	7.3	3.6	5.0	4.0	8.3	6.6
Vapor Gard	2X	5.7	5.0	7.4	3.4	4.4	5.0	6.7	5.0
Exhalt 4-10	1X	6.7	6.7	5.7	5.7	6.7	6.7	8.4	5.0
Exhalt 4-10	2X	4.7	5.0	9.0	5.0	6.7	6.7	6.7	5.0

[x]Mean separation within colcumns by Duncan's Multiple Range test, not significant.

Figure 1. Eastern white pine (Pinus strobus L.) treated with Wilt Pruf 2X.

Figure 2. Daily maximum and minimum temperature and relative humidity (RH) in cold storage from December 15, 1977 to February 3, 1978 and greenhouse from February 3, 1978 to March 14, 1978.



max RH
min RH
max temp
min temp
TEMPERATURE °C
30
20
10
RELATIVE HUMIDITY %
100
90
80
70
60
50
40
16
26
5
15
25
4
14
24
6
DECEMBER
JANUARY
FEBRUARY
MARCH

TABLE 4. Percent injury appearing across time in the greenhouse on eastern white pine sprayed with antitranspirant before storage and sprayed with 0.25N NaCl during 30 of 50 days storage. Plants were placed in the greenhouse on February 3, 1978.

Treatment		Time							
Antitranspirant	Rate	12/22/77	1/25/78	2/5/78	2/10/78	2/15/78	2/20/78	2/25/78	3/1/78
Control	-	1.7	2.5	6.0d[x]	9.5f	15.0e	14.5c	9.7c	11.2c
Wilt Pruf NCF	1X	1.7	5.0	21.2bc	55.0bc	82.5ab	96.7a	99.5a	98.5a
Wilt Pruf NCF	2X	1.7	6.0	23.7abc	38.7cd	51.2c	71.2a	86.7a	89.5a
Vapor Gard	1X	1.0	4.3	17.5c	30.0de	41.3cd	46.3b	62.5b	40.0a
Vapor Gard	2X	1.7	6.2	17.5c	17.5ef	26.2de	31.2bc	52.5b	47.5b
Exhalt 4-10	1X	1.5	6.5	31.3a	77.5a	87.5a	94.0a	99.3a	100.0a
Exhalt 4-10	2X	2.0	6.3	30.0ab	71.3ab	86.3ab	96.5a	99.5a	99.0a
No antitranspirant	-	1.5	7.5	22.5abc	53.8bc	70.0b	78.5a	97.3a	91.0a

[x]Mean separation within colcumns by Duncan's New Multiple Range test, 5% level.

TABLE 5. Percent injury appearing across time in the greenhouse on white spruce sprayed with antitranspirants before storage and sprayed with 0.25N NaCl during 30 of 50 days in storage. Plants were placed in the greenhouse on February 3, 1978.

Treatment		Time							
Antitranspirant	Rate	12/22/77	1/25/78	2/5/78	2/10/78	2/15/78	2/20/78	2/25/78	3/1/78
Control	-	5.0	5.0	3.3b[x]	4.0d	5.0d	4.7d	6.7c	5.0e
Wilt Pruf NCF	1X	6.7	10.0	26.7a	65.0a	86.7a	86.7a	94.4a	90.0ab
Wilt Pruf NCF	2X	5.0	6.7	23.3a	60.0ab	70.0ab	87.7a	95.0a	91.7a
Vapor Gard	1X	4.4	5.1	21.7a	43.4abc	50.1abc	51.7bc	56.7ab	60.1bcd
Vapor Gard	2X	4.7	8.4	16.7a	23.4cd	25.0cd	41.7c	65.0ab	45.0d
Exhalt 4-10	1X	4.7	6.7	20.0a	33.4bc	38.4bc	58.4abc	36.7bc	55.0cd
Exhalt 4-10	2X	6.0	11.7	21.7a	53.3ab	71.7ab	73.3abc	78.3a	78.3abc
No antitranspirant	-	7.3	10.0	25.0a	43.3abc	61.6abc	80.0ab	94.6a	88.3ab

[x]Mean separation within columns by Duncan's New Multiple Range test, 5% level.

TABLE 6. Percent injury across time on cold storage plants sprayed with antitranspirants before storage and sprayed with 0.25N NaCl during storage.

Date	% injury	
	Eastern white pine	White spruce
December 22, 1977[x]	1.6a[y]	5.5a
January 25, 1978	5.5a	7.9a
February 5, 1978	21.2b	19.8b
February 10, 1978	44.2c	40.7c
February 15, 1978	57.5d	51.0d
February 20, 1978	66.1e	60.5e
February 25, 1978	75.7f	65.9e
March 1, 1978	73.7f	64.0e

[x]Salt spray began on December 25, 1977 and ended on January 24, 1978, daily for 30 of 50 days in storage. Plants were then placed in greenhouse on February 3, 1978 for observation.

[y]Mean separation within columns by Duncan's Multiple Range test, 5% level.

experiment progressed.

With eastern white pine, differences were noted among treatments (Table 4, 2/5/78), following 2 days of greenhouse conditions. Exhalt 4-10 treated eastern white pine were the first to show salt-induced needle browning. Browning of the needles started at the tip, base, or middle. Symptoms were next noticed on Wilt Pruf treated plants, and finally on Vapor Gard and nonantitranspirant treated plants. Plants treated with Vapor Gard showed significantly less damage than plants treated with Exhalt 4-10.

