NaCl Injury to Dormant Roadside Peach Trees and Its Effect on the Incidence of Infections by *Leucostoma* spp.

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ABSTRACT

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Loring peach trees bordering a busy highway, which was treated repeatedly with NaCl as a deicing salt, suffered severe winter dieback of canopy shoots and greatly reduced fruit yield. Percent dead canopy wood was positively correlated with Na^+ and Cl^- concentrations in shoot tissue, which ranged, respectively, to 6.9 and 9.0 mg/g of oven-dried tissue (ODT) and was inversely correlated with distance from the highway and with fruit production per tree. Excised Redhaven peach shoots were dipped once in NaCl solution, incubated at 2 C, rinsed, and examined for Na absorption and bud viability. Shoots that contained 6.2 mg of Na^+ per gram of ODT showed severe bud mortality, and at 13.0 mg of Na^+ per gram of ODT, all buds were killed. Na^+ was absorbed at 90% RH but only slightly at 40% RH. Phytotoxicity was maximal after incubation at 90% RH for 8 days and was induced faster at 5 C than at 1 or 15 C. NaCl deicing salt sheared by traffic and blown into adjacent orchards was considered the principal injurious factor. *Leucostoma cincta* was associated with dead shoots, but it was principally a saprophytic colonist of dead tissue.

Additional key words: canker, *Cytospora*, *Prunus persica*.

In May 1974, extensive severe shoot dieback was observed on peach trees bordering a busy highway that had been treated repeatedly with NaCl deicing salt during the 1973–1974 winter. Injury was greater on the south side than on the north side of the east-west highway and decreased with increasing distance from the highway, similar to the pattern of salt injury described for other tree species (2,6,7,12,13). Injury did not appear to be related to the surface drainage from salted roads, which has affected roadside maple trees (9,10,17). Most of the dead peach shoots bore pycnidia resembling those of *Leucostoma cincta* (Pers. ex Fr.) Höhn., the principal causal fungus of the perennial canker disease of peach (11,16,18), but it was uncertain whether shoot infection was a partial cause or a consequence of the dieback. Furthermore, *Fusicoccum amygdali* Delaw. also causes shoot dieback and canker of peach trees and could be confused with *L. cincta* and is favored by elevated chloride levels (4). Although it is rare in Ontario (16), *F. amygdali* might have become an important pathogen of NaCl-stressed roadside peach trees.

The present study examined the severity of peach shoot dieback and crop reduction and their relationships to the Na^+ and Cl^- contents of dead shoot tissue. The incidences of shoot infection and the identity of fungi recovered from dead shoots in 1974 and 1975 were determined. The effects of relative humidity, temperature, and the period of incubation on the uptake and phytotoxicity of NaCl were examined under controlled conditions, and the Na^+ contents of injured shoots were compared with those of field samples to determine the most probable cause of injury.

MATERIALS AND METHODS

Field observations and tissue analyses. A severely injured Loring peach orchard (*Prunus persica* (L.) Batsch cultivar Loring) planted on the south side of a four-lane highway running in an east-west direction near St. Catharines, Ontario, Canada, was studied in 1974. The orchard was at the same elevation as the highway, and the soil was a well-drained fine sandy loam. Samples were taken from and observations were made of designated plots each consisting of two mature peach trees. Three plots (replicates) were marked at each of six distances, 20, 40, 50, 60, 80, and 120 m, from the edge of the highway closest to the orchard. In early June 1974, 25 shoots from the canopy (2.5–3 m high) and 25 scaffold shoots from the lower central region of the tree (1–1.5 m high) were pruned from each plot. Records were made of the lengths of the 1973 shoots, lengths of terminal dieback, the number of shoots with pycnidia or conspicuous zonations from fungal infections, and the number of developing fruits per canopy shoot. The terminal 10 cm of dead tissue from 25 canopy shoots per plot was collected 6 June 1974. These samples were not washed to remove any remaining surface deposits before being analyzed for Na^+ and Cl^- content. On 20 August 1974, 50 canopy shoots per plot were examined in the tree to determine the number of maturing fruits per canopy shoot. Fruits were harvested 27–30 August 1974 and weighed to determine, for each plot, the mean fruit crop per tree and the mean individual fruit weight from a sample of 50 fruits. In November 1974, the lengths of the 1974 canopy and scaffold shoots were measured.

