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Environmental Effects of Sodium Acetate/Formate Deicer, Ice Shear™

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Abstract. The environmental impacts of Ice Shear™, an alternative highway deicer, have been evaluated using standard laboratory tests; biochemical oxygen demand (BOD) tests, chemical oxygen demand (COD) tests, acute rainbow trout bioassays, and phytotoxicity tests were used. Ice Shear consists of equimolar sodium acetate and sodium formate. The organic matter of the deicer can be readily degraded microbiologically in the natural environment with a slow rate of degradation at lower temperatures but an increased rate at higher temperatures. At elevated temperatures, highway runoffs of the deicer may reduce the level of dissolved oxygen in the receiving waters to cause an adverse impact. However, the apparent activation energy calculated for the BOD rate of Ice Shear is low (8.78 kcal $mole^{-1}$), indicating that the temperature variation may not significantly influence the biodegradation of the deicer compound. Ice Shear appears relatively harmless to aquatic animals, showing a high 96-h LC_{50} value (16.1 g/L) derived for rainbow trout (*Oncorhynchus mykiss*). Ice Shear causes minimal toxicity to representative roadside vegetation; herbaceous (*e.g.,* sunflowers, beans, and lettuce) and woody (*e.g.,* pine seedlings) plants. Rather, the deicer at low concentrations (less than 2 g/kg soil) seems to work as a fertilizer, promoting the yield of biomass. The test results indicate that Ice Shear poses minimal environmental disturbance in both aquatic and terrestrial ecosystems.

Evidence of long-term negative impacts of the conventional highway deicing salt, sodium chloride (NaCl), on the natural environment has been documented in the literature (Hamman and Mantes 1966; Field *et al.* 1974; Prior and Berthoux 1976; Labadia and Buttle 1996). NaCl in highway runoff is responsible for an increase of the salinity or osmolality of receiving waters as the sodium dissolves and for an increase of the acidity of soil and water as the chloride accumulates (Huling and Hollocher 1972; Jones *et al.* 1992; Granato *et al.* 1995). Adverse impacts of deicing salts on the natural environment have become a significant threat to aquatic and terrestrial vegetation and animals. The trends of increasing sodium concentrations in the environment have forced many states to change the standard maximum concentration of sodium in drinking water, which has been regulated at concentrations above 20 mg/L for many years (Moore and Butler 1995).

Reevaluation of the conventional deicing salt has driven many scientists to seek alternative deicers. To overcome the disadvantages associated with the damaging properties of conventional deicing salts, new types of deicers have been developed that are effective, environmentally acceptable, and economically feasible. Typically a chemical used as deicing agent lowers the freezing temperature of water, by which it prevents a strong bond from forming between the snow or ice and the pavement surface. A deicing agent is known to perform more effectively when it has a lower molecular weight with greater solubility. Numerous candidates have been studied for their chemical properties, costs, toxicity, and other potentials as an effective deicer (Dunn and Schenk 1980; D'Itri 1992).

Alkaline salts of carboxylic acids (predominantly acetate), which are common byproducts of processed sawdust, showed deicing ability (Mahood and Cable 1919; Oehr and Barrass 1992). Recently, calcium magnesium acetate (CMA) was introduced and identified as an environmentally favorable alternative deicer, which may lack the disadvantages shown by the conventional inorganic deicers (Winters *et al.* 1984; Horner 1988; Buteau *et al.* 1992). Chemically, even though calcium and magnesium ions may contribute to the increase of water hardness when dissolved in water, both ions are less mobile and tend to precipitate, limiting the groundwater contamination (Dunn and Schenk 1980). Biologically, acetate is readily degradable by microorganisms to produce CO_2 and less likely to be conserved in soil or water (Fritzsche 1992). However, the major drawback of CMA is its relatively high production cost compared to NaCl without being as effective as deicer.

Earlier, the South Dakota Department of Transportation (SDDOT) introduced a cellulose-derived deicer, South Dakota Deicer (SDD), which consists of heterogeneous sodium carboxylate salts; Na-acetate, Na-formate, Na-lactate, Na-glycolate, Na-glycerate, and uncharacterized solids. An environmental impact study of SDD showed its relatively low toxicity to the environment (Bang and Roseland 1989). The researchers from SDDOT have developed Ice Shear™, an improved deicing mixture of equimolar Na-acetate and Na-formate, which exhibits an ability to lower the freezing point of water, penetrate ice, and lower the strength of bonding between the ice and

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pavement. Ice Shear can be applied in a solid or liquid form and has been proven an effective deicer with low corrosivity (Johnston and Huft 1993). In practice, a lower concentration of Ice Shear is proven to work more effectively as a deicer compared to CMA (unpublished laboratory observation).

