RELATIVE SUSCEPTIBILITY OF THIRTEEN PINE SPECIES TO SODIUM CHLORIDE SPRAY

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Abstract. *Seedlings of 13 pine species were sprayed with* either NaCl spray or distilled water for 3 consecutive winters. *Pinus thunbergii, P. ponderosa,* and *Pinus nigra* were generally most tolerant, with the least foliar injury, best survival, and least growth reduction. *Pinus strobus, P. banksiana, P. cembra, P. peuce,* and *P. densiflora* were most susceptible. Species intermediate in susceptibility were *P. strobiformis, P. aristata, P. parviflora, P. resinosa,* and *P. sylvestris.* Species with the lowest internal sodium and chloride levels after treatment generally were most tolerant to the salt spray.

It is now well documented that salt used for deicing of streets and highways can injure many woody species (3, 5, 7, 16). Trees and shrubs can be injured by salt spray, by salt that leaches into the soil or by a combination of these two (4, 18, 20).

Pine species are planted in large numbers along streets and highways in the United States and in other countries. Injury to pines by deicing salts is very often caused by salt spray (1, 2, 3, 4, 6, 7, 11, 12, 14, 15, 17). It is important to learn which pine species are most suitable for salt-exposed sites. A previous one-year study showed variation among 5-needled pines in their short-term response to salt spray (19). In the present study, the relative tolerance of 13 pine species to salt spray was evaluated for more than 3 years.

Materials and Methods

Species used were Japanese black pine (*Pinus thunbergii*), ponderosa pine (*Pinus ponderosa*), Austrian pine (*Pinus nigra*), southwestern white pine (*Pinus strobiformis*), Swiss stone pine (*Pinus cembra*), Japanese red pine (*Pinus densiflora*), bristlecone pine (*Pinus aristata*), Japanese white pine (*Pinus parviflora*), Balkan pine (*Pinus peuce*), red pine (*Pinus resinosa*), Scotch pine (*Pinus sylvestris*), jack pine (*Pinus banksiana*), and eastern white pine (*Pinus strobus*). Seedlings 31-46 cm tall of these species were grown in 4.7 L pots in a 2:2:1 (v/v/v) peat: perlite: soil mix, in a lath house. Seedlings were arranged in a split plot design in 2 blocks, with salt or water spray representing major plots and species representing minor plots. there were 24 seedlings of each species for each treatment (salt or water-spray). Plastic bags kept salt out of the soil mix, and plastic sheets separated salt water and plain water plots.

Plants were sprayed in late winter or early spring for 3 consecutive years. Some seedlings were sprayed with distilled water only as controls. In year one, the other seedlings were sprayed to run-off with distilled water either with or without 2% NaCl solution once daily from Monday through Friday for 4 weeks (of March 3, March 10, March 24, and March 31), then with 10% NaCl on April 14, 15, and 16. In year two, they were sprayed with 10% NaCl for 5 days per week for 2 weeks beginning March 25, and for 2 days in mid-April. In year three they were sprayed with a 20% NaCl solution for a total of 10 days during the weeks of March 8 and March 22. Foliar symptoms were evaluated by estimating the percent chlorosis and necrosis on the needles of each seedling; data on symptoms were recorded the first year 2 weeks, 4 weeks, and 17 weeks after spraying ended. Survival was recorded 17 weeks, 1, 2, and 2½ years after the final spray of the first year. New yearly growth was measured after the second, third, and fourth growing season.

Four weeks after completion of the first year's spraying, needle samples were taken from needles throughout each seedling for determination of sodium and chloride levels. External chloride was removed by two 1-min rinses in 150 ml of distilled, deionized water. Needles were then oven-dried (70°C for 48 hrs) and weighed.

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Dried needles were ground to a 20-mesh size using a Wiley mill. Chloride was determined by the method of La Croix *et al* (9), in which a specific ion electrode is used to determine the endpoint of $AgNO_3$ titration. Sodium was analyzed with an inductively coupled plasma spectrograph at the Research Extension Analytical Laboratory, OARDC, Wooster, Ohio.

Results

Survival significantly decreased for many species over time (Table 1). Survival of *P. strobus, P. resinosa, P. aristata,* and *P. densiflora* decreased within 17 weeks after the first year's spraying. After 2½ years, survival of only *P. strobiformis, P. nigra, P. thunbergii,* and *P. ponderosa* had not significantly decreased in response to the salt application. In contrast, survival of *P. cembra, P. banksiana, P. strobus, P. peuce,* and *P. aristata* was less than 20 per cent of control seedlings' survival.