For the purposes of this study, it was assumed that salt remained on the road surface for 6 hr after application of rock salt and sand-salt and that it could be redistributed by traffic as droplets of salt solution. The mean speed and direction of wind during the 6-hr period after an application was calculated from meteorological records of the 1973–1974 winter. Where frequent applications resulted in an overlapping of the 6-hr redistribution periods, the individual hourly records were included only once.

During the winter of 1974–1975, Sunhaven peach trees planted to the north of the highway were examined for salt residues and shoot injury. Twenty-five canopy shoots were pruned from each of three trees at 17, 30, and 120 m from the northern edge of the highway on 28 November 1974 (except from 17 m), 17 March, 2 May, and 9 June 1975. The May and June samples were subdivided into dead and living tissues, which were chemically analyzed separately for Na^+ content.

Shoot samples were dried at 70 C for 3 days, ground in a Wiley mill, dry ashed for 2 hr at 550 C, and dissolved in HCl as described by Cline and Reissmann (3). Sodium concentrations were determined against a Na^+ standard by atomic absorption spectrophotometry. Chlorine was determined in a second dry-ashed sample dissolved in HNO_3 and titrated with silver nitrate using potassium chromate to indicate the end point. The procedure was standardized against known chloride concentrations. The ionic concentrations were expressed as milligrams per gram of oven-dried tissue (ODT).

The principal fungi associated with dead canopy shoots were identified after incubating 6-× 1-mm slivers of subepidermal tissue on potato-dextrose agar (Difco) for 7 days at 22 C in diffuse light. In 1974, isolations were made from lesions on 60 Loring canopy shoots collected 3 June from plots 20, 60, and 120 m from the highway. In 1975, isolations were made similarly from 60 Sunhaven canopy shoots collected 17 March, 1 May, and 9 June from trees 17 m from the edge of the highway.

Laboratory treatment of peach shoots with NaCl solutions. Unbranched dormant canopy shoots, 45 cm long, were pruned in March from Redhaven peach trees, 400 m from and unaffected by, a salt-treated highway. A group of 10 shoots, constituting a replicate, was supported firmly with a water-tight seal of modelling clay in a 500-ml Erlenmeyer flask, with shoots standing in 200 ml of aerated sterile distilled water. At the mouth of the flask, the modelling clay was shaped into a collar.

In preliminary experiments, peach shoots sprayed with dilute solutions of NaCl and incubated at 2 C and 90% relative humidity (RH) remained wet for more than 12 hr. Repeat applications within 12 hr resulted in excessive spray runoff and the amount of spray deposition could not be easily standardized. Instead of repeated applications of dilute solutions of NaCl (5), a single application was made by dipping shoots once in more concentrated NaCl solutions.

Shoots were dipped once with slight agitation for 5 sec in solutions of NaCl (Fisher, Certified) in distilled water containing Tween 20 (Atlas Chemical Industries), 1 g/L of solution, to improve wetting of the shoots. For the check treatment, shoots were dipped in 1 g/L of Tween 20 solution. Excess solution that ran from shoots within 5 min of dipping was removed from the collar with absorbent tissue. After a period of incubation that varied with the particular experiment, the shoots were spray-rinsed with 60 ml of distilled water to remove any remaining surface salt deposits. Shoots were then maintained in their original flasks at 20 C and 70% RH in a growthroom with a daily 16-hr photoperiod with an intensity of 380 $\mu E/m^2/sec$ (daylight fluorescent and incandescent) measured with an LI-190SB Quantum Sensor (Li-Cor Ltd., Lincoln, NE) for 10 days and examined for injury. The criteria for bud viability were 1 mm or more of exposed leaf tissue for vegetative buds and exposed petals for floral buds.