Following 1 week of greenhouse conditions (Table 4), Vapor Gard treated plants had significantly less injury than Exhalt 4-10, Wilt Pruf 1X, and nonantitranspirant treated plants.

On the 17th day (Table 4), 5 out of 8 Vapor Gard and salt treated eastern white pine (3 of 1X and 2 of 2X), had started new growth (Fig. 3). No buds broke on any other NaCl treated eastern white pine (Fig. 4,5,6). The 5 Vapor Gard treated eastern white pine that had initiated new growth were kept in the greenhouse until April 7, 1978 when the needles were harvested. New growth of the eastern white pine sprayed with 2X level of Vapor Gard ceased before the needles expanded. By April 7, the Vapor Gard 1X treated eastern white pine had fully expanded needles, but had not initiated new root (Fig. 7).

Needle injury on the salt sprayed white spruce first appeared on the tip and proceeded down the entire needle. Leaf damage appeared on all salt treatments during the first 2 weeks

Figure 3. Eastern white pine treated with Vapor Gard (1X, 2X concentration) and sprayed with 0.25N NaCl for 30 days.

Figure 4. Eastern white pine treated with Wilt Pruf (1X, 2X concentration) and sprayed with 0.25N NaCl for 30 days.

Figure 5. Eastern white pine treated with Exhalt 4-10 (1X, 2X concentration) and sprayed with 0.25N NaCl for 30 days.

Figure 6. Eastern white pine sprayed with 0.25N NaCl for 30 days.

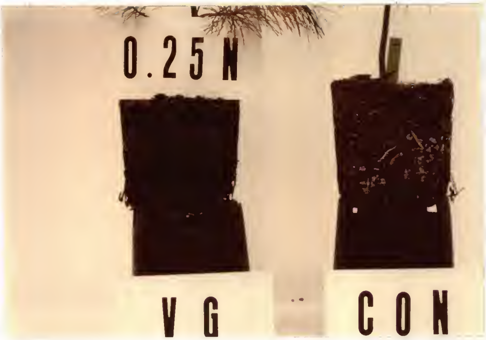


Figure 7. Root growth of eastern white pine treated with Vapor Gard 1X and sprayed with 0.25N NaCl for 30 days (left) compared to the (right).

in the greenhouse and increased steadily. Following 1 week under greenhouse conditions (Table 5), salt sprayed plants treated with the 2X rate of Vapor Gard had less injury than Wilt Pruf or the 2X rate Exhalt 4-10 treated plants. Also, plants treated with Exhalt 4-10 at the 1X rate had less damage than did the 1X rate Wilt Pruf treated plants.

After 2 weeks in the greenhouse, salt sprayed white spruce started new growth, including plants that had more than 65% injury. New growth occurred from axillary buds or from apical buds on the lower branches, while the apical buds on the main stem or upper branches were shriveled and dead. Sodium chloride tended to accumulate on the apical buds, thus giving greater damage in this region.

Injury from salt spray on roadside trees is apparently caused by tissue burn, from contact with highly ionized deicing salt (60). Since salt on the surface tissues of plants might cause an extreme diffusion pressure deficit, death might then be by desiccation after a rapid movement of cell water to the salt concentration on leaves, resulting in deplasmolysis of adjacent cell. Salts might have been absorbed though leaves to cause adverse internal physiological effects (37).

Salt injury symptoms on evergreen trees planted alongside highways do not develop until spring. Our experiments had the same delayed appearance of salt-induced injury.

2. Outside plants.

At the end of the experiment, all the needles of the nonsalt sprayed plants were healthy and dark green, except one eastern white pine treated with Wilt Pruf 2X. This plant died before new growth started (Table 7,8).

Immediately after the 30 day salt spray period, eastern white pine plants had no more injury than control plants. Snow completely covered the containers and some plants for 9 days (Fig. 2, 2/13 to 2/22). After the weather warmed, damage increased rapidly. On February 25 (Table 9) the damage on the Wilt Pruf 1X treated plants was significantly greater than on the other salt treated plants except the Exhalt 4-10 2X treated plants.

From March 21 till the end of the study on April 7 (Table 9), the antitranspirant treated plants sprayed with salt had 74.5% to 99.5% foliar injury; plants having only salt had only 52.5%. Antitranspirants did not provide a protection against salt spray.

Under outdoor conditions, the percent injur on white spruce plants through March 21 was not significantly different between salt sprayed and control plants (Table 10). At the end of this study on April 7, considerable damage had occurred on antitranspirant treated plants. White spruce sprayed with salt but with no antitranspirant had significantly less injury than other salt sprayed plants (Table 10). As with the outside eastern white pine, antitranspirant did not provide any protection for white spruce. This is contrary to the data recorded with the cold storage plants. Two days after spraying

TABLE 7. Percent injury appearing across time on outdoor eastern white pine sprayed with antitranspirants but not salt and stored outside.