Sodium ion in Ice Shear is readily soluble compared to calcium and magnesium ions in CMA, and both acetate and formate are substrates that promote bacterial growth. Due to the mobility and biodegradability of organic sodium salts in soil and water, Ice Shear may contribute negative impacts on aquatic and terrestrial vegetation and animals directly or indirectly. In aquatic environments, these microbial decomposition characteristics of the organic compounds may result in depletion of dissolved oxygen (DO) and highly soluble sodium may increase the salinity of the receiving surface and subsurface waters (Pilon and Howard 1987). In terrestrial environments, roadside vegetation and animals may be affected by direct contact with the chemical through splash from highway vehicles and by indirect contacts with the chemical (via runoff) absorbed and accumulated in soil.

The major objectives of this study are to evaluate the potential environmental effects of Ice Shear and understand its associated behavior in water and soil. Assessment of the impacts of the deicer is based on the standard laboratory environmental tests of BOD, COD, 96-h rainbow trout toxicity, and phytotoxicity. Values and factors of Ice Shear identified from the experiments are compared with those of CMA and SDD. Findings from this study are expected to provide guidelines and basic information on the potential impacts of Ice Shear when used as a deicer.

Materials and Methods

Chemicals

A liquid or solid form of Ice Shear was prepared fresh by mixing equimolar concentrations of sodium acetate trihydrate and sodium formate purchased from Fisher Scientific (Fair Lawn, NJ) prior to the appropriate individual environmental test. Reagents for the BOD experiments and acute rainbow trout bioassays were purchased from Aldrich Chemical Co. Inc. (Milwaukee, WI). A nitrification inhibitor, 2-chloro-6-(trichloro methyl) pyridine (TCMP), high range (0–1,500 mg/L) dissolved organic carbon (DOC) digestion vials, and COD standard solutions of potassium hydrogen phthalate (300 mg/L and 1,000 mg/L) were from Hach Co. (Loveland, CO).

BOD Experiments

BOD experiments were conducted according to the procedures of the American Public Health Association (APHA 1989) with minor modifications. Bacterial seed was obtained from the primary clarifier of the Rapid City Waste Water Treatment Plant, Rapid City, South Dakota. DO readings were made with a DO meter (Yellow Springs Instrument Co., Model 57), calibrated for altitude and daily air pressure readings furnished by the Department of Atmospheric Sciences at the South Dakota School of Mines and Technology. Two sets of 20-day BOD experiments were performed; one set using five different concentrations of Ice Shear (0.5, 1.0, 5.0, 10, and 50 mg/L) at the standard temperature of 20°C and the other using the deicer concentration of 10.0 mg/L at multiple temperatures of 4, 10, 20, and 40°C. All samples were made in triplicate and accompanied by duplicate sets of blanks with and without seed. Each bottle, except the unseeded blank set, was inoculated with 1 ml of the bacterial seed, which had been settled at 20°C for 24 h. For the BOD tests, one bottle was used for daily DO measurements. DO of the second bottle was measured at day 5, and the third bottle remained unopened until its DO was measured on the 20th day. The BOD rate constant, k, and ultimate BOD, L, values were calculated using the method of Sawyer *et al.* (1994). Activation energy based on k value was calculated according to the Arrhenius equation:

$$\log k = -\frac{E_a}{2.303\,R}\,\frac{1}{T} + \log A$$

where k is the BOD rate constant, E_a is the slope or the activation energy, R is the gas constant (1.98 cal mol^{-1} T^{-1}), T is temperature (°K), and A is the y intercept.

COD Tests

COD experiments with colorimetric reaction vessels in a closed reflux system were conducted according to Standard Method 5220D (APHA 1989). Five different concentrations of potassium hydrogen phthalate solutions ranging from 180 to 1,000 mg/L were prepared for the standard calibration curve. A sample solution was prepared by dissolving 1 g of the deicer in 1 L of distilled water. The sample was oven-dried at 80°C overnight and kept in a desiccator to cool and prevent rehydration. Two milliliters of each standard solution and the sample solution were pipetted into each vial containing 2 ml of distilled water. Duplicate vials of each sample were made. All vials were placed in a digestor (Hach COD Reactor 45600) at 150°C for 2 h and cooled at room temperature. Concentrations of the samples were determined using a Spectronic 20 (Bausch & Lomb) at 420 nm. Measurements were then compared with a calibration curve obtained from standards of potassium hydrogen phthalate solutions with COD equivalents of 153 to 850 mg/L of O_2. Units of COD were converted to mg/L.