In Experiment 1, shoots were dipped in 5.4 M (saturated NaCl in water with 1 g/L of Tween 20 at 2 C), 2.7 and 1.4 M NaCl, and were incubated at 2 C and 90% RH for 24 days, with a daily 12-hr photoperiod of 20 $\mu E/m^2/sec$. Another treatment involved shoots dipped in 5.4 M NaCl and exposed to similar lighting and temperature but maintained at 40% RH over a saturated solution of $CaCl_2$ (19). Other shoots were dipped in 5.4 M NaCl solution, but they were dried within 3 hr at 30% RH for analysis of initial surface deposits, and bud viability was not determined. The shoot rinse water, collar rinse water, flask water, and the shoot tissues (after viability had been determined), were analyzed for Na^+ content as previously described. Three flasks (replicates) were subjected to each treatment.

Experiment 2 examined the effect on bud viability of periods of incubation of 1, 3, 8, and 24 days of shoots dipped in 0, 1.5, and 2.0 M NaCl solutions. The shoots were incubated at 2 C and 90% RH with a daily 12-hr photoperiod of daylight-fluorescent illumination at 120 $\mu E/m^2/sec$. Immediately after the completion of the respective incubation periods, shoots were rinsed to remove remaining superficial salt deposits and were maintained at 20 C for 10 days and evaluated for bud viability as previously described.

Experiment 3 examined the effects on bud viability of salt-treated shoots of five incubation durations at four temperatures and their interaction. The shoots were dipped for 5 sec in 1.3 M NaCl solution and incubated for 0, 0.5, 1, 2, or 4 days at 1, 5, 10, or 15 C in darkness and at 90% RH. Shoots were rinsed after their respective incubation intervals and were returned to their respective temperature regimes for the remainder of the 4-day period, before being maintained in light at 20 C for 10 days to determine bud viability.

RESULTS

Field observations and tissue analyses. During the 1973–1974 winter, each application of road salt (almost pure NaCl) was made at a rate equivalent to 0.32 kg of NaCl per meter of four-lane highway, and a sand-salt mixture (containing a minimum of 5% NaCl) was spread at a rate equivalent to a minimum of 0.06 kg of NaCl per meter of four-lane highway. Between 16 November 1973 and 9 April 1974, 52 applications of road salt and 111 applications of sand-salt were applied on 58 days, totaling 24.3 kg of NaCl per meter of four-lane highway for the season. The speed and direction of wind passing over the highway for the 6-hr periods after salt and sand-salt applications were obtained from meteorological records. Wind from the NW, N, and NE directions occurred 59.4% of the time, from the SW, S, and SE for 23.2%, and from the W or E for 17.4% of the time. The mean speeds of winds from the northern and southern sectors were 22.8 and 13.9 km/hr, respectively. The orchards adjacent to the highway were located 3 km south of Lake Ontario, which remained open with very little ice cover during both winters. The relative humidity during winters remained at about 70–80% of saturation and increased during overcast weather and periods of snow or rain at temperatures below and above 0 C, respectively. The mean air temperature for December–March for 1973–1974 was −2.5 C and for 1974–1975 it was −0.9 C.

In 1974, shoot injury and crop reduction were very severe on trees 20 m from the highway but lessened with increasing distance. The appearance of canopy shoots at 50 m, with 55% dead wood due to terminal dieback is illustrated in Figure 1. Fruit crop reached 90 kg per tree at 80 m and showed negligible further increase at 120 m

(Table 1). Percentage of dead canopy wood declined from 97% at 20 m to 8% at 80 m and was only 1% at 120 m, representing a background level. The Na^+ and Cl^- contents (Y mg/g) of dead canopy shoots were highest at 20 m and were negatively correlated with distance (X m), and the relationships were described by the equations:

$$\log Y_{Na} = 2.33 - 1.12 \log X, (r = -0.98, P < 0.001)$$
$$\log Y_{Cl} = 2.02 - 0.82 \log X, (r = -0.99, P < 0.001).$$

The mass ratios of the Cl^-/Na^+ contents of dead canopy shoots ranged from 1.3 at 20 m to 2.1 at 120 m, with corresponding molar ratios of 0.85–1.37.

