A Study of Salt Pollution of Soil by Highway Salting

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•HEAVY applications of sand-salt mixtures to highways for snow and ice removal are common in New England, where several tons of salt per mile may be applied during a winter. The fate of these quantities of salt after being plowed or splashed from the highway is important. How does this salt affect the environment near the highway? This report provides general answers regarding changes in soil salinity during the course of a year.

The salt applied to a highway must either be carried by surface runoff into streams or by infiltration into the ground. Once salt-bearing water has infiltrated, the salt may become associated with the soil grains by adsorption or ion exchange, or it may remain in solution. Excessive salt infiltration might cause a reduction in soil fertility with resulting damage to plants, and an increase of salts in the groundwater to a level where shallow wells produce unpalatable water.

The fact that plants are unable to thrive in highly saline soils is well established and information for many species of plants and different soil conditions is recorded in agricultural literature. This information is of great value to engineers dealing with problems related to salts. Although some results from this study were referred to existing data on plant tolerance to salts, no attempt was made to supplement this type of information.

The main problem in highway deicing is, "How much salt may be applied without interfering with the environment?" Many related questions must also be answered: What concentrations of salt occur in soils near highways? How does the salt concentration fluctuate during the year? What is the capacity of different types of soil to retain salt as it is applied and to release it during spring and fall rains? How does the salt concentration vary with depth and distance from the highway? This study provides some answers to these related questions based on a 1-yr field study.

The ultimate question remains unanswered, however. Is there some amount of salt that may be applied to a highway during a winter without spoiling the environment near the highway? Considerably more work is required to answer this question.

LITERATURE REVIEW

Introduction

Many researchers have investigated salt with respect to its effect on plants and its occurrence and movement in soil. In considering the effects on plants, the total soluble salt content or salinity is of importance as well as the quantity of the various ionic species. Symptoms of injury would include foliar coloration, marginal leaf scorch and defoliation and death of the tree. These symptoms are similar regardless of whether injury is due to drought, salinity, sodium or chloride (1, 2). This, along with the fact that salt gives rise to salinity, sodium and chloride, makes it difficult to determine the extent of damage caused by each factor.

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Salinity

Salinity interferes with the mechanism by which a plant absorbs moisture from the soil (2, 3, 4). Since water enters the root through a membrane, an osmotic pressure gradient is established across the membrane, the magnitude of which depends on the difference in salt concentration on either side of the membrane. The direction of the gradient is such as to cause water to flow naturally across the membrane toward the higher salt concentration. Increasing salinity in the soil, therefore, makes it increasingly more difficult for water to be taken in by the plant. Osmotic pressures up to 17 atmospheres have been reported (3).

Since osmotic pressure is a concentration phenomena, the effect of a given quantity of salt per unit weight of soil depends on the moisture content of the soil. The salts become more concentrated, and therefore more detrimental, as the wilting percent moisture is approached. The wilting percentage of a sandy soil is lower than that of a finer textured soil. At the wilting percentage, a given quantity of salt is more harmful in a coarse textured soil (2, 4, 5).

Jackson (4) has presented a salinity scale (Fig. 1) which classifies the salinity of a soil according to the specific conductance and percentage of salts in the saturation extract of the soil. The percent moisture at saturation is four times the wilting percent moisture, so the salinity scale makes salinity comparisons in different textured soils more meaningful. Figure 1 also gives the crops suited to various salinity ranges and some of the effects on crops sensitive to salinity. Button (2) has indicated salt tolerances which are similar to those given in Figure 1. Others have also indicated the relative tolerance of various tree species (1, 2, 3, 6). In addition to the immediate damage of saline soils, there is evidence that low salinity may cause small but cumulative damage to trees over a period of years (2). In general, other factors being equal, growth is retarded by increasing salinity due to lack of water or, conversely, more water is required to obtain similar growth characteristics (3, 7).

Sodium

The sodium ion has two characteristics of importance. It changes the character of the soil and has a toxic effect on plants.

Soil has the ability to adsorb cations from solution, with the clay particles having the greatest capacity to do so. The adsorbed ions are in equilibrium with those in the surrounding water. If a sodium salt is applied to the soil, an ion exchange results with

SPECIFIC CONDUCTANCE OF THE SATURATED EXTRACT OF SOIL, MICROMHOS/CM

0 2000 4000 8000 16000

Nonsaline	Very slightly saline	Moderately saline	Strongly saline	Very strongly saline
Salinity effects mostly negligible	Yields of very sensitive crops may be restricted	Yield of many crops restricted. Alfafa, cotton sugar beets, cereals, and grain sorghums adapted.	Only tolerant crops yield satisfactory. Bare spots because of injury to germination.	Only a few very tolerant crops yield satisfactory. Only salt tolerant grasses, herbaceous plants, shrubs, and trees grow.

0 0.1 0.3 0.5 1.0

PERCENTAGE OF SALTS IN MOISTURE SATURATION EXTRACT

Figure 1. Salinity scale [reproduced from (4) by permission of publisher].

sodium replacing calcium on the soil grains. After this exchange of ions, the soil frequently becomes less permeable (2, 4, 6, 7, 8). The loss of calcium from the soil may also be injurious to plants since it is an essential nutrient (2).

There has been some indication of the sodium ion being toxic to trees. It has been shown to cause leaf tip burn in almond trees. In a comparison with calcium chloride, sodium chloride was shown to be the more toxic to elm and white pine (2).

Trees receiving drainage from a highway showed higher levels of sodium in their leaves and twigs than those not receiving the drainage (1). Maples appeared to be particularly sensitive to sodium in this case.