The characteristic symptom of injury was browning of the needles that began at the tips and progressed towards the base. Significant differences in foliar symptoms among species appeared 2 weeks after the first salt application was made, and were quite large 15 weeks later (Table 1). *P. strobus* showed the most symptoms, whereas *P. thunbergii, P. ponderosa* and *P. nigra* showed the least symptoms. Other species showed pronounced injury, but still less than that of *P. strobus. Pinus ponderosa* showed the lowest and *P. strobus* the highest concentrations of needle surface chloride, internal chloride, and internal sodium (Table 2). *Pinus strobiformis, P. thunbergii,* and *P. cembra* also had low levels of needle surface chloride. *Pinus ponderosa, P. cembra, P. strobiformis, P. nigra,* and *P. thunbergii* were low in internal chloride and internal sodium whereas *P. strobus, P. sylvestris, P. peuce,* and *P. parviflora* were high. In a correlation analysis of data, we found that high levels of foliar

Table 1. Foliar symptoms and survival of 13 pine species subjected to NaCl spray

Species	*Average symptoms (%)^z (treated minus control) Time after the first year's spraying ended*			*Survival of treated plants (expressed as % survival of control plants)^y Time after the first year's spraying ended*			
	2 weeks	*4 weeks*	*17 weeks*	*17 weeks*	*1 year*	*2 years*	*2½ years*
P. thunbergii	0 a	0 a	3 a	100	100	89	89
P. ponderosa	1 ab	2 ab	6 ab	100	95	95	95
P. nigra	5 bc	3 abc	5 ab	95	85	89	89
P. strobiformis	6 bcd	6 bcd	37 bc	90	80	75	65
P. cembra	6 bcd	5 bcd	24 abc	80	59*	47*	6*
P. densiflora	7 cd	11 cde	27 abc	57*	46*	32*	32*
P. aristata	7 cd	21 e	43 c	50*	43*	38*	17*
P. parviflora	11 cde	25 e	46 c	63	71	73	40*
P. peuce	12 cde	22 e	28 abc	67	50*	33*	17*
P. resinosa	14 de	17 de	42 c	47*	42*	37*	26*
P. sylvestris	14 de	23 e	33 bc	90	80	70*	60*
P. banksiana	18 ef	17 de	44 c	68	44*	22*	11*
P. strobus	27 f	45 f	85 d	40*	40*	25*	15*

^{z} Mean separation within columns by Duncan's New Multiple Range Test, 5% level. Numbers followed by the same letter within columns not considered significantly different.
^{y} An asterisk indicates a significant decrease at the 5% level in the number of seedlings surviving the salt spray compared to those surviving the water spray treatment.

sodium and chloride were significantly associated across species with less new growth, more symptoms, and low survival.

Height growth was most suppressed by salt in *P. strobus, P. densiflora, P. banksiana,* and *P. cembra,* and was least suppressed in *P. nigra, P. ponderosa,* and *P. thunbergii* (Fig. 1). These latter species showed greater suppression of new growth the second year after spraying began than in the third and fourth years.

Discussion

Salt tolerance (best survival, least foliar symptoms, and least growth reduction — i.e., *Pinus thunbergii, P. ponderosa, P. nigra)* accompanied low internal chloride and sodium. The highly susceptible species (with poor susceptible high foliar injury, and great growth reduction) were *P. strobus, P. banksiana, P. cembra, P. peuce,* and *P. densiflora.* The intermediates were *P. strobiformis, P. aristata, P. parviflora, P. resinosa,* and *P. sylvestris.*

In this study, *Pinus ponderosa* appeared very salt-tolerant; it deserves more testing wherever salt-spray occurs. *P. strobiformis* was the most salt-tolerant 5-needled pine. It could replace *P. strobus* on salt-spray sites.

Most species with low internal sodium and chloride levels tolerated salt spray. We (19) and others (6,7) found this pattern also in earlier, shortterm salt studies of pines.

One species, *P. cembra,* shows anomalous results: low levels of needle surface chloride, internal chloride, and internal sodium, yet the most severely reduced growth and survival 3 years after treatments. *Pinus cembra* may exclude most of these ions but be injured by extreme sensitivity to those few ions that do enter.