Treatment		Time				
Antitranspirant	Rate	12/22/77	1/30/78	2/25/78	3/21/78	4/7/78
Control	-	2.2[x]	7.2	7.5	5.7	4.2
Wilt Pruf NCF	1X	2.7	7.2	11.2	4.7	10.2
Wilt Pruf NCF	2X	2.5	4.3	9.8	27.3	31.0
Vapor Gard	1X	3.2	3.3	7.5	7.2	13.2
Vapor Gard	2X	3.0	4.8	8.5	6.5	11.3
Exhalt 4-10	1X	2.0	5.8	15.0	6.5	8.0
Exhalt 4-10	2X	3.2	5.0	7.5	7.0	6.0

[x]Mean separation within columns by Duncan's New Multiple Range test, not significant.

TABLE 8. Percent injury appearing across time on outdoor white spruce sprayed with antitranspirants but not salt and stored outside.

Treatment		Time				
Antitranspirant	Rate	12/22/77	1/30/78	2/25/78	3/21/78	4/7/78
Control	-	1.7[x]	13.4	20.0	16.7	17.4
Wilt Pruf NCF	1X	5.0	6.7	16.7	13.3	13.3
Wilt Pruf NCF	2X	1.7	10.0	16.7	16.7	13.4
Vapor Gard	1X	1.7	13.4	16.7	16.7	13.4
Vapor Gard	2X	5.0	16.7	16.7	16.7	16.7
Exhalt 4-10	1X	1.7	8.4	15.0	15.0	13.4
Exhalt 4-10	2X	1.7	8.4	13.4	15.0	15.0

[x]Mean separation within colcumns by Duncan's New Multiple range test, not significant.

TABLE 9. Percent injury appearing across time on outdoor eastern white pine sprayed with antitranspirants and sprayed with 0.25N NaCl for 30 days from December 25, 1977 to January 26, 1978 and stored outside.

Treatment		Time				
Antitranspirant	Rate	12/22/77	1/30/78	2/25/78	3/21/78	4/7/78
Control	-	2.2	7.2	7.5d[x]	5.7d	4.2c
Wilt Pruf NCF	1X	1.7	18.7	41.2a	96.2a	97.2a
Wilt Pruf NCF	2X	2.5	12.0	25.8bc	99.3a	99.5a
Vapor Gard	1X	3.2	11.5	19.0cd	95.7a	99.0a
Vapor Gard	2X	3.0	11.3	17.5cd	74.5b	98.8a
Exhalt 4-10	1X	2.0	16.3	27.5bc	96.3a	99.5a
Exhalt 4-10	2X	3.2	19.0	35.2ab	85.2ab	85.5a
No antitranspirant	-	1.5	12.5	25.0bc	53.8c	52.5b

[x]Mean separation within colcumns by Duncan's New Multiple Range test, 5% level.

TABLE 10. Percent injury appearing across time on outdoor white spruce sprayed with antitranspirants and sprayed with 0.25N NaCl for 30 days from December 25, 1977 to January 26, 1978 and stored outside.

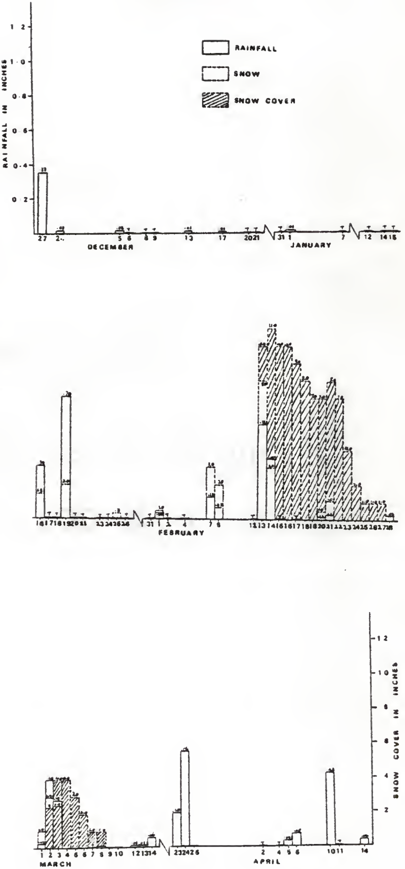
Treatment		Time				
Antitranspirant	Rate	12/22/77	1/30/78	2/25/78	3/21/78	4/7/78
Control	-	1.7	13.4	20.0	16.7	4.7c[x]
Wilt Pruf NCF	1X	5.0	13.3	28.3	53.3	90.3a
Wilt Pruf NCF	2X	1.7	11.7	21.7	26.7	58.4ab
Vapor Gard	1X	3.3	18.3	23.3	28.3	61.6ab
Vapor Gard	2X	1.7	16.7	23.4	31.7	50.0b
Exhalt 4-10	1X	0.0	18.3	30.0	38.3	68.3ab
Exhalt 4-10	2X	1.7	11.7	33.4	48.4	58.4ab
No antitranspirant	-	3.3	11.6	21.6	21.6	20.0c

[x]Mean separation within colcumns by Duncan's New Multiple Range test, 5% level.

antitranspirants, the container media froze, due to low temperatures. A frozen soil enhances winter desiccation more than an unforzer soil (36). For eastern white pine in the soil, cold temperature freezes the upper 20 cm of soil which causes water stress and stops root growth (50). When air temperature between 15°C and -30°C were recorded, the temperature in the center of an exposed 8.8 liter container varied between 15°C and -15°C (65). A similar situation occurred in this experiment, with low temperature from 12°C to -22°C before February 1978 (Fig. 8). The temperature in the center of the 3.8 liter containers should have been lower than in a 8.8 liter container. In any case, the outdoor container media in the trial was frozen though the winter. Since the medium was frozen, the plants could not absorb enough water and the potted eastern white pine and white spruce faced a water deficiency.

