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A preliminary investigation into the effects of deicing salts on roadside soils in Essex County.

James H. Coffey
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NL-339 (3/77)

A PRELIMINARY INVESTIGATION INTO THE EFFECTS OF DEICING SALTS ON ROADSIDE SOILS IN ESSEX COUNTY

by

James H. Coffey

A thesis submitted to the Faculty of Graduate Studies through the Department of Geography in partial fulfillment of the requirements for the degree of Master of Arts at the University of Windsor

Department of Geography
University of Windsor
1976

To Mary and Jessica

ABSTRACT

It was the primary purpose of this research to examine the impact of deicing salt; namely sodium chloride (NaCl), on the soil adjacent to Highway 18 in Essex County. Three soil types, Granby Sand, Berrian Sandy Loam, and Toledo Clay were studied to determine whether they reacted differently to the addition of sodium chloride during the winter 1975-1976.

Changes in total salinity, sodium concentration, and cation-exchange capacity were studied over time, over distance from the highway, and over depth in the soil. Using the Ordered Hypothesis for Multiple Treatments, it was found that none of the variables changed significantly over the study period, at the soil surface or at the 0.3m depth. Simple regression and correlation techniques were employed to test for the change in each variable with distance from the highway. Neither total salinity, nor cation-exchange capacity changed significantly with distance. Sodium on the other hand was found to decrease significantly with distance. Surface and depth values were compared using the Wilcoxon Rank-Sum test and were found not to differ significantly. Total slainity and sodium content were found to have high correlation when examined on a monthly basis, particularly in the sandy loam soils, but not when all data were combined. The relationship between sodium and cation-exchange capacity was also tested using simple regression, and was found to be not significant, except when all values were combined, in which case, the hypothesis had to be rejected because of the very high unexplained variation. Using the Wilcoxon Rank-Sum test, it was shown that total salinity and sodium content did not differ significantly between soil types, however, cation-exchange capacity differences were significant, due more to clay and organic matter rather than the sodium content of the soil.

A soil column experiment was conducted to test the hypotheses under controlled conditions. Total salinity and sodium values increased significantly with additions of sodium chloride, whereas, cation-exchange capacity was not found to decrease significantly. Regression analysis performed on the column data, generated a significant positive correlation between total salinity and sodium and a significant negative correlation between cation-exchange capacity and sodium.

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CHAPTER ONE

INTRODUCTION

The environmental impact of man's industrial processes has, over the past several decades, become a prime concern with the general public as well as with scientists. This concern has been borne out primarily in urban areas where air pollution has become the cause of numerous respiratory disorders. The impact is not felt solely in cities however, as rural residents are increasingly becoming aware of the detrimental side effects of insecticides, fungicides, herbicides, and fertilizers. All too often environmental impact has been superseded by the economic gain which could be gleaned from a particular process or product. The public desire for a clean, natural environment has forced governments to legislate against numerous pollution practices, primarily in the areas of waste disposal into the atmosphere and water courses. Standards are also maintained in terms of chemical compositions of fertilizers and pest controls (e.g. DDT). If concern is to be had for the so-called major pollutants, than that concern must also be extended to those seemingly minor ones, which through repeated use could, in time, produce major environmental problems.

The deicing salts, sodium chloride ($NaCl$) and calcium chloride ($CaCl_2$) have the potential to produce environmental problems. The most evident side effect of deicing salts is the corrosion of auto bodies. Less notable results of its corrosive powers are evident in the breakdown of concrete sidewalks, the burning of lawns and shrubs, and the corrosion of buried utility transmission lines.

McConnell and Lewis (1972) state that the American motorist's demand for speed and convenience, even when bad weather affects road conditions, has led to a dramatic increase in the quantity of salts applied to U.S. highways. Approximately 9 million tons of deicing salts were used in 1972 alone, and it is expected that the amount used will double every five years. Comparable figures are not readily available from Canadian sources, but it is expected that, given its northerly location, the difference in population and highway networks, its volume would be proportional. Inevitably the questions as to where the salt goes, and what are its harmful side-effects must be asked. It is the purpose of this research to attempt to determine whether deicing salts do have a detrimental impact on the roadside environment, particularly with regard to its effects on the soil.