Sodium is generally considered nonessential to plant growth. There are indications, though, that it may interfere with potassium, an essential element, while in other cases it may function in the place of potassium (1, 2, 6).

Chloride

The effect of the chloride ion is especially important in relation to highway salting because it is present in both the salts used, i. e., sodium chloride and calcium chloride. Chloride is not reported to have any deleterious effects on soil characteristics, except as an anion contributing to the salinity, but it is important in relation to groundwater. The U. S. Public Health Service Drinking Water Standards (9) recommend a maximum of 250 mg/l as chloride for drinking water. These standards do not set any particular limits for sodium or calcium except that the total dissolved solids should not exceed 500 mg/l.

Chloride has been found to exert a toxic effect on plants. Excessive chloride is evidenced by its accumulation in the leaves and causing leaf burn (1, 2, 6, 10). Studies in New Hampshire (1) indicate chloride may not be as damaging as sodium since it tends to accumulate only in the leaves which fall off each year, while sodium is also found in the twigs which are a permanent part of the tree. However, in a limited study, Button (10) found that chloride accumulates in twigs as well as in leaves.

Calcium

Calcium is an element commonly found in soils and is essential for plant growth (2, 4). It is added to soil when lime is applied for pH control and also as gypsum to replace excessive quantities of sodium. High concentrations of calcium, however, will cause excessive salinity and may be specifically toxic (2).

Temperature

Temperature can have an effect on the extent of salt injury to plants (6). At lower temperatures plants consume less water through transpiration, and therefore lesser quantities of salts are brought into the plant. Higher temperatures also decrease the moisture content of the soil, which in turn intensifies the salinity problem (4).

Freezing temperatures may markedly affect the infiltration characteristics of soil and, consequently, the extent to which salt intrudes or is excluded, depending on the type of cover, type of soil, and rate of freezing (11). Almost normal infiltration was found in forest soil frozen to a depth of four inches, while corn and pasture areas showed almost no infiltration when frozen to a similar depth. Heavy-textured soil gave less infiltration when frozen than light-textured soil. Slow freezing is conducive to the formation of an ice with low permeability.

After a 7-yr study, Holmes (6) observed no injury to trees where salt was applied only during the winter, concluding that most of the salt was removed with surface runoff and did not penetrate the frozen soil. Grass died in some areas, however, apparently as a result of the salting.

Salt Movement in Soil

Salts are carried from one point to another by the movement of soil moisture (12). As previously indicated, frost formation may, to various degrees, impede the movement of water through the frozen layer. The frozen surface has been found to have a

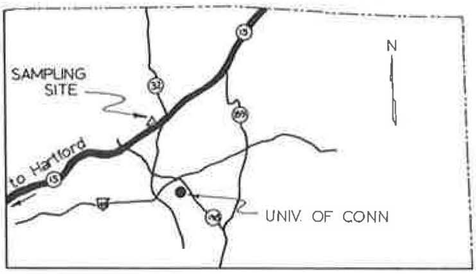

Figure 2. Sampling location on Route 15 in northeastern Connecticut.

higher moisture content than unfrozen soil beneath (11). This is the result of moisture moving up to the frozen area from the lower layers.

In nonfrozen soil the direction of moisture and salt movements depends on the moisture content of the soil (12). With moisture at or near field capacity, movement is toward the groundwater. With low moisture conditions, moisture moves to the surface and evaporates. When the water table is near the surface, large quantities of water evaporate from the soil surface. When water moves to the surface to evaporate or is transpired, salt moves upward also and accumulates near the surface (3, 5, 12). The rate of upward movement depends on the soil permeability. Dissolved salts in low permeability soils did not readily move to the surface, while with higher permeability, higher salt concentrations were found at the surface (5).

Controlled field experiments, in which KCl was applied once to Panoche clay loam and displaced with applications of water, have revealed that chlorides are effectively displaced by intermittent applications of water (18). Relatively small quantities of water displaced chlorides from the top 2 feet to a depth of about 3 feet; however, greater quantities were required to displace the chloride through the lower depths. As the chlorides were displaced from the top 2 feet a bell-shaped chloride-depth profile was produced. The maximum chloride concentration decreased as it moved downward. At a depth of 5 feet only a small increase in chloride concentration was observed as the salt was leached from the soil. For a given total water application, the frequent application of small quantities most efficiently displaced chlorides from the top 2 feet of soil.

More limited information is available on horizontal movement of salts. This factor will depend primarily on local runoff conditions. Studies in New Hampshire (1) showed above-normal concentrations of sodium in the soil only within 30 feet of the highway. Observations at one location in Connecticut (Fig. 2) showed trees above the pavement on the slope of a cut, but within 10 feet laterally, received chloride from the splashing of vehicles and wind-blown mist (10). The level of accumulation, however, was insufficient to cause apparent damage. Only those trees which received brine drainage from the pavement showed injury.

Fifteen sets of samples were collected between January 4 and April 27, 1966, and three additional sets of samples were collected in October 1966. Three snowfalls and salt applications had occurred before the first samples were obtained in January. The samples collected in October 1966, are useful as a base of comparison. It is expected that conditions during the fall of 1965 were quite similar to those during the fall of 1966. Of course, long-term field observations would be required to determine whether or not the salts decrease during the spring and summer to the same level each year.