Acute Rainbow Trout Bioassays

The testing procedures used for the acute rainbow trout bioassays closely followed those recommended by the U.S. Environmental Protection Agency (US EPA 1975, 1978). The contents of chemicals in distilled water analyzed (Bang 1996) were considered within the limits recommended for trout bioassays provided by the guidelines of EPA and Rapid City Fish Hatchery (Piper *et al.* 1982). The procedures provided by APHA (1989) were followed to reconstitute distilled water and determine the alkalinity and hardness of the test water. The dissolved oxygen in the test tanks was measured with a DO meter. The specific conductivity was measured with a conductivity/total dissolved solid (TDS) meter (Hach Model 44600). The experiments were carried out in 10-gal glass vessels containing 32 L of reconstituted distilled water maintained at an average temperature of 10 ± 2°C. Juvenile rainbow trout (*Oncorhynchus mykiss*) were obtained from the Rapid City Fish Hatchery, Rapid City, SD. Fish were approximately 9 weeks old with an average length of 5.08 ± 0.64 cm. Conditions for acclimation of the test organisms were described previously (Bang and Roseland 1989). As a measure of mortality, LC_{50} values were determined using log-probit analyses (Sprague 1969).

Two sets of 96-h experiments were conducted under static conditions so that a narrow range of deicer concentrations could be used. Based on the previous tests of SDD (Bang and Roseland 1989) and a range-finding test (Bang 1996), the concentrations of Ice Shear used were 0 (control), 12.5, 15, 17.5, 20, and 22.5 g/L of reconstituted water. Each of the six tanks was furnished with an air stone and filter membrane, and aerated constantly to achieve oxygen saturation and thorough mixing of the deicer. The 96-h experiments commenced upon transfer of 30 acclimated fish into each tank containing a given concentration of the deicer. At the beginning of the treatment, readings were made on the number of fish, DO, pH, temperature, and the specific conductivity. During the test period, changes of pH, DO, and temperature were monitored daily. Behavior and mortality of the fish were closely monitored and recorded twice daily throughout the entire test period. Dead animals were removed immediately when found. At the end of the 96-h exposure to the various concentrations of deicer, last readings of all parameters were made and surviving animals were placed into deaerated water to be terminated.

Phytotoxicity

All plant toxicity tests followed greenhouse pot experiment methods (Jenny *et al.* 1950; John 1982; Rosen *et al.* 1994) with a modification and comprised two types of pot tests; Pot Test I with garden seeds and Pot Test II with pine seedlings. Spray and root saturation treatments were the methods employed for deicer application. Pot Test I used seeds of lettuce (*Lactuca sativa*), sunflower (*Helianthus annuus*), and bean (*Phaseolus vulgaris*) purchased from Excel Co. Pot Test II used native ponderosa pines (*Pinus ponderosa*) obtained from the Pactola Lake region of the Black Hills, SD. Pine seedlings with root hairs and all main roots intact were removed during the early snow melt while still dormant.

A standard 5-in plastic pot was used for all pot tests. For Pot Test I, each pot was filled with a 1 kg soil mixture of 66% potting soil (Hyponex) and 33% sand supplemented with 3.5 g of fertilizer (6-18-12, NPK Fertilizer, Osmocote). Peat humus was added to improve the drainage, while prewashed coarse sand was used to prevent packing as well as to aid faster drainage and keep the soil dry. A suitable quantity of dry Ice Shear ranging from 0 (control), 0.5, 1.0, 2.0, and 4.0 g/kg of soil was then mixed directly into the individual pots. For Pot Test II, each pot was filled with a 1 kg soil mixture of 50% potting soil (Hyponex) and 50% native forest soil from the Black Hills. Appropriate concentrations of deicer were prepared separately (as explained in the next section). All test pot samples were prepared in triplicate.