The percentage of dead canopy wood (Y%) was positively correlated with Na^+ and Cl^- contents (X mg/g) in dead tissue, and the following equations describe the data:

$$\arcsin \sqrt{Y} = 2.54 + 92.37 \log X_{Na} \ (r = 0.95, P < 0.001)$$
$$\arcsin \sqrt{Y} = -33.65 + 121.86 \log X_{Cl} \ (r = 0.92, P < 0.001).$$

Fig. 1. Severe terminal dieback of fruit-bearing canopy shoots of peach trees 50 m from a highway deiced repeatedly during the winter with NaCl. Limited fruit development and vigorous vegetative growth occurred from the lower parts of shoots (6 June, 3–4 wk postbloom).

The number of maturing fruits/canopy shoot in August (Y) just before harvest was appreciably lower than the number of immature fruits/canopy shoot in June (Table 1), and the former showed an inverse linear dependence on percentage of dead canopy wood (X%):

$$Y = 1.73 - 0.02(\arcsin \sqrt{X}), (r = -0.92, P < 0.001).$$

Likewise, the fruit crop/tree (Y kg) was also inversely correlated with percentage of dead canopy wood (X%), as described by the linear equation:

$$Y = 101.91 - 1.17(\arcsin \sqrt{X}), (r = -0.94, P < 0.001).$$

Fruit crop/tree (Y kg) between 20 and 80 m from the highway showed very highly significant ($P < 0.001$) negative correlations with the sodium (X_{Na}) and chlorine (X_{Cl}) contents of dead canopy shoots, and the relationships were linearized with the equations:

$$Y = 120.48 - 147.05 \log X_{Na}, (r = -0.97, P < 0.001)$$
$$Y = 170.68 - 184.18 \log X_{Cl}, (r = -0.93, P < 0.001).$$

All canopy and scaffold shoots at 20 and 40 m from the highway had both terminal dieback and symptoms of fungal infection. With increasing distance the damage to canopy shoots declined more rapidly than that to scaffold shoots (Table 1). In the region of greatest canopy shoot injury, the scaffold shoots were too badly damaged to be suitable as replacement limbs.

A few severely injured adjacent trees died, but most grew vigorously during the 1974 growing season. The 1974 canopy and scaffold shoots at 20 m were as long as the 1973 shoots and much longer than those on noninjured, heavily fruited trees at 120 m (Table 1). Individual fruit weight (Y g) was significantly higher where there were fewer developing fruits/shoot in August (X), between 40 and 120 m:

$$Y = 198.25 - 46.69X, (r = -0.93, P < 0.001).$$

Similarly, individual fruit weight (Y g) was positively correlated with the percentage of dead canopy wood (X%) between 40 and 120 m, with a dependence expressed by the equation:

$$Y = 115.08 + 1.04(\arcsin \sqrt{X}), (r = 0.87, P < 0.001).$$

However, many of the larger fruits were misshapen with split pits and were of greatly reduced commercial value.

TABLE 1. Effect of the proximity of peach trees to a major highway, deiced with NaCl during the 1973–1974 winter, on fruit production, sodium and chloride content of dead canopy shoot tissue, the amounts of dead wood, dieback, and shoot infection and the lengths of canopy and scaffold shoots

Topic (units)	Distance from highway (m)					
	20	40	50	60	80	120
Fruit production						
Crop/tree (kg)	0.3	37.5	43.2	72.9	89.8	91.4
Single fruit weight (g)	NA[a]	181	166	144	118	126
Canopy shoot data						
mg Na^+/g dead tissue ODT[b]	6.9	3.5	3.2	2.2	1.7	0.9
mg Cl^-/g dead tissue ODT	9.0	4.6	4.4	3.8	3.0	1.9
Fruits/shoot, June	0.2	3.5	5.6	8.3	9.0	8.2
Fruits/shoot, August	0.0	0.3	0.8	1.3	1.5	1.6
Dead wood (%)	97	75	55	20	8	1
Shoots with dieback (%)	100	100	97	64	27	4
Shoots diseased (%)	100	100	95	51	32	12
1973 shoot length (cm)	39	30	29	27	26	26
1974 shoot length (cm)	43	36	30	25	21	17
Scaffold shoot data						
Dead wood (%)	91	91	80	55	22	9
Shoots with dieback (%)	100	100	100	99	83	72
Shoots diseased (%)	100	100	100	97	72	37
1973 shoot length (cm)	129	96	89	89	85	81
1974 shoot length (cm)	128	107	94	81	72	59

[a]NA indicates that reliable data were not available.
[b]ODT indicates oven-dried tissue at 70 C for 3 days.