Samples were excavated in two ways. At first a split spoon sampler was used, but this was difficult to handle and extremely time consuming. Also, in order to obtain a sufficiently large sample for the chemical analyses, it was necessary to use soil from several inches above and below the desired depth. A 6-in. power auger was later used to dig a 3-ft deep hole. The sides of the hole were brushed to remove disturbed soil and the samples were then taken from the sidewall. This method was faster and easier, and samples of any desired size could be collected. Samples were transported and stored in covered, unwaxed paper cups.

All holes were refilled after the samples had been collected in order to preserve the original drainage pattern in the area. Sampling on subsequent days required moving parallel to the highway to a location several feet from any refilled holes. Visual examination of the samples indicated that the same type soil was always obtained.

Collecting a set of 20 samples consumed about 8 man-hours when the power auger was used.

SOIL CHEMICAL ANALYSES

All soil samples were analyzed for total soluble salt, chloride, and sodium. The techniques used resulted in measurement of the salt present in both the soil and the soil water when the samples were collected.

Soil salinity is commonly used by agriculturalists to indicate the total soluble salt level, and the salt tolerance of plants is specified in terms of salinity. Since the salts applied to highways are sodium chloride and calcium chloride, the chloride ion serves as a convenient tracer and is used here as a measure of the salt originating from the highway. There is evidence that both cation concentration and cation type in soil are critical. Specifically, the sodium ion has been shown harmful to plants. Most soils show a tendency to exchange normal cations such as calcium for sodium. Therefore, sodium ion concentration was also measured.

Total Soluble Salt

Total soluble salt was measured using a Betz Conducto-Bridge, Model X 50. This instrument measures the ability of a solution to conduct a current. As the soluble salt concentration is increased, the solution becomes a more effective conductor. The specific conductance of a solution is the conductance that would be measured at 25 C between electrodes 1 sq cm in cross section and placed 1 cm apart. The units associated with this measurement, as indicated by the instrument, are micromhos per centimeter. A temperature adjusting circuit is part of the meter so all results are in terms of 25 C.

The Conducto-Bridge must be calibrated against standard solutions of sodium chloride. A typical calibration curve is shown in Figure 3. The instrument calibration was checked frequently. The electrodes required replatinizing (recoating) occasionally to retain proper instrument response.

Basically, the total soluble salt measurement consisted of agitating a mixture of 100 milliliters of distilled water and 50 grams of soil to dissolve the salts, filtering this mixture, and measuring the conductance of the filtrate (13). A few of the early samples were too small to permit the use of a 50-gram sample. In such cases a 35-gram soil sample was agitated with 70-ml distilled water. At least 70 ml of filtrate was needed to submerge the conductivity electrode to the required extent. With the aid of the calibration curve the conductance reading was converted to a total soluble salt concentration as milligrams of sodium chloride per kilogram of soil, or parts sodium chloride per million parts soil (ppm). A more detailed procedure is presented in Appendix A of this report.

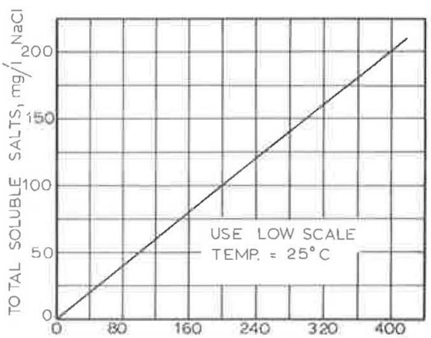

Figure 3. Conductivity meter calibration curve.

Chloride

The filtrate which was analyzed in the soluble salt test was also used for the chloride analysis. Chloride ion concentration was determined using the Mercuric-Nitrate test as described in "Standard Methods for the Examination of Water and Wastewater" (14). This is a rapid, accurate titration technique using mercuric nitrate as a titrant and diphenylcarbozone as an end point indicator. Results are reported as milligrams of chloride per kilogram of soil, or parts chloride per million parts soil (ppm).

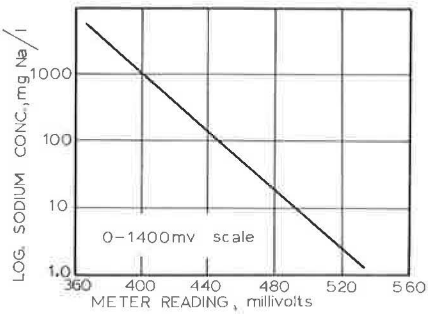

Figure 4. Sodium electrode calibration curve.

Sodium

Three methods for sodium analysis were considered: gravimetric analysis, flame photometry, and electrometric. Gravimetric analyses are extremely time consuming and require considerable skill. Work by Bower (15) and Fehrenbacher (16) has shown that the results of flame photometric measurements compare with those made electrometrically using a sodium specific electrode. The sodium electrode method can be used over a wider range of sodium without dilutions, and is simpler and more rapid than a flame photometer. For these reasons the sodium ion concentration was measured using a sodium sensitive electrode.

A Beckman Zeromatic pH Meter was converted to a "sodium meter" by replacing the hydrogen sensitive electrode with a Beckman 39137 Cationic Electrode which is sensitive to sodium ions.

This electrode is effective over a concentration range of 1.0 to 0.0001 Normal, a temperature range of 0 to 80 C, and a pH range of 9 to 13. The reference electrode is the standard saturated KCl-calomel half-cell with a fiber-type salt bridge. The glass sodium electrode tip is sensitive to differences in ionic activity. When connected to the pH meter circuit, the activity difference between the test sodium solution and the reference solution is indicated as a voltage. The meter is calibrated using standard sodium chloride solutions so that the indicated meter voltage may be converted to sodium ion concentration. A typical calibration curve is shown in Figure 4.