For the garden plants in Pot Test I, a plastic grid was placed over the top of the prepared soil containing a given amount of the deicer. Seeds were planted in the following proportions: lettuce, 26 seeds at approx. 0.6 cm depth; sunflower, 10 seeds at approx. 1.3 cm depth; and bean, 10 seeds at approx. 2.5 cm depth. Pots were then watered with distilled water until saturated. For Pot Test II, pine seedlings were transferred to the individual pots after the initial weights of the plants were recorded. The pine seedlings were allowed 10 days of acclimation before the treatment with deicer solutions started. Pots were watered once a day with distilled water until the Jobe's spikes showed saturation. Gro-Lights were set on automatic timers to produce 8 h of light a day. On day 10, the seedlings were divided into two separate groups; one for root-saturation treatment and the other for spray treatment. For the former treatment with the deicer, 50 ml of water containing one of four different concentrations of Ice Shear was added daily for five days until the soil was saturated. The plants were watered with distilled water for the remainder of the test period. For the latter, water containing different concentrations of deicer dissolved in 100 ml distilled water was directly sprayed as a fine mist onto the plants. Each pot was isolated while it was misted to prevent any drift onto neighboring plants. Moisture needs were supplemented with distilled water supplied at the bottom of the pots.

Test plants were grown for 21 days for Pot Test I and for 30 days for Pot Test II under Gro-Light in the Laminar Flow Biohazard Safety Cabinet (132 × 92 × 183 cm, Labconco Model 47720). A 12-h photoperiod was used for garden vegetables and an 8-h photoperiod for pine seedlings. Photoperiod was controlled for each set of pot tests by an automatic timer. Each pot was rotated a quarter-turn daily to ensure equal light exposure. Distilled water was used throughout the experiments. Moisture contents of the pots were determined by using Water Signals (Jobe). The soil temperature averaged 22 ± 0.5°C, while the air temperature and the humidity averaged approximately 28 ± 1°C and 45%, respectively.

Results

BOD Tests

Standard BOD Experiments: Figure 1 illustrates the results for the first 20-day BOD experiments using the five different concentrations of Ice Shear. The 5-day BOD of the blank was calculated to be 0.21 mg/L, which was close to the limit (0.20 mg/L) set by the APHA (1989) guideline. There were no significant BOD changes at the lower concentrations of Ice Shear (0.5 and 1.0 mg/mL), while considerable microbial activities were detected at the higher concentrations (5.0, 10.0, and 50 mg/L). The BOD measurements from the higher concentrations reached the maximum within 4–6 days of incubation and remained relatively constant. According to the APHA (1989) guideline, at least one sample dilution must meet the criterion of a residual DO of at least 1 mg/L and a DO depletion of at least 2 mg/L after 5 days to achieve a valid BOD test. Both sample concentrations, 5.0 mg/L and 10.0 mg/L, from the standard BOD experiment met the criterion. The latter concentration was chosen to study BOD changes at multiple temperatures. Table 1 summarizes the BOD rate constant, k (0.127 day^{-1}), ultimate BOD, L (3.15 mg/L), and the percentage of the ultimate BOD exerted in 5 days (78.2%), 10 days (89.4%), and 20 days (98.9%) for 10 mg/L Ice Shear at 20°C.

Multiple-Temperature BOD Experiments: The 20-day multiple-temperature BOD experiments were carried out in two sets; one set with a nitrification inhibitor and the other without. The degradation rate of the deicer at the concentration of 10.0 mg/L was clearly affected by the temperature, but not by the presence of the inhibitor. Patterns of the BOD changes of the set without inhibitor are graphed in Figure 2. BOD increased at faster rates at higher temperatures showing no lag at 40°C and a one-day lag at 20°C. At both temperatures, the BOD values reached the plateau for around 10 days and gradually decreased. At 4 and 10°C, drastic increases in the rates of BOD occurred after 8 and 6 days, respectively. There were no noticeable signs of noncarbonaceous oxygen demand at any temperature after 15 days of incubation. Table 2 summarizes the complete BOD results from Ice Shear compared with those from SDD and CMA at different temperatures. According to these results, k values of CMA increase at a faster rate compared to those of Ice Shear and SDD as the temperature increases. The variations of the BOD rate constants of the three organic salts with temperature are graphed in an Arrhenius plot (Figure 3), which shows the temperature dependence of k values of the three deicers. Activation energy for the BOD reaction according to the Arrhenius equation was calculated to be 8.78 kcal $mole^{-1}$ for Ice Shear, 9.69 kcal $mole^{-1}$ for SDD, and 16.5 kcal $mole^{-1}$ for CMA.