In the 1974–1975 examination of Sunhaven peach trees, the Na^+ content of canopy shoots in November, before highway salting commenced, was only 0.4 and 0.3 mg/g of ODT at 30 m and 120 m, respectively (Table 2). However, by March 17 the Na^+ content of whole shoots had increased to 6.6 mg/g of ODT at 17 m. In May, the canopy shoots at 17 m showed 39% dead wood, and the Na^+ contents of the dead and living tissues were, respectively, 16.3 and 3.0 mg/g of ODT at 17 m.

A factorial analysis of the Na^+ content of shoots in May and June (time: T), for live and dead tissue (condition: C) at 17, 30, and 120 m (distance: D) is summarized in Table 2. With reference to the respective variance ratios (F), there were significantly higher Na^+ contents in dead than in live tissues, higher contents close to the highway than at greater distances, and a significant decline between May and June, which was associated with a cumulative rainfall of 84 mm. The very highly significant (P = 0.0001) interaction between shoot condition (C) and distance (D)

TABLE 2. Effect of the time of sampling and the distance of peach trees from a major highway deiced with NaCl during the winter of 1974–1975 on Na^+ content of living and dead shoot tissue and the amount of dead canopy wood at 17 m and a summary of the factorial analysis of Na^+ residue data for May and June

Sampling date	Percent of canopy wood dead at 17 m	Shoot condition (live or dead)	Na^+ content of tissue (mg/g ODT) Distance from highway (m) 17	30	120
28 November	0 a[x]	live	NA[y]	0.4	0.3
17 March	29 b	live + dead	6.6	4.2	1.6
2 May	39 c	dead	16.3	5.4	1.6
		live	3.0	4.5	1.8
9 June	49 d	dead	10.9	5.4	1.5
		live	1.2	1.5	0.9

Source of variation	df	Sum of squares	F	Probability (P)
Treatment				
May/June (T)[z]	1	32	127	0.0001
Condition (C)	1	197	776	0.0001
Distance (D)	2	247	485	0.0001
T×C	1	0	0	0.9791
T×D	2	15	29	0.0001
C×D	2	213	419	0.0001
T×C×D	2	17	33	0.0001
Error	24	6		
Total	35	727		

[x]Means followed by different letters differ significantly (P = 0.05) by Student-Newman-Keuls multiple range test.
[y]NA: Data were not available.
[z]T = Time, C = condition, and D = distance.

quantifies the considerable decline of Na^+ content in dead tissue with distance, compared with the slight if any decline in live tissues, which were low initially.

The rock salt used for highway deicing during the 1973–1974 and 1974–1975 winters was analyzed and contained in excess of 99% NaCl. During this period, $CaCl_2$ was not used on the highway for any purposes.

In 1974, the predominant fungus associated with dieback of canopy shoots at 20, 60, and 120 m was *L. cincta*, which was recovered from 91% of the shoots. *L. persoonii* (Nits.) Höhn was recovered from 8% of shoots, of which 5% were coinfections with *L. cincta*. In 1975, *L. cincta* was isolated from only 0, 15, and 18% of dieback-affected shoots in March, May, and June samples, respectively. *L. persoonii* was present in only 2% of shoots in June and there were no coinfections. *Aureobasidium pullulans* (de Bary) Arn. and *Alternaria* sp. were recovered from 57 and 12% of shoots, respectively, with some coinfections, and 22% of shoots had uninfected dieback. Rainfall during March–May 1974 was 209 mm, in contrast to 152 mm during the same period in 1975. The greatest difference occurred between April 1974 with 75 mm of rain on 12 days, compared with April 1975, with only 16 mm on 6 days.