A water deficiency enhances salt damage of the plant (38). The smaller amount of salt injury that occurred on the non-antitranspirant treated plants may be because they absorbed more water from the atmosphere and thereby lessened the desiccation damage. Film-forming antitranspirants reduce transpiration by covering the stomata of plants to reduce the water vapor leaving the leaf. However, this effect only works when soil water is available (13). Therefore, the antitranspirant film probably did not reduce plant water loss by transpiration and probably reduced the ability of the plants to absorb additional moisture from the rain or snow (42), thereby causing

Figure 8. Daily rain and snow fall at Manhattan, Kansas from November 26, 1977 to April 14, 1978.


RAINFALL
SNOW
SNOW COVER
RAINFALL IN INCHES
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
SNOW COVER IN INCHES

the plants to dessicate further.

B. Chloride content.

The chloride content of nonsalt-sprayed eastern white pine in cold storage ranged from 0.05 to 0.10% while outdoor plants had a range of 0.09 to 0.15% (Table 11). The antitranspirants had no effect on chloride content. Normal chloride levels in roadside eastern white pine are 0.02 to 0.24% in dry weight (25,26). The results here with nonsalt sprayed eastern white pine under cold storage-greenhouse and outdoor conditions corresponds with this figure. Nonsalt sprayed white spruce had a chloride content ranging from 0.03 to 0.09% (in dry wt. per sample) for cold storage-greenhouse plants and 0.04 to 0.05% for outdoor plants (Table 12).

High chloride concentration in plant tissue is considered a major cause for injury to honeylocust (20), English ivy (21), Norway maple (62), and sugar maple (31). Many species show partial necrosis or complete kill by chloride content of 0.5% or greater. Eastern white pine will show injury when chloride is at least 0.38% (55). Percent injury was found highly correlated with chloride content (Table 13). This high correlation of chloride content with plant injury (Table 13) indicate chloride is one of the major elements causing plant damage in this study.

Each plant sprayed with salt had an extremely high chloride content (Table 12,14). Cold storage eastern white pine

TABLE 11. Chloride content of antitranspirant treated eastern white pine (mean of 32 plants).

Treatment		Cl content (% oven dry wt.)	
Antitranspirant	Rate	Cold storage	Outdoor
Control	-	0.08[x]	0.10
Wilt Pruf NCF	1X	0.06	0.10
Wilt Pruf NCF	2X	0.08	0.10
Vapor Gard	1X	0.10	0.15
Vapor Gard	2X	0.05	0.09
Exhalt 4-10	1X	0.07	0.15
Exhalt 4-10	2X	0.06	0.10

[x]Mean separation within colcumns by Duncan's New Multiple Range test, 5% level.

TABLE 12. Chloride concentration of cold storage and outdoor stored white spruce sprayed with 0.25N NaCl for 30 days.

Treatment			Cl content	
NaCl	Antitranspirant	Rate	Cold storage	Outdoor
0	Control	-	0.05[x]	0.05
0	Wilt Pruf NCF	1X	0.09	0.05
0	Wilt Pruf NCF	2X	0.04	0.04
0	Vapor Gard	1X	0.05	0.04
0	Vapor Gard	2X	0.03	0.05
0	Exhalt 4-10	1X	0.04	0.05
0	Exhalt 4-10	2X	0.05	0.05
0.25N	Wilt Pruf NCF	1X	2.88	1.11
0.25N	Wilt Pruf NCF	2X	2.56	0.53
0.25N	Vapor Gard	1X	2.66	0.47
0.25N	Vapor Gard	2X	2.26	0.52
0.25N	Exhalt 4-10	1X	1.15	0.61
0.25N	Exhalt 4-10	2X	2.42	0.93
0.25N	No antitranspirant	-	2.38	0.18

[x]% oven dry wetght per sample.

TABLE 13. Correlation between chloride content and percent injury on eastern white pine and white spruce in cold storage and outside storage sprayed with 0.25N NaCl for 30 days.

	Eastern white Pine		White spruce	
	Cold storage Cl content	Outdoor Cl content	Cold storage Cl content	Outdoor Cl content
% injury				
	0.88293[x]	0.79948	0.81769	0.86154
	0.0001	0.0001	0.0004	0.0001

[x]Spearman correlation coefficients / Prob R under HO=0
N=32 for eastern white pine, 48 for white spruce.

TABLE 14. Chloride content of antitranspirant treated eastern white pine sprayed with 0.25N NaCl for 30 days.