The sodium electrode is also sensitive to several monovalent cations other than sodium. Interference from hydrogen ions is easily avoided by adjusting the pH of the sample so that the H^+ concentration is less than one ten-thousandth the sodium concentration to be measured. The pH of all samples analyzed for sodium was adjusted to pH 10.

Sodium was extracted from the soil using a solution of sulfuric and hydrochloric acid. Activated carbon was also added to adsorb organics extracted from the soil (17). The mixture was agitated and then filtered and the sodium analysis made on the filtrate. A more detailed procedure is presented in Appendix B.

RESULTS AND DISCUSSION

Before examining the results of this study, it would be useful to review the salting procedures and quantities of salt applied by the Connecticut State Highway Department. This information was obtained from Mr. J. Bauer at the Department's local headquarters in Willington, Connecticut.

Records are maintained by the crews responsible for snow and ice control, and consist of the cubic yards of sand, tons of salt and the number of salt applications for each storm. The salt application rate used on Route 15 is 800-1000 lb/mi, while secondary routes receive 500-600 lb/mi. Additional salt is also mixed with the sand. The crew responsible for Route 15 at the sampling site is assigned 35.8 mi of the route beginning at exit 100 and extending to the Massachusetts line. The sampling site was between exits 101 and 102. In addition, this crew is responsible for 58.2 mi of secondary roads in the area. Records for total sand and salt used by this crew are given in Table 1. The sections assigned to each crew are not rigidly fixed and it is possible that at times another crew may have also applied salt at the sampling site.

The salt used is primarily sodium chloride with some calcium chloride being mixed in for use when the temperature is 26 F or less. Salt is applied at the beginning of a storm and also after the storm when necessary to remove any snow and ice packed on the highway.

TABLE 1

SALTING RECORD FROM
CONNECTICUT HIGHWAY DEPARTMENT

Date	Sand (cu yd)	Salt (ton)	No. Salt Applications
Dec. 20, '65	845	255	
Dec. 26	193	41	
Jan. 2-3, '66	160	270	
Jan. 6	283	47	
Jan. 8-9	522	208	2.5
Jan. 13	207	113	2
Jan. 19	108	57	1
Jan. 21	197	33	1
Jan. 23-24	233	427	5
Jan. 27	216	94	1
Jan. 30	346	209	4
Feb. 3-4-5	387	213	3
Feb. 13	108	57	1
Feb. 16-17	153	27	1
Feb. 19-20	162	18	
Feb. 24-25-26	396	284	4
Mar. 12	256	354	3

As anticipated, the greatest salt concentrations were found near the highway (Fig. 5). Some salt travels more than 100 ft laterally from the highway, even when the ground is very gently sloped. In general, the salt concentrations decrease farther from the highway and the fluctuations in concentration are smaller. After February the tendency for salt to travel laterally even 25 ft appears considerably reduced. This was probably the result of lesser amounts of frost allowing more infiltration of snow melt and rainwater.

The greatest salt concentrations were at the soil surface regardless of the distance from the highway. The highest salt concentration measured was 450 ppm at the soil surface 5 ft from the pavement on February 10. Unfortunately, a complete record at the 5-ft distance was not obtained. The maximum concentration at the other distances occurred in January so concentrations greater than 450 ppm probably had occurred at the 5-ft distance, but were not observed. The soil saturation moisture percentage was approximately 50 percent for the topsoil and 25 percent for the subsoil. Therefore, the maximum observed salt concentration in the saturation extract was 900 mg/l for the topsoil, well within the limit for a nonsaline soil on the salinity scale shown in Figure 1. The highest level recorded in the subsoil was 164 ppm, or 656 mg/l in the saturation extract. The complete total soluble salts data record is presented in Table 2.

By March 1 most of the salt had been leached from the top 3 ft of soil at distances 25 ft or more from the highway. By April 1 this was true 5 ft from the highway also. After March or April only small changes in salt concentration were observed, as shown in Figures 6 and 7. The concentration at all distances from the highway and depths continued to decrease slightly during the summer. Small fluctuations, such as observed after about April 1, probably reflect the effect of having to obtain samples from a slightly different location each day and are considered insignificant.

Although certain trends were observed, insufficient data were obtained to precisely follow salt movements and establish the rates of movement. To do this would require frequent analyses of soil water obtained from undisturbed soil.

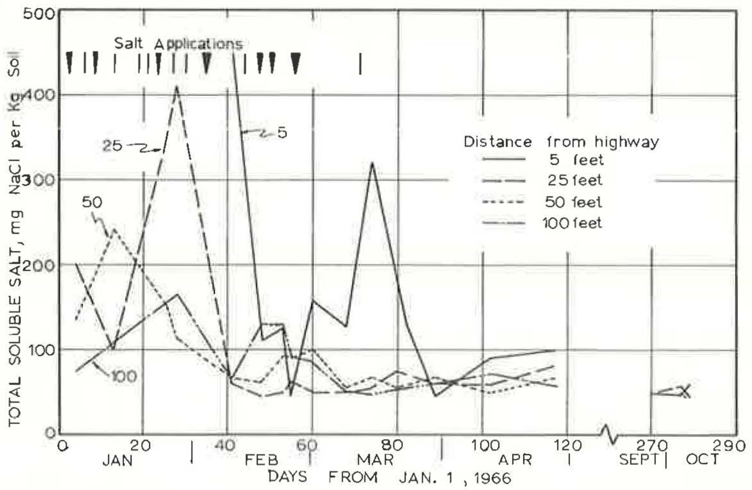

Figure 5. Total soluble salt concentration at soil surface several distances from highway.