Laboratory treatment of peach shoots with NaCl solutions. In Experiment 1, the dipping of dormant Redhaven peach shoots in 5.4 M NaCl solution deposited 18.5–19.5 mg of Na^+ per gram of ODT (Table 3). At 90% RH, 68% of this initial surface deposit was absorbed, raising the tissue content from 0.3 to 13.0 mg of Na^+ per gram of ODT, 1% remained on the surface, and 31% drained off the shoots and was collected in the clay collar. Solution drainage resulted from the hygroscopic absorption of water vapor by the salt solution mainly during the first 24 hr of incubation at 90% RH. Shoots incubated for 24 days at 40% RH showed only 10% absorption, raising the shoot content to 2.2 mg of Na^+ per gram of ODT, and 81% remained on the shoot surface as a crystalline deposit that was densest at the nodes. Shoots dipped in 5.4 M NaCl and dried at 30% RH over 3 hr showed a similar high surface deposit, and only 8% of it was absorbed into the tissue. The shoots dipped in 2.7 M and 1.4 M NaCl acquired lower initial surface deposits, and at 90% RH, 97% of these deposits were absorbed, and only 2% was lost by surface drainage.

Bud viability was reduced significantly from 76 to 49% by a dip in 1.4 M NaCl, which raised tissue contents to 4.2 mg of Na^+ per gram of ODT, and viability was further reduced to 24 and 0% in shoots with contents of 6.2 and 13.0 mg of Na^+ per gram of ODT, respectively (Table 3).

In Experiment 2, the brief dipping of peach shoots in 1.5 or 2.0 M NaCl and the periods of incubation of 1–24 days gave very highly significant (P= 0.0001) reductions of bud viability (Table 4). There was also a significant interaction effect. Bud viability of NaCl-dipped shoots was significantly reduced from 76 to 60% after incubation for 1 day and declined to 2–4% after incubation at 90%

TABLE 3. The effect of dipping dormant peach shoots in solutions of NaCl and their subsequent incubation[w] at different relative humidities on NaCl deposition on and absorption by shoots and bud viability

Concentration of NaCl in dip (molar)	Relative[w] humidity (% RH)	Salt deposit[x] on shoots (mg Na^+/g ODT)	Movement of salt deposits (%) Shoot absorption	Surface retention	Solution drainage	Tissue[y] content (mgNa^+/g ODT)	Viability[y] of buds (%)
5.4	90	18.5	68	1	31	13.0 e	0 d
2.7	90	6.1	97	1	2	6.2 d	24 c
1.4	90	4.0	97	1	2	4.2 c	49 b
0	90	0	0	0	0	0.3 a	76 a
5.4	40	18.9	10	81	9	2.2 b	74 a
0	40	0	0	0	0	0.3 a	74 a
5.4	30	19.5	8	86	6	1.9 b	NA[z]
0	30	0	0	0	0	0.3 a	NA

[w]Incubation times after shoots were dipped in NaCl solutions were: 90 and 40% RH, 24 days; 30% RH, 3 hr.
[x]Increase in Na^+ deposit per gram of oven-dried tissue (ODT), relative to Na^+ content of appropriate check shoots dipped in Tween 20 solution (1 g/L).
[y]Means in the same column followed by different letters differ significantly (P= 0.05) by Student-Newman-Keuls multiple range test.
[z]NA: Data were not available.

RH for 8–24 days of shoots dipped in 2.0 M NaCl solution. Shoots exposed to 1.5 M NaCl solution were less severely affected and the reductions of bud viability occurred only after longer periods of incubation than for shoots dipped in 2 M NaCl solution.

In Experiment 3, the bud viability of shoots dipped in 1.3 M NaCl was significantly affected by periods of incubation of 1–4 days and by temperatures of 1–15 C, and there was a small but significant interaction between these factors (Table 5). The most rapid and most severe loss of bud viability occurred at 5 C with lesser effects at 10 and 15 C, and the slowest response was at 1 C. Nevertheless, at 1 C, bud viability was significantly reduced from 82 to 75 and 57% after 2 and 4 days incubation at 90% RH, respectively.

