Soil Salinity Related to Ponderosa Pine Tipburn

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ABSTRACT

Ponderosa pine tipburn symptoms identical to those occurring naturally in Denver, Colo., were induced with a variety of chloride salts applied in solution. A strong positive correlation was found between experimentally induced needle injury and foliar concentration of Cl. Total soluble salt levels and chloride levels in soil around injured pines in Denver exceeded levels in soil around healthy pines.

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Additional key words: foliar diagnosis, electrical conductivity, saline soils, EC_{25}.

A tipburn disease of ponderosa pine (*Pinus ponderosa* Laws.) characterized by a sequence of needle resin infiltration, banding, and tip necrosis has been observed for the past 15 years at various locations in Denver, Colo. Staley et al. (6) described the disease, and found strong correlations between sodium and chloride content of the needles and injury under natural conditions.

Salt injury to various pine species has been reported by several investigators (2, 5, 7, 8, 9, 10). Monk & Peterson (4) tested the salt tolerance of 20 trees and shrubs, and classified members of the family Pinaceae as intolerant.

A study was initiated to evaluate the effects of various sodium and chloride salts on ponderosa pine and to further relate ponderosa pine tipburn to salt toxicity.

Effect of various concentrations of NaCl, Na_2SO_4, and $NaHCO_3$.—The effects of three sodium salts on ponderosa pine seedlings were examined to determine if Na could be causally indicted. Thirty 3-year-old ponderosa pine seedlings, potted in 2 kg of a mixture of one-third washed sand, one-third sphagnum peat, and one-third field soil [a silty clay loam, used for turf production composited from the plow layer of former agricultural land classified as loamy alluvial land (3)] were divided into three groups of 10 each. Soils containing seedlings in group 1 received NaCl solution treatments as follows: 0, 3,000, 6,000, 9,000, and 12,000 ppm NaCl. Soils containing group-2 seedlings were treated with Na_2SO_4 solutions, and soils with group-3 seedlings received $NaHCO_3$ treatments at the same concentrations as those listed above for NaCl. Tap-water applications were alternated with salt-solution applications to promote a uniform salt concentration throughout the pot soil during the experiment.

Electrical conductivity (EC_{25}) measurements of saturated soil extracts were taken at the beginning and conclusion of the test with an RD 26 Solu-Bridge. The extracts were prepared by saturating a 300-g soil sample from each pot with distilled water, allowing 1 hr for reactions to occur, and filtering the solution from the soil paste through Whatman No. 1 filter paper under vacuum. Prior to treatment, the soil mixture used in the experiment was found to have an average $EC_{25} \times 10^3$ of 0.7 mmhos/cm.

Various symptoms were observed on salt treated

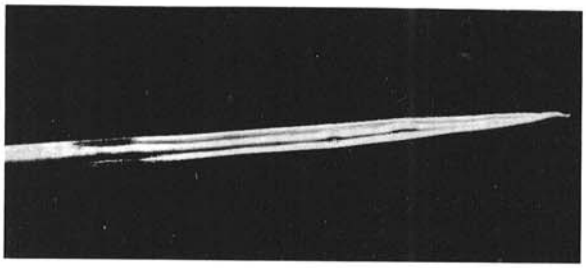

Fig. 1. Ponderosa pine needle banding and tipburn induced with salt treatments.

seedlings 2 months after treatment was begun. Salt solutions had been applied 15 times during this period. Seedlings treated with all concentrations of NaCl developed banding and tipburn (Fig. 1). The $EC_{25} \times 10^3$ of soils treated with NaCl solutions ranged from 10.4 to 92 mmhos/cm. No definite injury was observed on seedlings treated with Na_2SO_4 solutions and for which soil $EC_{25} \times 10^3$ ranged from 4.3 to 15.3 mmhos/cm. At the termination of the experiment, seedlings treated with $NaHCO_3$ were faded and appeared straw-colored but exhibited no resin bands. The $EC_{25} \times 10^3$ of soils treated with $NaHCO_3$ ranged from 1.3 to 13.3 mmhos/cm.

Effect of salt solutions of isosmotic potential.—A second salt toxicity experiment was conducted using four salt solutions of isosmotic potential to confirm previous results, to investigate a possible indictment of Cl, and to differentiate between osmotic and specific ion effects on ponderosa pine seedlings. Salt mixtures were employed in two treatments to minimize the effects of cation imbalance.