Treatment		Cl content (% oven dry wt.)	
Antitranspirant	Rate	Cold storage	Outdoor
Control	-	0.08d[x]	0.10e
Wilt Pruf NCF	1X	4.89ab	2.41a
Wilt Pruf NCF	2X	3.26bc	2.14ab
Vapor Gard	1X	2.19c	1.96abc
Vapor Gard	2X	3.13bc	1.46bcd
Exhalt 4-10	1X	5.60a	1.37cd
Exhalt 4-10	2X	4.33ab	1.58bcd
No antitranspirant	-	3.47bc	1.09d

[x]Mean seoaration within colcumns by Duncan's New Multiple Range test, 5% level.

contained 1.64 to 5.94% chloride and outdoor eastern white pine contained 0.94 to 2.20% chloride (Table 14). This chloride content is much higher than the previously reported 1.13 to 1.67% in roadside eastern white pine which had 70 to 90% deicing salt injury (26).

The Exhalt 4-10 1X treated cold storage eastern white pine had significantly higher content than plants treated with non-antitranspirant (Table 14). The Exhalt 4-10 and Wilt Pruf 1X treated plants had higher chloride content than Vapor Gard 1X. Wilt Pruf and Vapor Gard 1X treated eastern white pine under outdoor conditions had significantly higher chloride contents than non-antitranspirant treated eastern white pine (Table 14).

The chloride concentration of salt-sprayed white spruce varied from 1.15 to 2.88% under cold storage to 0.18 to 1.11% under outdoor conditions (Table 12). Salt tolerant roadside trees can withstand above normal amounts of chloride in their leaves or have other mechanisms to avoid accumulation in the leaves (52). The lower concentration of chloride in white spruce than in eastern white pine may be due to mechanisms which reduce chloride accumulation.

Outdoor plants sprayed with salt had significantly lower chloride contents in the needles than plants placed in cold storage and then in the greenhouse (Table 15). During the salt spray period outside, 16 days of rain or snow were recored (Fig. 8) and the precipitation rangeed from a trace to 3 inches on the ground. Snow and rain might have washed off the salts,

TABLE 15. Comparison of chloride concentration in leaves of cold storage and outdoor eastern white pine. Plants were sprayed with antitranspirants before salt treatment (include plants not sprayed antitranspirant but sprayed salt).

Region	Cl content (% oven dry wt.)	
	0.25N NaCl sprayed	No salt sprayed
Cold stored[1]	3.37a[x]	0.07
Outdoor stored[2]	1.15b	0.11

[1]Plants first were placed in cold storage for 50 days and for 30 days 0.25N NaCl spray was applied in storage. Plants were then placed in greenhouse for observation until new growth started.

[2]Plants remained outside through out experiment. For 30 days, 0.25N NaCl spray was applied during the same time as application to cold stored plants.

[x]Mean separation within colcumns by Duncan's New Multiple Range test, 5% level.

resulting in less accumulation on outdoor plants. Salt accumulated on cold storage plants throughout the experiment and was not removed.

C. Salt tolerance of eastern white pine and white spruce.

White spruce has been listed as being more tolerant of salt spray than eastern white pine (38). It is also moderately tolerant to salt contaminated soil (7). Antitranspirant effects vary with different plant species (58). Therefore, it is understandable that chloride content and percent injury differ between white spruce and eastern white pine. All the cold storage and outside white spruce treated with salt had new growth. No damage was observed on that new growth at the end of the experiment.

Lumis (38) reported that the bluer the color of spruce needles, the greater the resistance to salt spray. He conclude that the waxy cuticle that contains the blue color aided in prevention of salt damage. I observed that antitranspirant sprays on white spruce needles turned the needles a shiny oily green and lowered the intensity of blue color. A decrease in this intensity of color may have decreased the natural protection of the white spruce.

Eastern white pine has a thinner cuticle and epidermis, and a thin, noncontinuous hypodermis than Australian pine (Pinus nigra Arnold) and Japanese black pine (Pinus thunbergii Parl). Therefore, it is more sensitive to aerial salt spray than

Australian pine and Japanese black pine (2,23). Possibly because of the anatomical and morphological characteristics of the needle, the salt solution did not spread evenly over the surface but instead formed droplets on the surface of the needles of the nonantitranspirant treated plants. These salt droplets dropped easily from the plants when the twigs were shaken by the wind. When the salt solution was sprayed on antitranspirant treated white spruce, the solution spread evenly over the needle surface, and covered the entire needle surface, providing a larger contact area. This could explain why there was greater salt injury in antitranspirant sprayed plants.

D. Antitranspirants.

Application of antitranspirants did not significantly reduce damage to eastern white pine and white spruce from salt spray. Antitranspirants applied to outside eastern white pine and white spruce even increased the damage (Table 9). However, Vapor Gard protected the cold storage eastern white pine against salt damage. The significantly higher visual rank of salt accumulation on the needle surface and total salt on the needle surface on Vapor Gard sprayed plants coupled with low needle injury indicated Vapor Gard protected the plants somewhat by not increasing salt movement into plants (Table 16). Previous research (53) has show that Vapor Gard was successful in reducing salt damage on eastern white pine. But in this study, needle chloride content did not decrease in Vapor Gard

TABLE 16. Comparison of chloride concentration, percent injury, total salt on needle surface, and visual rank of salt accumulation on cold stored eastern white pine treated with 3 antitranspirants and sprayed with 0.25 N NaCl for 30 days.