Sodium chloride is used more extensively as a deicing salt, primarily because calcium chloride is approximately four times more expensive (McConnell and Lewis, 1972). Depending on the temperature, however, calcium chloride may be either mixed or sprayed into the sodium chloride as calcium brine has a lower freezing point than does sodium brine. Both salts melt ice and snow by dissolving in water, thereby lowering the freezing point of the resulting brine solution below that of pure water. As the brine spreads over the road, it breaks the bond between the ice and the road surface.

Once salt is deposited onto the road surface, it enters the environment in several ways. A large portion is carried directly into local water courses and into roadside soil by surface runoff. Kunkle (1971) stated that between 25 and 50 percent of the salt used on a road, infiltrates to the groundwater, depending of course, on local relief, soil type, and precipitation. A portion of this salt will remain in the soil. Some salt is evidently removed directly through the atmosphere and can constitute a significant percentage of the particulate matter in the air (Kunkle, 1971). Finally a substantial amount is removed by traffic, either by adhering to the car's underbody and being transported and deposited elsewhere, or by being splashed directly onto the roadside (Hofstra and Hall, 1971). Eventually most of the deicing salt used will find its way into either the soil or water.

It is the purpose of this research to examine the effect of that salt retained by the soil on various soil parameters, namely; total salinity, sodium concentration, and cation-exchange capacity. Each variable is studied in terms of its change over time (winter 1975/76), change with distance from the road, change between the soil surface and depth, and difference between soil types. The relationship between sodium and total salinity, and sodium and cation-exchange capacity is also investigated.

CHAPTER TWO

REVIEW OF LITERATURE

Most salinity studies have dealt with soils in arid or semi-arid regions and their effects on crop production. Nightingale (1974) discussed soil and groundwater salinization below land used for diversified irrigated agriculture. Bernstein (1958, 1961, 1964) has conducted extensive studies concerning the salt tolerance levels of numerous plants, particularly grasses and forage legumes. Coom (1965) studied the absorption and transport of sodium and potassium in beans and cotton. Numerous other studies have been concerned with the effect of salts on plants (Brownell, 1965, Hayward and Bernstein, 1958, Gauch and Wadleigh, 1943, 1944, and Rains and Epstein, 1967). Very few articles, however, deal specifically with the effects of salt on the soil beneath the plants. Many workers have alluded to the fact that the soil may be detrimentally effected by salts. Recent studies by Mukhtar, Swoboda and Geoffrey (1974) deal with the effect of sodium and calcium chlorides on the stability of soil structure. Parlange (1973) has conducted numerous studies on the movement of salt and water in relatively dry soils, and Abrol and Bhumbla (1973) investigated salt leaching in highly saline soils. Ravikovitch and Navrot (1972) combined both plant and soil studies by investigating the effect of soil temperature on plants grown in saline soils.

The above mentioned studies have dealt with naturally-occurring salts. These salts actually play an integral part in maintaining the natural plant ecology of their respective regions and are not considered foreign to their local environment. The fact that cash crops are affected is no doubt, an important motive for the large number of studies concerned with salt-plant relationships.

Roadside soils, in those areas experiencing heavy snowfall, are exposed to the winter application of deicing salts. Within the past ten years, a number of articles have substantiated the theory that salt applications are having detrimental effects on groundwater and the roadside environment. Many city Public Works studies have been conducted in New England, where well-water supplies have been directly contaminated by salt applications. Many sugar maples are dying because of high salt intake along Connnecticut roads (Prior and Berthouex, 1967). Roberts and Zybura (1967) found that sodium chloride levels were sufficiently high to restrict grass growth up to 10 feet from the roadside in Iowa. Piatt and Krause (1974) found that roadside aspen were being detrimentally effected by salting near Santa Fe, New Mexico. It was determined by Zelazny and Blaser (1970) that the deterioration of silver maples in Vermont corresponded to high levels of sodium chloride found in leaf and twig tissues in trees close to the roads. Again the emphasis in these studies was on the effect of salt on the plant rather than the soil, although minimal attention has been given to the soil aspect.