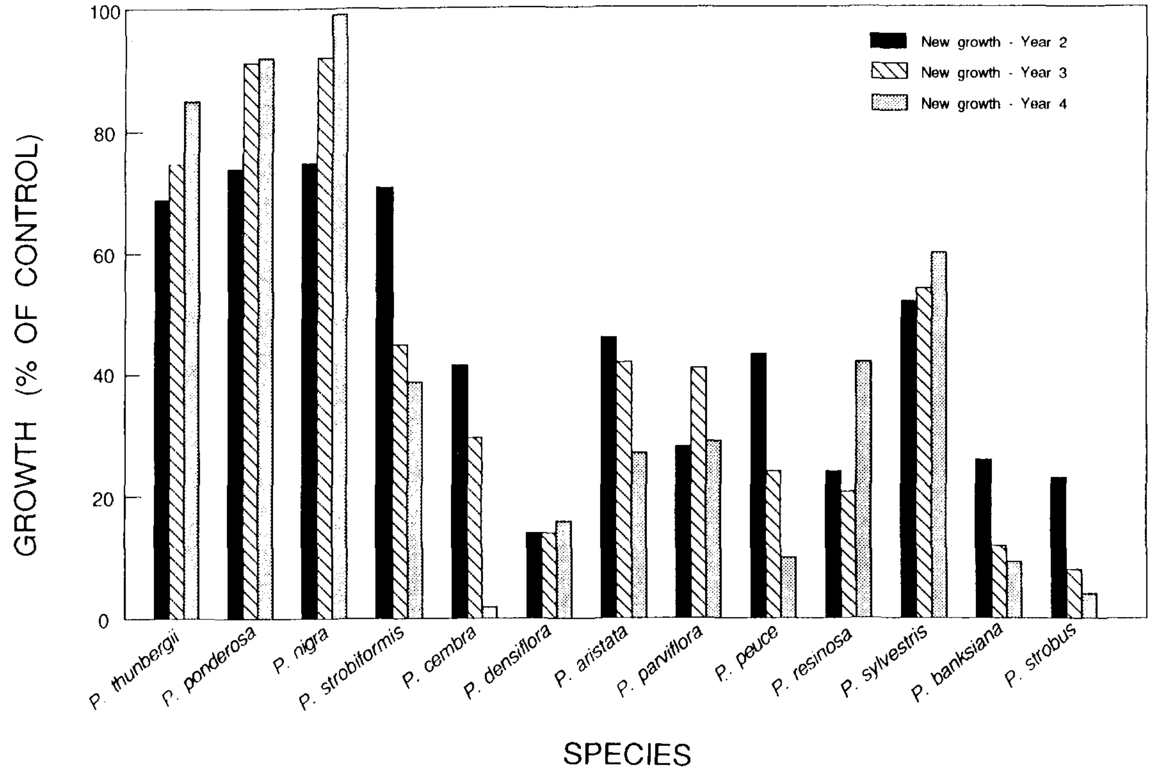

Fig. 1. Yearly height growth of sodium chloride-treated pine seedlings (expressed as a per cent of water-treated trees). Years 2, 3, and 4 refer to the second, third, and fourth years after the first year of salt treatment.

Table 2. Average chloride and sodium concentrations in needles from pine seedlings treated with NaCl.[z]

Species	*Needle Surface Chloride (% dry wt)*	*Internal Chloride (% dry wt)*	*Internal Sodium (% dry wt)*
P. thunbergii	.024 ab	1.164 bcd	.620 abcd
P. ponderosa	.013 a	0.606 a	.435 a
P. nigra	.033 bcd	1.026 bcd	.637 bcd
P. strobiformis	.021 ab	0.983 bc	.585 abc
P. cembra	.024 ab	0.940 b	.483 ab
P. densiflora	.056 def	1.404 cde	.758 cde
P. aristata	.037 bcde	1.440 de	.882 def
P. parviflora	.062 ef	1.708 ef	1.330 fg
P. peuce	.041 cde	1.714 ef	1.078 ef
P. resinosa	.035 bcde	1.447 de	0.859 def
P. sylvestris	.040 cde	1.814 ef	1.303 fg
P. banksiana	.044 cde	1.353 bcde	0.741 cde
P. strobus	.093 f	2.151 f	1.347 g

[z] Mean separation within columns by Duncan's New Multiple Range Test, 5% level. Numbers followed by the same letter within columns are not considered significantly different.

Needle thickness of *P. nigra, P. ponderosa,* and *P. thunbergii* may help exclude salt ions. Barrick *et al.* (1) considered that differences in epicuticular waxes and needle surface characteristics explained greater salt tolerance in *P. nigra (vs. P. strobus).* Logan (10) considered that the cuticle of *P. nigra,* twice the thickness of that of *P. strobus,* was responsible for its greater tolerance to salt spray.

The quantity and quality of surface waxes appear to play an important role in the foliar uptake of polar solutions in general (8, 13). Holloway (8) showed surface wax to be an effective hydrophobic barrier to liquids with high surface tension if the wax covers the entire epidermis. Plants containing plate-like, overlapping leaf waxes are less penetrable to polar solutions like salt water than those with vertically oriented rod-like waxes, which do not entirely cover the surface. Differences in wax structure and cuticle thickness may explain differences among pine species' sensitivity to deicing salt, but further studies are needed. Tolerant species, which generally accumulated the lowest quantities of needle surface chloride in this study, may be able to present a better hydrophobic barrier to entry of salt solution.

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