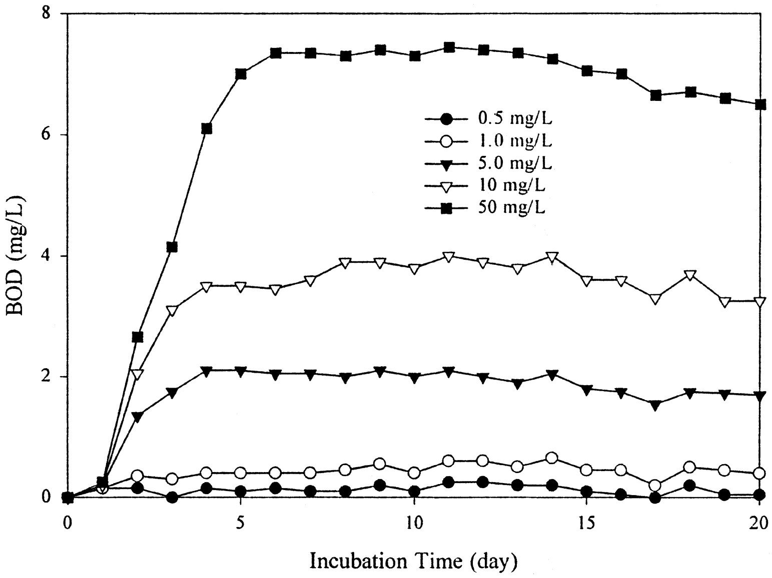

Fig. 1. Changes of BOD over time at 20°C with different concentrations of Ice Shear

Table 1. Summary of the 20-day BOD experiments at 20°C with 10 mg Ice Shear/L

Rate Constant k (day^{-1})	Ultimate BOD L (mg/L)	% Ultimate BOD Exerted in		
		5 Days	10 Days	20 Days
0.127	3.15	78.2	89.4	98.9

COD Tests

Based on the standard curve obtained from the duplicate, a linear equation of $y = 4761.2x$ ($R^2 = 0.9954$) was obtained, where y corresponds to COD in mg/L and x to the absorbance. From the average values obtained from the two samples, the COD of Ice Shear was determined to be 361 mg/L.

Acute Rainbow Trout Bioassays

Details of the acute bioassay results are summarized in Table 3. The pH remained relatively stable at all concentrations of the deicer, even though it increased slightly toward the end of the experiment. No significant changes were observed in the specific conductivity. However, the turbidity of tank water and the ammonia build-up increased at higher concentrations of deicer (tanks 5 and 6) as the duration of exposure advanced. Hardness of tank water increased linearly as the concentration of the deicer increased. Alkalinity appeared to be a quadratic function of the concentration. Some adverse effects of Ice Shear on physiological behavior became evident in tanks 5 and 6, where apparent disorientation in fish movement was observed with some fish swimming vertically or in erratic and frantic patterns. At stronger concentrations of Ice Shear, several fish showed concave abdomen and spinal curvature. Observations after the death of affected fish indicated that gill distention was the most prominent physiological manifestation. The 96-h LC_{50} for rainbow trout was calculated to be 16.1 g Ice Shear/L in a double logarithmic plot according to the method of Sprague (1969).

Phytotoxicity

Observations on greenhouse pot experiments were made with two sets of pot tests; Pot Test I with garden plants and Pot Test II with evergreen seedlings.

Pot Test I: After incubation for 21 days, plant growth was terminated and shoots, roots, and ungerminated seeds were harvested from the pots. Plants were weighed for comparison with all clinging soil lumps removed. Evaluations included potential effects on germination of the seeds and growth of plants, results of which were summarized as percent compared to control in Table 4. Ice Shear seemed to have no effect on the germination of the sunflowers but to have some negative impact on beans. However, the germination and biomass yield of lettuce were greatly affected in the presence of Ice Shear, showing little germination at the highest concentration of the deicer (4 g/kg of soil) and significantly low weight yield in the pots with any addition of the deicer. The sunflowers appeared to benefit from the addition of Ice Shear—the weights of the plants increased with the increase of the deicer concentration. All bean plants reached at least the two-leaf stage with a healthy green color. Some beans exhibited noticeable abnormal features such as lateral growth of the ground stem with the growth at the apical meristem suppressed. As a result, there was a marked difference in the weight of the shoots and roots of the beans at the middle concentrations of the deicer (1.0 and 2.0 g/kg of soil).