Antitranspirant	Rate	Cl content[a]	% injury[b]	Total salt[c]	Rank[d]
Control, no salt	-	0.08d[x]	11.2c	0.00d	0.0f
Wilt Pruf NCF	1X	4.89ab	98.5a	0.07c	1.8d
Wilt Pruf NCF	2X	3.2bc	89.5a	0.06cd	2.4c
Vapor Gard	1X	2.19c	40.0b	0.10b	3.0b
Vapor Gard	2X	3.13cd	47.5b	0.14a	3.4a
Exhalt 4-10	1X	5.60a	100.0a	0.06cd	1.1e
Exhalt 4-10	2X	4.33ab	99.0a	0.09bc	2.1cd
No antitranspirant	-	3.47bc	91.0a	0.03d	1.4e

[a]% oven dry wt.

[b]% needle brown on 3/1/78.

[c]x 10^{-2}M per g fresh wt.

[d]Visual rank 1-least to 4-most of salt accumulation on eastern white pine needles.

[x]Mean separation within columns by Duncan's New Multiple Range test, 5% level.

treated plants. High chloride concentration would kill plants eventually.

Spraying 0.25N NaCl on plants for 30 days deposited nearly 7.5N NaCl on the plant surface. Cold storage plants carried this amount of salt in warm greenhouse condition. No higher plants can survive salt concentration in this range (61). Apparently, antitranspirants have no effect against salt at these high levels and long period.

Under these experimental conditions, Wilt Pruf and Exhalt 4-10 are not capable of reducing damage from salt spray on eastern white pine and white spruce.

Futher research is necessary to determine if antitranspirants can reduce salt damage at a lower concentration of salt, and to determine if there is a time limitation on the ability of the antitranspirant to prevent salt movement into plant tissue. A long term lower salt concentration application or deposit may provide similar conditions to roadside environments and be useful in determining the efficiency of an antitranspirant in protecting eastern white pine and white spruce against salt damage.

LITERATURE CITED

1. Barr, A. J., J. H. Goodnight, J. P. Sall, and J. T. Helwig. 1976. A user's guide to SAS 76. SAS Ins. Inc. 329 pp.

2. Barrick, W. E., J. A. Flore, and H. Davidson. 1976. Surface morphology of selected _Pinus_ Species as related to deicing salt spray injury. _HortScience_ 11:297 (Abstr.).

3. Bartlett, R. A. 1962. Spraying trees and shrubs for winter damage protection. _Trees_ 23:13.

4. Bernstein, L., L. E. Francois, and R. A. Clark. 1972. Salt tolerance of ornamental shrubs and ground covers. _J. Am. Soc. Hort. Sci._ 97:550-556.

5. Blaser, R. E. 1976. Plants and de-icing salt. _Am. Nurseryman_ 144(12):8-9 & 48-53.

6. Brown, J. G. and R. K. Jackson. 1955. A note on the potentiometric determination of chloride. _Proc. Am. Soc. Hort. Sci._ 65:187.

7. Carpenter, E. D. 1970. Salt tolerance of ornamental plants. _Am. Nurseryman_ 131(2):12 & 54-71.

8. Cantliffe, D. J., G. E. MacDonald, and N. H. Peck. 1970. The potentiometric determination of nitrate and chloride in plant tissue. New York's Food and Life Sci. Bul. N. Y. State Agr. Exp. Sta. No. 3 7 pp.

9. Chrometzka, P. 1974. The salt tolerance of plants. _Deutsche Baumschule_ 26(11):256-257 (Abstr.).

10. Davenport, D. C. 1972. Relative water content of leaves underestimation caused by antitranspirant film. _J. Exp. Bot._ 23:651-654.

11. Davenport, D. C., P. E. Martin, and R. M. Hagan. 1969. Antitranspirants uses and effects on plant life. _Calif. Agr._

23(5): 14-16.

12. Davenport, D. C., P. E. Martin, and R. M. Hagan. 1972. Antitranspirants for conservation of leaf water potential of transplanted citrus trees. HortScience 7:511-512.

13. Davenport, D. C., P. E. Martin, and R. M. Hagan. 1973. Effect of antitranspirant on water use by highway oleander (Nerium oleander L.) plantings. J. Am. Soc. Hort. Sci. 98: 421-425.

14. Davenport, D. C., K. Uriu, N. A. Fisher, and R. M. Hagan. 1971. Antitranspirants----effects and uses in horticulture. Am. Hort. Mag. 50:110-113.

15. Davenport, D. C., K. Uriu, and R. M. Hagan. 1972. Sizing cherry fruit with antitranspirant sprays. Calif. Agr. 26(8) :9-10.

16. Davenport, D. C., K. Uriu, and R. M. Hagan. 1974. Effects of film antitranspirants on growth. J. Exp. Bot. 25:410-419.

17. Davenport, D. C., K. Uriu, P. E. Martin, and R. M. Hagan. 1972. Antitranspirants increase size, reduce shrivel of olive fruit. Calif. Agr. 26(7):6-8.

18. Davidson, H. 1970. Pine mortality along Michigan highways. HortScience 5:12-13.

19. Demeritt, M. E., jr. 1970. Prospects for selecting and breeding trees resistant to deicing salt. Proc. Northeastern Forest Tree Improv. Conf. 20:130-140.