TABLE 2

TOTAL SOLUBLE SALTS CONCENTRATION,
mg NaCl PER Kg SOIL (ppm)

Date	Depth (ft) Top	0.5	1	2	3
	(a) 5 ft from edge of paved shoulder				
1-4-66	No samples taken from this location until 2-10-66				
1-13-66					
1-24-66					
1-28-66					
2-10-66	450	270	86	164	110
2-17-66	110	105	105	160	82
2-22-66	125	86	41	110	63
2-24-66	45	99	37	120	52
3-1-66	158	70	56	57	140
3-9-66	127	44	62	140	68
3-15-66	320	43	50	56	60
3-23-66	130	110	85	79	60
3-29-66	46	56	62	100	60
4-12-66	91	82	78	75	62
4-27-66	100	125	84	135	97
9-27-66	50	52	55	65	78
10-4-66	48	60	54	64	58
10-6-66	60	54	48	44	54
	(b) 25 ft from edge of paved shoulder				
1-4-66	201	136	38	58	35
1-13-66	100	105	48	43	48
1-24-66	322	124	—	—	—
1-28-66	410	78	69	34	30
2-10-66	60	45	60	46	37
2-17-66	45	42	38	58	63
2-22-66	50	38	34	34	32
2-24-66	62	50	32	48	45
3-1-66	50	52	46	34	37
3-9-66	50	22	30	20	25
3-15-66	56	47	24	32	28
3-23-66	75	60	44	39	32
3-29-66	61	43	35	32	22
4-12-66	60	47	52	36	35
4-27-66	82	44	45	48	45
9-27-66	49	32	32	34	30
10-4-66	58	37	34	34	33
10-6-66	45	35	35	29	31

Date	Depth (ft) Top	0.5	1	2	3
	(c) 50 ft from edge of paved shoulder				
1-4-66	135	44	42	38	36
1-13-66	240	82	42	33	34
1-24-66	164	105	—	—	—
1-28-66	114	64	38	34	68
2-10-66	68	96	52	66	39
2-17-66	63	72	42	87	51
2-22-66	91	54	66	44	35
2-24-66	90	33	30	44	41
3-1-66	100	67	48	33	56
3-9-66	56	30	34	35	35
3-15-66	68	39	30	31	38
3-23-66	56	45	35	30	26
3-29-66	68	25	40	29	32
4-12-66	50	35	36	27	—
4-27-66	68	53	50	—	50
9-27-66	48	35	37	36	30
10-4-66	50	66	40	34	34
10-6-66	44	30	28	28	30
	(d) 100 ft from edge of paved shoulder				
1-4-66	74	—	56	46	56
1-13-66	—	67	60	—	—
1-24-66	150	80	—	—	—
1-28-66	166	108	44	40	39
2-10-66	65	52	93	52	51
2-17-66	130	92	45	122	50
2-22-66	130	128	52	75	42
2-24-66	92	45	43	46	50
3-1-66	84	50	38	42	38
3-9-66	51	29	33	35	61
3-15-66	48	34	30	37	35
3-23-66	55	30	30	34	28
3-29-66	61	40	35	38	31
4-12-66	73	46	50	40	25
4-27-66	60	43	35	47	43
9-27-66	50	43	45	48	40
10-4-66	47	34	32	34	34
10-6-66	43	33	39	32	34

In general, the salt concentration decreased with depth, and the fluctuations in salt concentration were smaller at lower depths. This should be expected since the salt is both diluted and dispersed as it moves through the soil. Samples taken 5 ft from the

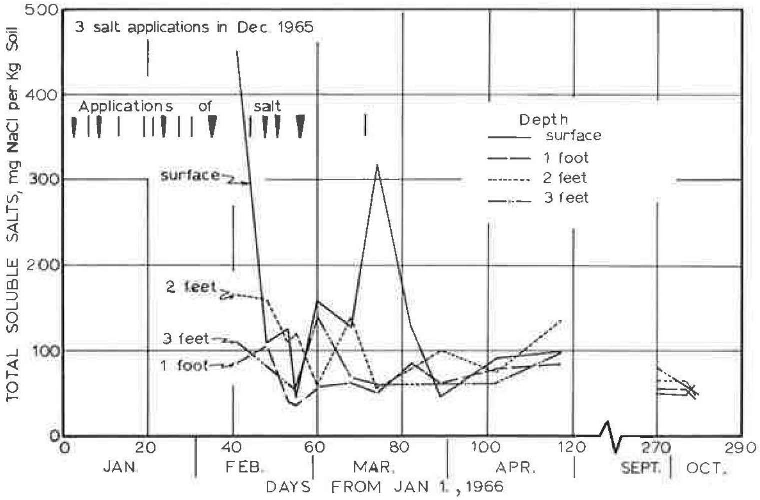

Figure 6. Total soluble salts at several depths 5 ft from highway.