Pot Test II: In the pots with roots saturated, stronger, healthier plants were produced in the pots with the lowest concentration (0.5 g/kg of soil) than the control pot without deicer. At low to moderately high concentrations of Ice Shear, the seedlings exhibited good tolerance. Pine seedlings of both control and the lowest concentration retained healthy, green, soft needles and also a number of new root hairs. However, some degrees of progressive browning of needles and less vigorous growth were observed as the concentration of the deicer increased. In the pots of the spray treatment experiments, the seedlings seemed to thrive despite the treatment except for those with the highest

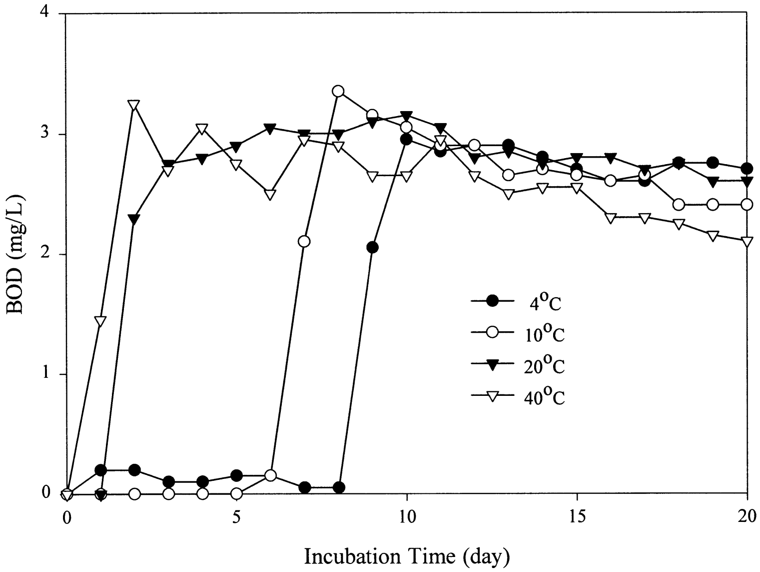

Fig. 2. Changes of BOD over time at multiple temperatures with 10 mg Ice Shear/L

Table 2. Comparison of the BOD data of Ice Shear, SDD, and CMA[a] at multiple temperatures

	2/4°C[b]			10°C			20°C			40°C		
	Ice Shear	SDD	CMA	Ice Shear	SDD	CMA	Ice Shear	SDD	CMA	Ice Shear	SDD	CMA
k (day^{-1})	0.052	0.053	0.02	0.081	0.092	0.064	0.126	0.142	0.130	0.199	NA	NA
L (mg/L)	2.9	2.259	NA	3.15	2.869	NA	3.15	3.681	NA	3.501	NA	NA
Ultimate BOD (%) exerted in												
5 days	41.6	45.8	NA	64.2	65.3	NA	79.7	80.5	69.0	97.9	NA	NA
10 days	69.8	70.6	NA	86.6	87.2	NA	92.3	96.2	83.0	98.2	NA	NA
20 days	90.1	91.4	NA	98.1	98.5	NA	95.5	99.9	92.0	99.2	NA	NA

NA, Not available

[a] Concentration of the deicer: 10 mg/L; SDD data from Bang and Roseland (1989) and CMA data from Horner (1988)

[b] Ice Shear taken at 4°C, while SDD and CMA taken at 2°C

concentration (4 g/kg of soil) of the deicer, where the seedlings did become very pale and started to lose needles by the 25th day. At a concentration of 2 g/kg, pine seedlings showed a remarkable growth rate. They produced a new apical meristem and very heavy new root hairs. The control pots had some minor discoloration compared to the remainder. No new growth of root hairs was observed from the seedlings grown in the pots that received the strongest concentration. The percent changes in total biomass yield of pine seedlings subjected to both treatments are compared in Figure 4. Overall, total biomass of pine seedlings increased in the presence of moderate amounts of Ice Shear via both treatments, the results of which agreed with the observation of external appearance of the plants. However, at a low concentration of deicer (0.5 g/kg of soil) in the spray pot, a slightly hampered growth of the seedlings was observed. At the highest concentration of Ice Shear, the negative impacts were clearly shown among the plants from both treatments.