20. Dirr, M. A. 1974. Tolerance of honeylocust seedlings to soil applied salts. HortScience 9:53-54.

21. Dirr, M. A. 1975. Effects of salts and application methods on English ivy. HortScience 10:182-184.

22. Dirr, M. A. 1975. Manual ofwoody landscape plant: their identification, ornamental characters, culture, propagation

and uses. Stipes Pub. Co. Champaign. Ill. 552 pp.

23. Dirr, M. A., W. E. Splittstoesser, and M. C. Chu. 1976. Anatomical characteristics of _Pinus thunbergli_ Parl. and _Pinus strobus_ L. needles, and their relationship to the salt resistance of susceptiblity of the two species. _HortScience_ 11:297 (Abstr.).

24. Field, R., E. J. Struzesk, jr., H. E. Masters, and A. N. Tafuri. 1973. Water pollution and associated effect from street salting. Environmental Protection Technology Series 50 pp.

25. Gale, J., R. M. Hagan. 1966. Plant antitranspirants. _Ann. Rev. Plant Physiol._ 17:269-282.

26. Hall, R., G. Hofstra, and G. P. Lumis. 1972. Effects of deicing salt on eastern white pine: foliar injury, growth supression and seasonal changes in foliar concentrations of sodium and chloride. _Can. J. Forest._ Res. 2:244-249.

27. Hanes, R. E., L. W. Zelanzy, and R. C. Blaser. 1970. Effects of deicing salts on water quality and biota. Nat. Acad. Sci. Hyw. Res. Board. Rept. 91. 70 pp.

28. Hofstra, G. and R. Hall. 1971. Injury on roadside trees: leaf injury in pine and white cedar in relation to foliar levels of sodium and chloride. _Can. J. Bot._ 49:613-622.

29. Hofstra, G. and G. P. Lumis. 1975. Levels of deicing salt producing injury on apple tree. _Can. J. Plant Sci._ 55:113-115.

30. Holmes, F. W. 1961. Salt injury to trees. _Phytopathlogy_ 51: 712-718.

31. Holmes, F. W. and J. H. Barker. 1966. Salt injury to trees. II. Sodium and chloride in roadside sugar maples in Massachusetts. _Phytopathology_ 56:633-636.

32. Kotheimer, J., C. N. Niblett, and A. E. Rich. 1965. Salt

injury to roadside trees II, a progress report. Forest Notes Spring 1965. No.85:3-4.

33. Koziowski, T. T. 1971. Growth and development of trees. Vol. I. Seed germination, ontogeny, and shoot growth. Academic Press. N.Y. and London 443 pp.

34. Lacasse, N. L. and A. E. Rich. 1964. Maple decline in New Hampshire. Phytopathology 54:1071-1075.

35. Langille, A. R. 1976. One season's salt accumulation in soil and trees adjacent to a highway. HortScience 11:575-576.

36. Larcher, W. 1975. Physiological plant ecology. Spring-Verlag. Berlin, Heidelberg, and N.Y. 252 pp.

37. Levitt, J. 1972. Responses of plants to environmental stresses. Academic Press. N.Y. and London 697 pp.

38. Lumis, G. P., G. Hofstra, and R. Hall. 1973. Sensitivity of roadside trees and shrubs to aerial drift of deicing salt. HortScience 8:475-477.

39. Lumis, G. P., G. Hofstra, and R. Hall. 1975. Salt damage to roadside plants. J. Abr. 1:14-16.

40. Martin, J. D. 1974. Antitranspirants and their possible uses in floriculture. Maryland Florist No.190:1-9.

41. Martin, J. D. and C. B. Link. 1973. Reducing water loss of potted chrysanthemums with pre sale application of anti-transpirants. J. Am. Soc. Hort. Sci. 98:303-306.

42. Mirov, N. T. 1967. The genus Pinus. The Rondal Press Co. N.Y. 602 pp.

43. Monk, R. and H. B. Peterson. 1962. Tolerance of some trees and shrubs to saline conditions. Proc. Am. Soc. Hort. Sci. 81:556-561.

44. Monk, R. W. and H. H. Wiebe. 1961. Salt tolerance and

protoplasmic salt hardiness of various woody and herbaceous ornamental plants. Plant Physiol. 36:378-382.

45. Piatt, J. R. and P. D. Kranus. 1974. Road and site charact-erics that influrence road salt distribution and damage to roadside aspen trees. Water, Air, and Soil Pollution 3:301-304.

46. Poljakoff-Mayber, A. and J. Gale. 1975. Plants in saline environments. Spring-Verlag. Berlin, Heidelberg, and N.Y. 213 pp.

47. Reisch, K. W., E. M. Smith, and L. C. Chadwick. 1964. The use of anti-desiccants in eastablishing liners. Proc. Int. Plant Prop. Soc. 14:88-95.

48. Rich, A. E. 1972. Effects of salt on eastern highway trees. Am. Nurseryman 135(11):36-42.

49. Rich, A. E. and N. L. Lacusse. 1964. Salt injury to road-side trees. Forest Notes Winter 1963-1964 No.80:3-5.

50. Romberger, J. A. 1963. Meristems, Growth, and development in woody plants. USDA. Forest Service Tech. Bul. 1293. 214 pp.