DISCUSSION

Redhaven peach shoots treated with NaCl under controlled conditions showed complete loss of bud viability at a tissue content of 13 mg of Na^+ per gram of ODT but tolerated 2.2 mg of Na^+ per gram of ODT without injury. By comparison, roadside Loring shoots with 97% dead wood contained only 6.9 mg of Na^+ per gram of ODT in June 1974, whereas Sunhaven shoots in June 1975 showed only 49% dead wood but contained 10.9 mg of Na^+ per gram of ODT. Shoot injury of other deciduous phanerogamous trees has been associated with Na^+ and Cl^- contents of 1–10 mg/g of ODT in the roadside environment (14,15) and as high as 13.1 mg of Cl^- per gram of ODT in treated apple (*Malus sylvestris* Mill.) shoots (8). Contents as high as 20–25 mg of Cl^- per gram of ODT were reported for injured coniferous foliage (5,6). The Na^+ and Cl^- contents of dead shoots of roadside peach trees were therefore high enough to have been major injurious factors and were significantly positively correlated with percentage of dead canopy wood and negatively correlated with crop production per tree.

The molar ratio of Cl^-/Na^+ in dead peach shoots approximated unity, indicating that either or both ions could have contributed to the injury. Similar ratios were reported for the shoots of lilac (*Syringa vulgaris* L.) and green ash (*Fraxinus pennsylvanica* Marsh.) (15), whereas ratios generally between 1 and 2 were apparent for salt-injured apple shoots (8). This indicated a general physiological similarity between the shoots of peach and of these other tree species regarding the absorption of NaCl and its injurious effects on shoots.

NaCl reduced the cold hardiness of lilac and apple shoots and made them more susceptible to low temperature injury (14), and perhaps peach shoots were similarly affected. This effect would be in addition to the phytotoxicity observed at 2 C. A reduction in cold hardiness provides a possible explanation for the greater injury to the less cold hardy Loring shoots, with lower Na^+ content, than the Sunhaven shoots.

The vigorous growth of shoots and the development of heavier fruits on injured trees with fewer fruits differed strikingly from the reduced shoot growth and slow development of foliar injury symptoms on peach trees in saline soil (1). This indicated that the winter injury was transient and affected only the exposed aerial parts of trees and was not attributed to saline soil conditions as described for roadside maple trees (9,10). Prior measurements of Na^+ and Cl^- in roadside peach soils had shown that ionic concentrations were not unduly elevated (Cline, *unpublished data*) and further determinations were not made in 1974 and 1975. This confirmed findings by Hofstra et al (7) that soil residues were not elevated at distances greater than 30 m from a four-lane highway.

Salt deposits were visibly heaviest on the side of peach shoots facing the highway and resembled dried pesticide spray deposits applied as small droplets by an airblast sprayer. This evidence was consistent with the view (6,15) that the aerial parts of roadside trees accumulate high levels of NaCl from deicing road salt that is sheared by the tires of fast-moving vehicles (1,6,12,13). Clouds of salt solution droplets are blown away from the highway to a variable extent depending on wind speed and direction. In 1974, the injury to peach trees was greater on the southern than on the northern side of the east-west highway. This was attributed to the greater redistribution of salt spray by moderately strong northerly winds, than that by the lighter, less frequent southerly winds, during periods of salting throughout the 1973–1974 winter. During that winter, 24 kg of NaCl per meter (24 metric tons/km) of four-lane highway was used, equivalent to 16 metric tons/ha per season. This quantity was similar to some previously described rates (7,13), but it was lower than that reported and used experimentally by Holmes (9).

Environmental factors affected the uptake and phytotoxicity of NaCl. At 90% RH, NaCl remained in solution that was hygroscopic, resulting in the drainage from the shoots of some of the diluted solution. The relative humidity of air in equilibrium with saturated NaCl solution at 2 C is 75% RH (19). A small loss of bud viability occurred after incubation of salt-treated shoots for 1

TABLE 4. Effect of duration of incubation[x] of dormant peach shoots dipped in solutions of NaCl on bud viability