Twenty 1-year-old ramets (individuals produced by grafting scions from selected trees onto seedling rootstocks) with scions from a healthy ponderosa pine (H) and 20 with scions from a ponderosa pine injured by the tipburn (I) were used. The ramets were brought into the greenhouse while dormant, divided into four groups of five healthy (H) and five injured (I), and potted in 15- X 33-cm cans in soil composed of unsterilized 50% alluvial silt loam from a ponderosa pine forest and 50% ponderosa pine humus, a preparation which has consistently supported vigorous growth of pine seedlings under greenhouse conditions. All ramets broke dormancy and initiated production of symptom free foliage 1 month prior to salt applications. In group 1, six ramets (3 H and 3 I) were treated with solution of NaCl (6 g/liter) applied to the soil from above (T_1). Similarly, six ramets of group 2 were treated with a mixture of $CaCl_2$ (5.3 g/liter) and $MgCl_2$ (4.2 g/liter) in which 70% of the total osmotic potential (OP) resulted from $CaCl_2$ (T_2). Six ramets of group 3 received a mixture of $CaCl_2$ (3.8 g/liter and 50% OP), $MgCl_2$ (4.2 g/liter and 30% OP), and NaCl (0.8 g/liter and 20% OP) (T_3). Six ramets of group 4 were treated with Na_2SO_4 solution (9.7 g/liter) (T_4). To serve as a control, four ramets in each group (2 H and 2 I) received water (C). Salt mixtures in T_2 and T_3 were used to more closely simulate natural conditions and minimize effects of cation imbalance. All salt solutions were adjusted to a total OP of 5.05 atmospheres and were applied to the soil in 250-ml portions at each watering period. Ramet injury of current foliage was recorded weekly by measuring the per cent of injured needle length on six needles/ramet. Soil pH and electrical conductivity measurements were taken prior to salt application, midway through the test, and at the conclusion of the experiment. Needle samples were then collected from each ramet, air-dried for 1 month, and ground in a Micro-Wiley mill. The samples were quantitatively analyzed for Na by flame photometer, Ca and Mg by atomic absorption, and Cl by $AgNO_3$ titration. Ramets in groups 1 and 4 were analyzed gravimetrically for S.

The pH of all salt-treated soils decreased during the experiment, dropping from an initial range of 6.7-7.8 to a final range of 5.1-6.9. The $EC_{25} \times 10^3$ increased throughout the test from an initial range of 0.18 to 2.03 mmhos/cm to a final range of 10.26 to 83.40 mmhos/cm. The highest final EC_{25} values were found in soils treated with Ca and Mg chlorides; the lowest, in soils treated with Na_2SO_4.

The tipburn syndrome was first observed on chloride salt-treated ramets 3 months after treatment began. During this period, salt solutions were applied 19 times. All ramets treated with chloride salts developed tipburn. The total injury resulting from NaCl exceeded amounts induced by Ca and Mg chlorides or by Ca, Mg, and Na chlorides (Table 1, Fig. 2). Ramets treated with Na_2SO_4 did not exhibit typical symptoms and were only slightly injured. Since the ramets reacted differently to each treatment while the OP of solutions used was constant, the resulting injury appeared related mainly to specific ion action rather than osmotic action. Ramets with scions from the healthy parent showed less injury than ramets from the injured parent (Table 1).

Linear correlation analysis showed correlation coefficient (r) values as follows: percentage injury:percentage Na, $r = +.29$; percentage injury:percentage Ca, $r = +.72$; percentage injury:percentage Mg, $r = +.62$; percentage injury:percentage Cl, $r = +.79$; percentage injury:percentage S, $r = -.44$. The null hypothesis was rejected at the 1% level under these experimental conditions in the relationships between injury and Ca, Mg, and Cl. Partial correlation coefficients calculated for injury:percentage Ca, $r = +.13$ and injury:percentage Mg, $r = +.05$ eliminating the effects of Cl, were not significant. However, the second order partial coefficient for injury:percentage Cl, eliminating the effects of Ca and Mg, $r = +.75$, was significant at the 1% level.

Analysis of soils beneath healthy and injured trees.—Soil cores 3.8 cm in diam and 60 cm in depth were taken within 3 and 4 m of four healthy and four injured ponderosa pines. The cores were broken into four 15-cm segments. Saturation extracts were prepared from each segment and analyzed for pH,

TABLE 1. Foliage analyses values and per cent injury of ponderosa pine ramet groups irrigated with iso-osmotic salt solutions

Treatment	Condition of scion source[a]	% Injury	mg/g dry wt tissue				
			Na	Ca	Mg	S	Cl
T_1) NaCl	Healthy	7.93	11.28	7.42	2.34	1.24	28.07
	Injured	18.45	14.41	6.54	2.12	1.07	33.24
T_2) 70% $CaCl_2$-30% $MgCl_2$	Healthy	7.74	1.25	10.92	2.45	NA[b]	22.74
	Injured	13.80	.13	10.63	2.65	NA	24.79
T_3) 50% $CaCl_2$-30% $MgCl_2$-20% NaCl	Healthy	11.59	.50	9.92	3.19	NA	24.71
	Injured	11.01	.29	10.42	2.91	NA	25.44
T_4) Na_2SO_4	Healthy	0	6.20	2.94	2.14	4.10	0.25
	Injured	0.01	7.45	2.01	1.32	4.87	0
C) Control	Healthy	0	0.07	2.81	1.76	1.52	0.46
	Injured	0	0.06	2.39	1.42	1.72	0.71

[a] Scion source refers to the parent tree from which scions were collected for preparation of ramets.
[b] Not analyzed.