51. Shortle, W. C., J. B. Kotheimer, and A. E. Rich. 1972. Effect of salt injury on shoot growth of sugar maple, Acer saccharum. Plant Dis. Rept. 56:1004-1007.

52. Shortle, W. C. and A. E. Rich. 1970. Relative sodium chloride tolerance of common roadside trees in southeastern New Hampshire. Plant Dis. Rept. 54:360-362.

53. Smith, E. M. 1971. Some aspects of the use of anti-desicc-ants to prevent winter injury. Arborist's News 36(4):37-38.

54. Smith, E. M. 1975. Tree stress from salts and herbicides. J. of Arboriculture 1(11):201-205.

55. Smith, E. M., L. C. Chadwick, and K. W. Reisch. 1966. The use of anti-desiccants in reducing transpiration and pro-

tecting ornamental plants against winter injury. Proc. Am. Soc. Hort. Sci. 88:703-707.

56. Smith, W. H. 1970. Salt contamination of white pine planted adjacent to an interstate highway. Plant Dis. Rept. 54: 1021-1025.

57. Snell, W. H. and N. O. Howard. 1922. Notes on chemical injuries to eastern white pine (Pinus strobus L.). Phytopathology 12:362-368.

58. Snyder, W. E. 1964. The effect of several antitranspirant materials on apparent transpiration of selected ornamental plants. Proc. Int. Plant Prop. Soc. 14:227-235.

59. Staff of Bureau of Mines. 1975. Mineral facts and problems. Bureau of Mines Bul. 667. U.S. Dept. of Interior. p.922-927.

60. Sucoff, E. 1975. Effect of deicing salts on woody vegetation along Minnesota roads. Minn. Agr. Exp. Sta. Tech. Bul. 303. 52 pp.

61. Waisel, Y. 1972. Biology of halophytes. Academic Press. N.Y. and London 395 pp.

62. Walton, G. S. 1969. Phytotoxicity of NaCl and $CaCl_2$ to Norway maples. Phytopathology 59:1412-1415.

63. Wester, H. V. and E. E. Cohen. 1968. Salt damage to vegetation in the Washington, D. C. area during the 1966-1967 winter. Plant Dis. Rept. 52:350-354.

64. Westing, A. H. 1969. Plants and salt in roadside environment. Phytopathology 59:1174-1181.

65. Wiest, S. C., G. L. Good, and P. L. Stepokus. 1976. Analysis of thermal environments in polyethylene over wintering structures. J. Am. Soc. Hort. Sci. 101:687-692.

ACKNOWLEDGEMENTS

I wish to express my appreciation to my major Professor Dr. Steven M. Still, for his guidance, patience, and encouragement throughout my graduate study.

Sincere appreciation are extended to Dr. Robert J. Campbell and Dr. Charles E. Long for their valuable advice and suggestions. I would like to thank Dr. George A. Milliken, Associate Professor of Statistics, for his assistance in statistical analysis.

Special thanks to Miss Wan-Ju Hung for her encouragement and spiritual support during the past two years. I also wish to express my appreciation to all others who have helped me in this research in numerous ways at one time or another.

Finally, I am forever indebted and grateful to my parents whose encouragement and sacrifice made my graduate studies possible.

THE EFFECT OF ANTITRANSPIRANT
APPLICATION TO EASTERN WHITE PINE AND WHITE SPRUCE
IN REDUCING DEICING SALT DAMAGE

BY

CHI-TI CHEN

B.Agr., College of Chinese Culture
Taipei, R.O.C., 1973

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Horticulture
KANSAS STATE UNIVERSITY
Manhattan, Kansas

1979

Ninety-six out of 112 4-year-old eastern white pine (Pinus strobus L.) and 72 out of 84 white spruce (Picea glauca Voss) seedlings were sprayed with the following film-forming antitranspirants: Vapor Gard, Wilt Pruf, and Exhalt 4-10 at 1X (manufacturer's recommended rate for winter protection) and 2X (double 1X rate) on November 26, 1977. Three weeks later, half of these plants were placed in cold storage. The rest remained outdoors. After 30 days, salt treatments were sprayed on both the cold storage and outside plants with 0.25N NaCl applied daily starting on December 25, 1977. The plants which were kept in cold storage were placed in the greenhouse for observation until the control plants started new growth. The outdoor plants remained outside for observation until the outside control plants started new growth.

Injury occurred on salt sprayed plants. The cold storage and outside plants both had high chloride content (0.94 to 5.94 % of oven dry wt. in eastern white pine and 0.18 to 2.88% of oven dry wt. in white spruce) in the needles. Antitranspirants did not provide a better salt protection for eastern white pine and white spruce trees under these experimental conditions.

Vapor Gard treated eastern white pine trees were the slowest to produce needle browning under both outdoor and greenhouse conditions. Eastern white pine trees treated with Vapor Gard under greenhouse conditions broke bud. Comparison of percent injury, total salt on needle surfaces, and visual rank of salt accumulation on cold storage eastern white pine trees treated with Vapor Gard had significantlt less injury and higher salt crystallization on the needle surfaces. It was observed that Vapor Gard might protect plants from salt spray but not at high levels.