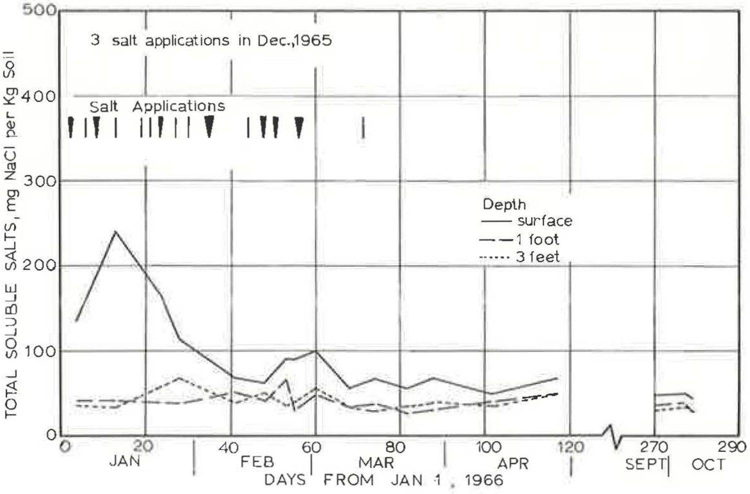

Figure 7. Total soluble salts at several depths 50 ft from highway.

highway revealed that the concentration at the 2-ft depth was often greater than that at the $1/2$ and 1-ft depths. The pattern observed may result from the irregular spacing of salt applications and sampling times. The soil at the 2-ft depth may absorb salts more readily than other depths, although visually the soil at all depths appeared similar. Differing compaction during construction of the highway may also have resulted in sufficiently different permeabilities to give the results obtained. Most likely a combination of factors results in the salt being rapidly transported to the 2-ft depth and then gradually dispersed and diluted from there.

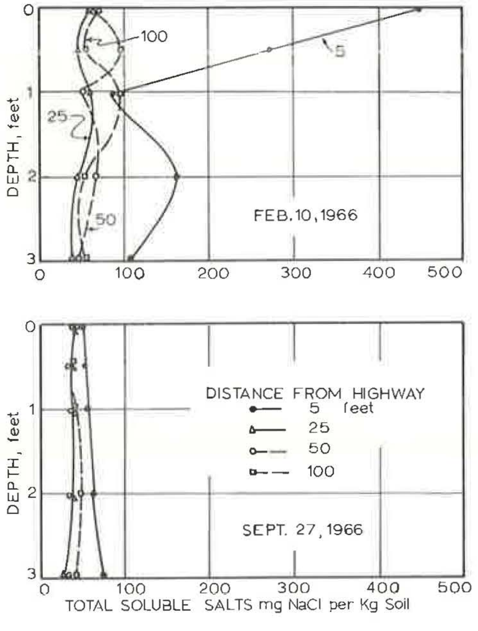

Figure 8. Depth profile of total soluble salt concentration.

During the highway salting season large variations of salt concentration with depth were observed, while at other seasons little variation was found. Figure 8 compares a depth profile observed shortly after a salt application with one existing about six months later, after spring rains and snow melts had leached most of the salts from the soil. On February 10 the effects of two salt applications are evident at a distance of 5 ft from the highway. The salt from the earlier application has been leached below the 1-ft level and shows as a peak concentration at the 2-ft depth. A subsequent application has only begun to penetrate the soil and is concentrated mostly at the surface, possibly because of frozen ground conditions. At other distances from the highway the concentration at any depth may be greater or less than that at another depth. Insufficient information is available to define or predict the rates of travel which produced these results, but the observed conditions are in accordance with the observations of Miller et al (18).

In general, the concentrations of chlorides showed the same fluctuations as the total soluble salts, and graphical representations of chloride data would be similar to those already presented. The same trends would be revealed and the same conclusions would be indicated. Complete chloride data are presented in Table C-1 of Appendix C.

Sodium concentration data did not fit the pattern established by the chlorides and total soluble salts. Early in the study some scattered high values of sodium were observed, but not as frequently as in the total soluble salts and chloride data. After mid-February, however, the sodium concentration rarely exceeded 25 ppm. This may be related to the exchange of sodium by the soil particles, or to the extraction procedure used in the sodium analysis, but no explanation is evident. The sodium data are presented in Table C-2.

CONCLUSIONS

The maximum concentrations of salts may be found at the soil surface and nearest the highway. These studies indicate that the soil salinity problem resulting from highway salting is minimal for similar field conditions. Adverse drainage conditions, however, could create more serious problems and should be avoided.

There is some tendency for salts to travel laterally away from the highway, but the most prevalent movement is downward into the soil. As infiltration proceeds, the salt concentration is markedly decreased from that at the surface. The salt concentrations in the subsoil are generally decreased as depth increases, but occasionally this pattern may not appear. Salts are readily leached from the top several feet of soil and by April the majority of the salts have disappeared. The salt concentrations continue to decrease gradually through the summer and reach a low level before salt applications are resumed again the following winter.

Chloride measurements are generally proportional to total soluble salts measurements. Sodium ion concentrations, however, appear to establish a pattern somewhat different than the total salts.

Further work is required to define the seasonal pattern of changes in soil salinity more carefully and to ascertain whether the salt levels decrease to their former level over the summer season. Rates of movement of salts through soils of all types must be known in order to better understand the patterns observed in certain depth profiles, and to be able to predict the concentrations which will result at various depths and distances from the road. In order to answer the question of how much salt may be applied in any specified situation without causing damage, answers must be obtained. Soil type, drainage patterns, salt application rates, infiltration rates, frequency of salt and water application, and frost conditions are all involved in the problem. At present, even the most simple cases involving salt applications to unfrozen ground are not entirely understood.

ACKNOWLEDGMENTS

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Appendix A

TOTAL SOLUBLE SALT ANALYSIS

A Betz Conducto-Bridge, Model X 50, was used to measure the conductance of a soil extract solution. This instrument has two ranges of conductance which may be used. The lower range, which indicates 0 to 150 micromhos per centimeter, was used since the salt concentrations found were relatively low.