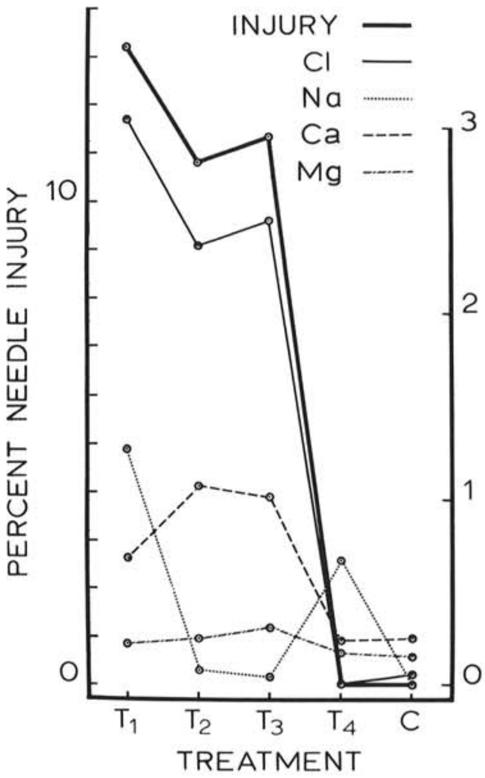

Fig. 2. Relation between average foliar Na, Ca, Mg, and Cl, and needle injury in pine seedlings irrigated with isosmotic salt solutions. Treatments 1-4 and the control are described in the text.

DISCUSSION.—These studies suggest that salt, and more specifically Cl concentrations in the soil, are associated with the development of ponderosa pine tipburn in Denver.

Symptoms resulting from irrigation with three Na salts (Cl^-, $SO_4^=$, and $CO_3^=$) were identical with the natural tipburn only in the NaCl treatment. The foliar analyses in conjunction with the isosmotic saline irrigations showed that Cl content was more closely correlated with injury than any other factor tested. The analytical results presented in Fig. 2 indicate that toxic levels were reached only in the Cl concentrations of treatments 1 to 3. Sodium concentrations were sufficiently low in treatments 2 and 3 to rule out Na as a sole causal agent of tipburn. In treatments 1 to 3, Ca and Mg were present in concentrations believed to be below the toxic level (1), and their partial correlation coefficients with injury were not statistically significant after the Cl influence had been eliminated.

Foliar Na concentrations in nature are clearly correlated wih symptom severity. Our experiments show that tipburn can develop without high concentrations of Na, and that high levels of soil and foliar Cl concentrations are the primary factors associated with the development of ponderosa pine tipburn. Sodium shortened the time for the onset of tipburn symptoms and increased the intensity of EC_{25}, and Cl concentration.

The EC_{25} of water extracts from soil around injured pines exceeded levels present in soil around healthy pines (Table 2). These differences were significant at the 10% level. The Cl concentration of soil around injured pines exceeded levels in soil around healthy pines, and differences were significant at the 1% level (Table 2). No consistent patterns of pH, EC_{25}, or Cl concentration were detected with relation to soil depth.

TABLE 2. Electrical conductivity (EC), chloride content, and pH of soil around healthy and injured ponderosa pines in Denver, Colo.

Soil plot no.	Condition of tree on plot	$EC_{25} \times 10^3$ [a] (mmhos/cm)	Cl (mg/liter extract)[a]	pH[a]
1	Injured	0.827	75.4	7.60
2	Injured	3.404	206.4	7.27
3	Injured	3.423	218.3	7.27
4	Injured	4.525	320.6	7.23
5	Healthy	0.793	26.0	7.58
6	Healthy	1.943	113.2	7.33
7	Healthy	2.718	168.2	7.23
8	Healthy	0.642	17.4	7.75

[a] Values are based on 24 measurements.

symptom expression in ramets from injured trees to a greater extent than did the other cations.

Groups of injured pines can now be recognized as the most frequent pattern of occurrence. This pattern is confused, however, by discontinuous plantings superimposed upon a discontinuum of injurious salt concentrations. Apparent differences in salt tolerance between individual pine trees further complicate the pattern of disease expression.

During the years 1964-1968, the time of natural tipburn appearance was correlated directly with the annual total precipitation. This may be due to dilution of salts in the soil solution, or in lakes and wells used for irrigation. In any event, with high rainfall, symptoms appear in September; with lesser amounts, symptoms appear in July or August.

It is of interest to note that symptomatic trees as large as 6 inches in diam have recovered their vigor when transplanted to a site with adequate internal soil drainage and watered heavily. Partial recovery can be seen within one growing season, and is dramatic enough in the second season to be more than satisfying to a new owner.

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