Discussion

From the comparisons of the overall BOD results (Table 2) of the multiple-temperature experiments of Ice Shear, SDD, and CMA, microbial degradation rates of Ice Shear are found to be close to those of SDD and CMA. High k values of the test deicer at higher temperatures suggest that during the spring thaw the highway runoff of the deicer may cause some degree of oxygen depletion in the receiving waters for a short period of time. There is a potential danger during warmer weather that reaeration of the receiving waters may not be fast enough to replenish the oxygen demanded by aquatic animals. However, according to the Arrhenius plot (Figure 3), Ice Shear requires the lowest activation energy, followed by SDD and CMA, respectively. That is, Ice Shear is least sensitive to the temperature change, while CMA decomposes at a much faster rate at higher temperatures. This implies that adverse environmental impacts caused by microbial degradation of Ice Shear are not expected to be as significant as those of CMA.

While BOD data are available for the organic deicers related to Ice Shear such as SDD and CMA, there is little information on COD references available for compounds related to Ice Shear at the time of this writing. From the results of the COD experiments, 361 mg of oxygen was required to completely oxidize 1 g of Ice Shear in 1 L, which lies below the theoretical value of 426 mg. The difference between theoretical and experimental values may be due to the incomplete dehydration

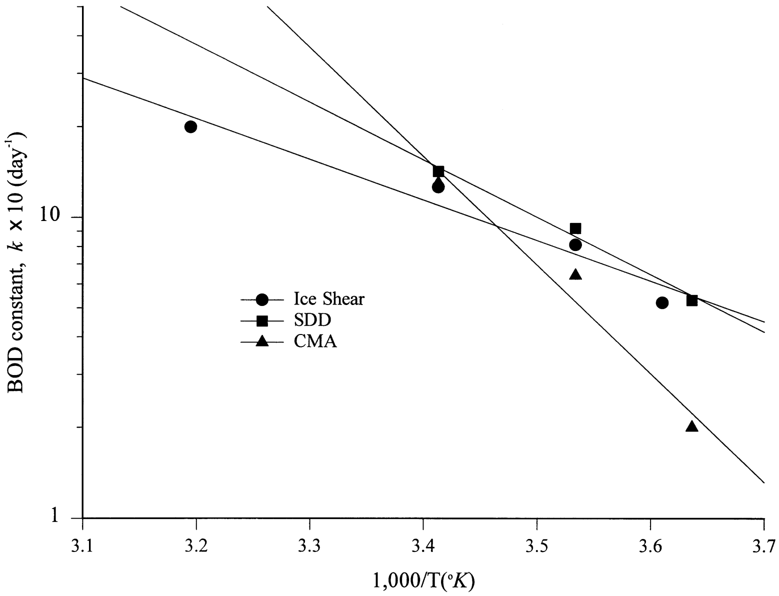

Fig. 3. Arrhenius plot for BOD rate constants, *k* (day^{-1}), of Ice Shear, SDD, and CMA

Table 3. Summary of experimental data of acute rainbow trout bioassays

Conc. of Ice Shear (g/L)	Hardness ($mg\ CaCO_3/L$)		Alkalinity ($mg\ CaCO_3/L$)		Conductivity (mmhos/cm)		pH		No. of Live Fish		Mortality (%)
	0 h	96 h	0 h	96 h	0 h	96 h	0 h	96 h	0 h	96 h	
0	1,500	1,786	119	132	0.16	0.25	6.1	7.0	30	30	0
12.5	1,799	1,808	2,132	3,700	9.45	9.65	6.4	7.0	30	30	0
15.0	1,857	1,929	3,848	4,716	10.78	11.18	6.6	7.2	30	26	13.5
17.5	1,929	2,357	4,696	6,088	12.18	12.4	6.8	7.2	30	8	73
20.0	2,000	2,786	6,088	7,848	14.12	14.35	7.2	7.6	30	0	100
22.5	2,072	3,215	5,664	7,996	15.33	15.5	7.35	7.7	30	0	100

Average temperature: 10 ± 2°C
Average dissolved oxygen: 9.8 ± 1.0 mg/L

Table 4. Effects of Ice Shear on seed germination and total biomass yield of sunflowers, beans, and lettuce from Pot Test I[a]

Conc. of Ice Shear (g/kg of Soil)	Seed Germination			Total Biomass Yield		
	Sunflower	Bean	Lettuce	Sunflower	Bean	Lettuce
0	100	100	100	100	100	100
0.5	100	100	52	103	132	12
1.0	100	100	19	107	436	25
2.0	100	83	19	109	210	19
4.0	100	67	0	124	92	6

[a] Values are in percent and represent the mean for three replicates

of water in the sodium acetate trihydrate molecule prior to the digestion. When COD and ultimate BOD values (*L*) are compared on the basis of 10 mg Ice Shear, it can be concluded that 3.61 mg of oxygen/L is required for chemical oxidation, while 3.15 mg/L is required for microbial oxidation of Ice Shear. Both results demonstrate that over 87% of the organic carbons of Ice Shear are biodegradable within 3 weeks in natural settings.