Calibration of Conductivity Meter

Prepare a series of sodium chloride solutions of known concentration. Determine the meter conductance reading corresponding to each of these concentrations according to the procedure given in the "Instrument Operation" paragraph. Construct a graph of conductance, micromhos per centimeter, versus concentration, mg/l NaCl. The instrument should be recalibrated periodically.

If the black coating of the electrodes becomes thin or chipped, the instrument readings will not be reliable. The electrodes may be renewed by replatinizing. This procedure is described in the Conducto-Bridge Instruction Manual.

Preparation of Soil Samples (13)

Weigh out 50 grams of soil which has been passed through a 2-mm sieve. Place this sample in a 250-ml Erlenmeyer flask and add 100-ml distilled water. Agitate this mixture with an Eberbach shaker for 20 min and then allow 20 min for clarification. Filter the supernatant through Whatman's No. 1 filter paper. The filtrate conductance is then measured using the Conducto-Bridge.

Use of the Conductivity Meter

Measure the temperature of the sample and set the temperature compensating dial on the meter. Set the conductivity range for the low readings. Immerse the electrode so that the perforations in the casing are submerged. Adjust the scope to the largest dark band and record the observed conductivity reading. Convert this reading to total salt concentration, as mg/l NaCl, with the aid of the calibration chart. This value can be related to the soil as ppm by multiplying by two. Rinse the electrode well with distilled water between readings.

Appendix B

SODIUM CONCENTRATION MEASUREMENT

A Beckman Zeromatic pH Meter may be modified to measure sodium electrometrically by replacing the hydrogen sensitive electrode with a Beckman 39137 Cationic Electrode. The cationic electrode, which is sensitive to sodium, was paired with a standard calomel reference electrode. The "sodium meter" was operated to measure millivolts over the 0 to 1400-mv range. The procedure for accomplishing this is stated in the pH meter instruction manual.

Calibration of the Sodium Electrode

The electrode actually measures ionic activity and not concentration. Therefore, the electrode calibration must cover the range of concentrations that are to be measured. The pH of the calibration standards should be the same as that to which the soil sample extracts are to be adjusted.

Prepare a series of standard sodium chloride solutions. A tenfold dilution factor between standards is convenient. Solutions of 0.1 to 0.0001 molar sodium were used and the pH of each dilution was adjusted to 10.

Immerse the electrodes in each of the standard solutions and record the observed millivolt readings. Construct a calibration curve by plotting millivolts versus the sodium ion concentration of each standard solution.

Preparation of Soil Samples (17)

The sodium must be extracted from the soil with an acid solution. Prepare an extracting solution consisting of 12-ml concentrated sulfuric acid, 73-ml hydrochloric acid, and sufficient distilled water to make 18 liters.

Place 20 grams of soil which has been passed through a 2-mm sieve in a 250-ml Erlenmeyer flask. Add 80 ml of extracting solution and about 0. 8-grams activated carbon. Agitate this mixture on an Eberbach shaker for 5 min and filter through Whatman's No. 1 filter paper.

Immerse the electrodes in the filtrate and measure the sodium ion response in millivolts. With the aid of the calibration chart convert the millivolts reading to sodium ion concentration, as mg/l Na. This value can be related to the soil as ppm by multiplying by four. Rinse the meter electrodes thoroughly with distilled water between measurements.

Appendix C

TABLE C-1

CHLORIDE CONCENTRATION, mg Cl^- PER Kg SOIL (ppm)

Date	Depth (ft)					Date	Depth (ft)				
	Top	0. 5	1	2	3		Top	0. 5	1	2	3
	(a) 5 ft from edge of paved shoulder						(c) 50 ft from edge of paved shoulder				
1-4-66						1-4-66	36	—	8	10	8
1-13-66	No samples taken from this location until 2-10-66					1-13-66	66	22	12	12	12
1-24-66						1-24-66	48	30	—	—	—
1-28-66						1-28-66	33	13	13	9	18
2-10-66	204	136	27	88	60	2-10-66	17	27	9	14	6
2-17-66	34	51	50	98	36	2-17-66	26	22	15	27	15
2-22-66	64	46	13	66	34	2-22-66	25	12	20	13	15
2-24-66	12	28	12	71	12	2-24-66	22	10	12	14	10
3-1-66	47	24	18	20	87	3-1-66	30	18	12	16	14
3-9-66	55	17	30	86	24	3-9-66	16	12	11	16	14
3-15-66	20	30	30	29	27	3-15-66	22	14	12	16	14
3-23-66	55	44	22	20	38	3-23-66	12	9	12	10	8
3-29-66	19	22	24	56	27	3-29-66	19	9	9	8	12
4-12-66	28	38	20	39	17	4-12-66	18	12	15	9	—
4-27-66	22	25	18	10	22	4-27-66	13	12	12	25	11
9-27-66	10	12	17	18	27	9-27-66	12	7	8	9	8
10-4-66	12	18	12	14	12	10-4-66	13	15	10	16	10
10-6-66	20	16	12	20	20	10-6-66	16	12	12	10	12
	(b) 25 ft from edge of paved shoulder						(d) 100 ft from edge of paved shoulder				
1-4-66	48	41	12	16	8	1-4-66	15	—	15	10	6
1-13-66	36	24	11	12	13	1-13-66	—	11	54	—	—
1-24-66	105	40	—	—	—	1-24-66	34	22	—	—	—
1-28-66	104	20	28	12	13	1-28-66	36	27	13	18	12
2-10-66	16	15	18	15	9	2-10-66	15	12	14	14	14
2-17-66	14	28	16	25	14	2-17-66	30	28	12	26	15
2-22-66	16	10	14	16	14	2-22-66	36	30	13	18	16
2-24-66	17	12	12	14	10	2-24-66	22	14	12	12	16
3-1-66	18	10	14	12	16	3-1-66	26	16	10	10	12
3-9-66	12	8	8	8	9	3-9-66	10	10	9	10	12
3-15-66	16	10	10	8	8	3-15-66	16	9	10	16	14
3-23-66	20	16	14	12	8	3-23-66	16	10	8	8	8
3-29-66	18	12	12	10	8	3-29-66	15	15	12	12	7
4-12-66	18	12	14	12	12	4-12-66	20	18	16	15	8
4-27-66	26	12	11	16	14	4-27-66	12	10	9	10	16
9-27-66	8	18	8	7	6	9-27-66	19	10	4	7	7
10-4-66	13	12	8	12	16	10-4-66	13	12	12	9	8
10-6-66	14	10	16	14	12	10-6-66	16	12	14	12	12