Duration of incubation (days)	Percent bud viability: NaCl concentration (molar) 0	1.5	2.0	Mean
1	76 Ab[y]	62 Ba	60 Ba	66 a
3	83 Aa	41 Bb	24 Cb	49 b
8	75 Ab	21 Bc	2 Cc	33 c
24	73 Ab	23 Bc	4 Cc	33 c
Mean	77 A	37 B	22 C	

Source of variation	df	Sum of squares	F	Probability (P)
Treatments				
NaCl concentration (C)[z]	2	11,128	412	0.0001
Incubation time (T)	3	4,239	105	0.0001
C × T	6	2,182	27	0.0001
Error	36	486		
Total	47	18,035		

[x]Shoots dipped in NaCl solutions were incubated at 2 C and 90% relative humidity until rinsed with water and maintained at 20 C.

[y]Means in the same row or column followed by the same upper case letter (A–C) or lower case letter (a–c), respectively, differ significantly ($P = 0.05$) by LSD.

[z]C = Concentration of NaCl and T = time.

TABLE 5. Effect of temperature and duration of incubation[y] at 90% relative humidity on bud viability of peach shoots dipped in 1.3 molar NaCl solution

Duration of incubation (days)	Percent bud viability: Temperature of incubation (C) 1	5	10	15	Mean
0	82 Aa[z]	82 Aa	84 Aa	84 Aa	83 a
0.5	82 Aa	65 Cb	75 ABb	72 BCb	74 b
1	82 Aa	51 Dc	60 Cc	72 Bb	66 c
2	75 Ab	46 Cc	57 Bc	57 Bc	59 d
4	57 Ac	34 Cd	46 Bd	55 ABc	48 e
Mean	76 A	56 D	64 C	68 B	

Source of variation	df	Sum of squares	F	Probability (P)
Treatments				
Temperature (Te)	3	1,102	54	0.0001
Incubation time (T)	4	3,399	126	0.0001
Te × Ti	12	506	6	0.0001
Error	40	270		
Total	59	5,277		

[y]Shoots dipped in 1.3 molar NaCl solution were incubated at 90% relative humidity, for up to 4 days, rinsed with water, and similarly incubated for the remainder of the 4-day period, then maintained at 20 C.

[z]Means in the same row or column followed by the same upper case letter (A–D) or lower case letter (a–e), respectively, differ significantly ($P = 0.05$) by LSD.

day at 90% RH and 2 C, and the phytotoxic response was complete after an 8-day incubation. This was in contrast to the rapid crystallization of salt deposits at 40% RH and 2 C and the absence of any phytotoxicity after incubation for 24 days. These results indicate that NaCl was toxic only when it was present in solution. There was no evidence that dried crystalline deposits of NaCl killed buds through desiccation. The dead and desiccating peach shoots observed in injured roadside peach orchards evidently resulted from the initial phytotoxicity of NaCl to peach tissue, compounded with any aggravated winter injury, and the subsequent loss of moisture from the dead tissues through evaporation.

These findings extend those of Hofstra et al (7) that the absorption of NaCl increased linearly provided the absorptive surface remained wet. Hofstra et al (7) also found that foliar absorption of chloride by *Pinus strobus* L. was independent of temperature between +2 and +15 C. However, in the present study there was a moderate but highly significant effect of temperature over this temperature range with the most rapid phytotoxic response occurring at +5 C.

Although there is a potential for severe injury of shoots within a few days when all factors are optimal, the slow accumulation of NaCl over several weeks or months by experimentally treated and roadside apple trees (8) suggests that injury is limited by low surface NaCl deposits, low temperatures, and low humidity.

In 1974, most of the dead wood on canopy and scaffold shoots was infected by *L. cincta*, but the incidence was much lower in 1975, possibly because of the much lower rainfall in April 1975. The dead shoots in the March 1975 samples were uninfected. This supported the view that the primary cause of dieback was NaCl injury and that *L. cincta* infections were secondary. This relationship is consistent with the usual occurrence of *L. cincta* on peach as a saprophyte or weak parasite (11,16,18). *F. amygdali* was not recovered from injured shoots, therefore, there was lessened concern that *F. amygdali* could become a serious pathogen of peach under the saline conditions (4) of the roadside environment in southern Ontario.

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