Earlier, Von Malorny (1969) reported the low toxicity of formate to aquatic animals. Information obtained from the acute bioassays confirms that the toxicity level of Ice Shear to rainbow trout is relatively low even under unrealistically high concentrations of the deicer. The measured LC_{50} of Ice Shear of 16.1 g/L is comparable to that of CMA of 17.5 g/L (Horner 1988). At the temperature (10 ± 2°C) used for cold-water aquatic species such as rainbow trout, the deicer was readily decomposed microbiologically even during the transport (Table 2). Relatively small changes in pH shown in the test tanks, in spite of the accumulation of nitrogenous waste products of fish, could be attributed to the buffering action of CO_2, the end product of microbial degradation of Ice Shear. However, some degree of turbidity in the tanks was apparent at higher concentrations throughout all bioassay experiments. The intensity of the turbidity seemed proportionally related to the increases in pH and organic or inorganic deposits along the tank surfaces.

As indicated in Table 4, improvements in growth and yield of garden plants have been observed with smaller additions of the deicer. The same result is apparent from the tests with pine seedlings as shown in Figure 4. Organic salts in small quantities appeared beneficial for maximizing yields in fertile, yet acidic soil, mimicking plant hormonal activities. Adverse effects of the deicer at an extremely high concentration (4 g/kg of soil) were

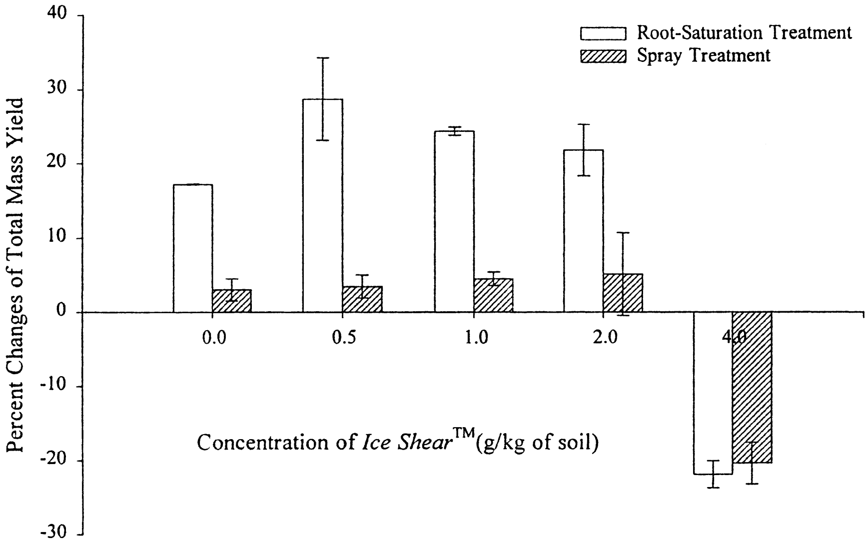

Fig. 4. Percent of total biomass of pine seedlings treated with different concentrations of Ice Shear by root-saturation and spray treatments from Pot Test II. Values are in percent and represent the mean for three replicates

evident from the slow germination and retarded growth or yield due to the dangerously high levels of osmolality surrounding the plants. Among all plants tested, lettuce was the only species showing significant negative impacts with Ice Shear, which is not clearly understood at this writing. All plants chosen in greenhouse pot experiments are known to be glycophytic species and therefore intolerant of and susceptible to salt (Horner 1988).

In summary, the chemical compounds in Ice Shear are readily oxidized biologically. Biodegradation of Ice Shear during transport is rapid enough to dilute the concentration of organic salts in typical highway runoffs (Coghlan 1990; Ostendorf *et al.* 1995). Therefore, the concentrations of Ice Shear that reach receiving waters and soil are expected to be at a much lower level than those used in this study. This alternative highway deicer is relatively harmless to rainbow trout and roadside vegetation. At lower concentrations in soil, the deicer likely serves as a fertilizer for plants. However, no clear explanation is offered for the fact that lettuce is not tolerant to the deicer while other broadleaf vegetation tested is. Overall, this study confirms that Ice Shear has a low environmental toxicity, providing convincing evidence for a positive potential of Ice Shear to replace the conventional inorganic highway deicer, where environmental considerations are paramount.

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