TABLE C-2

SODIUM ION CONCENTRATION, mg Na PER Kg SOIL

Date	Depth (ft)					Date	Depth (ft)				
	Top	0.5	1.0	2.0	3.0		Top	0.5	1.0	2.0	3.0
(a) 5 ft from edge of paved shoulder						(c) 50 ft from edge of paved shoulder					
1-4-66						1-4-66	—	6.6	—	—	3.2
1-13-66	No samples obtained from this location until 2-10-66					1-13-66	23.9	1.2	—	2.0	—
1-24-66						1-24-66	106.0	45.2	—	—	—
1-28-66						1-28-66	172.0	70.0	70.0	14.8	—
2-10-66	138.0	—	23.9	14.8	41.3	2-10-66	106.0	12.0	14.7	106.0	1.5
2-17-66	23.9	14.8	9.2	14.8	14.8	2-17-66	23.9	2.0	9.2	14.8	3.2
2-22-66	5.5	14.8	9.2	5.5	3.2	2-22-66	9.2	2.0	6.0	3.2	9.2
2-24-66	19.8	14.8	4.4	5.5	3.2	2-24-66	54.4	14.8	9.2	1.2	5.6
3-1-66	14.8	9.2	1.9	6.6	5.5	3-1-66	9.2	5.5	2.0	3.2	2.0
3-9-66	14.8	2.0	1.2	5.5	9.2	3-9-66	14.8	5.5	3.2	6.6	3.2
3-15-66	41.1	9.2	3.2	5.5	5.5	3-15-66	14.8	9.2	9.2	2.0	5.6
3-23-66	14.8	9.2	5.5	3.2	5.5	3-23-66	14.8	9.2	9.2	14.8	5.6
3-29-66	9.2	3.2	4.4	2.6	14.7	3-29-66	14.8	3.2	3.2	9.2	12.0
4-12-66	14.8	9.2	9.2	9.2	5.2	4-12-66	9.2	5.6	5.6	5.6	—
4-27-66	12.0	23.9	9.2	5.5	3.2	4-27-66	9.2	9.2	4.4	5.6	3.2
9-27-66	3.2	3.2	8.4	3.2	3.2	9-27-66	—	—	18.4	8.4	18.4
10-4-66	—	—	5.1	—	1.4	10-4-66	—	—	—	8.3	5.1
10-6-66	—	—	—	—	—	10-6-66	23.2	18.4	23.2	23.2	18.4
(b) 25 ft from edge of paved shoulder						(d) 100 ft from edge of paved shoulder					
1-4-66	9.2	—	—	—	—	1-4-66	—	—	14.7	64.4	23.8
1-13-66	5.5	0.8	1.2	—	—	1-13-66	—	106.4	39.1	—	—
1-24-66	285.0	9.2	—	—	—	1-24-66	138.0	59.0	—	—	—
1-28-66	—	83.0	50.5	24.0	24.0	1-28-66	—	49.4	41.2	—	49.4
2-10-66	14.8	3.2	9.2	24.0	24.0	1-10-66	1.6	23.8	9.2	14.8	106.4
2-17-66	14.8	4.4	3.2	9.2	1.2	2-17-66	83.0	14.8	5.5	14.8	14.8
2-22-66	3.2	4.4	5.2	5.2	3.2	2-22-66	9.2	3.2	5.5	5.5	0.8
2-24-66	9.2	5.2	1.2	4.4	5.2	2-24-66	14.8	5.4	5.4	9.2	12.0
3-1-66	9.2	5.2	2.0	2.0	3.2	3-1-66	14.8	3.2	3.2	5.4	3.2
3-9-66	2.0	2.0	1.4	—	1.2	3-9-66	9.2	9.2	6.6	3.2	9.2
3-15-66	23.7	3.2	3.2	9.2	3.2	3-15-66	12.0	5.6	6.7	18.4	5.6
3-23-66	23.7	12.0	9.2	5.2	5.2	3-23-66	23.8	23.8	23.8	9.2	5.6
3-29-66	9.7	2.5	6.6	5.5	3.2	3-29-66	9.2	3.2	9.2	4.4	3.2
4-12-66	23.9	9.2	2.5	5.5	1.9	4-12-66	14.8	18.4	5.6	14.8	9.2
4-27-66	12.0	1.5	4.4	14.8	14.8	4-27-66	4.4	14.8	6.6	14.8	9.2
9-27-66	3.2	3.2	3.2	5.1	—	9-27-66	—	—	18.4	3.2	—
10-4-66	—	8.3	—	1.3	—	10-4-66	1.2	—	—	—	1.2
10-6-66	—	—	—	—	—	10-6-66	—	—	—	—	—