Manifest in current literature, is conflicting evidence as to the detrimental effects of salt on the soil. Van de Voorde and Van Dijck (1973) state that only a negligible part of the total addition of salt is absorbed on the soil particles, and even excess levels of sodium are not so harmful as to cause the disappearance of vegetation, but that it only grows less luxuriantly. This opinion, however conflicts with the conclusions of other workers (Zelazny and Blaser, 1970, and Roberts and Zybura, 1967). In Windsor, the Ministry of Transport and Communication has found that the salt-tolerant shrubs planted around the E.C. Row and Howard Avenue Interchange, are suffering from twig and tissue burning and rings of salt have been found at their bases (Coulter, 1975).

Richards (1951) has provided the most complete synthesis to date on the effects of salts on soils. Through the U.S. Salinity Laboratory, he and others have conducted extensive research into saline and alkali soils in arid and semi-arid regions of the United States. He found that as large numbers of sodium ions leach through the soil, they tend to replace other cations previously absorbed by the clay and organic portions of the soil. When sodium reaches such a level that it occupies more than 15 percent of the total exchange capacity of the soil, soil structure begins to deteriorate. When such a sodic soil loses its ability to remain sufficiently aggregated, its permeability and water-holding capacity decrease markedly. The resulting excess runoff and diminished aeration provide poor conditions for the growth of many plants.

Hutchinson and Olson (1967) found that sodium occupied 17 percent of the exchange capacity of a roadside soil in Maine. Their samples closely compared to the soils of the arid regions of the United States where a soil having greater than 15 percent sodium is designated as an alkali soil. Westing (1969) stated that neither the chloride nor the calcium ions from road salt appear to have an adverse effect on the soil itself. Chlorine is not readily fixed by soil colloids and tends to leach out rather quickly. Calcium usually makes up a high proportion of the exchangeable cations of soils and appears to have beneficial, rather than deleterious effects on the soil. The sodium therefore has two characteristics of importance; it changes the character of the soil by making it less permeable, and it has a toxic effect on plants.

Cation-exchange is defined as the interchange between a cation in solution and another cation on the surface of any surface-active material such as a clay colloid or organic colloide (Donohue, 1971). The cation-exchange capacity is the sum total of exchangeable cations that a soil can absorb expressed in millequivalents per 100 grams of soil. Common soil cations are calcium, magnesium, sodium, potassium, ammonium, and hydrogen. The two factors having the greatest influence on the cation-exchange capacity are clay and organic matter, since they serve as reservoirs for cation storage. A significant increase in any one cation, in this case sodium, will decrease the total exchange capacity by replacing other cations in the soil. Therefore, it may be that the winter application of deicing salts will increase the sodium levels of the roadside soils, thereby decreasing the exchange capacity of the soil.

There is a consensus of opinion among researchers as to the factors determining the distance over which a brine solution will migrate in soil. This distance is dependent on the slope away from the road, the amount of precipitation, the soil texture and structure, and the volume and frequency of salt applied (Westing, 1969). As a result, salt concentration in the soil should decrease with distance from the road. According to Westing (1969), little if any change is demonstrable at any time of the year beyond 30-40 feet (9-12 meters) from the road. Zelazny and Blaser (1970) found significant sodium counts at 75 feet (22.5 meters) where a rather steep slope existed. The relationship between concentration and distance also applies to depth. In each study mentioned thus far, concentrations were always highest at the surface diminishing with depth. Prior and Berthouex (1967) found the most significant change to occur at the 1 foot (0.3 meter) level, but this is dependent on slope and soil type, and other local factors. Zelazny and Blaser (1970) made the observation that high concentrations of sodium occurred at a depth of 18 inches (0.46 meters) even in the winter. This indicates that salts are capable of percolating into frozen soil rather than flowing across its surface. It is expected then that total salinity (a measure of all salts combined) and sodium values will decrease as the distance away from the road increases, both at the surface and at a specified depth.

In summary, most of the papers concerned with saline and alkali soil have dealt with those soils primarily in relation to the crops grown in them. It is only recently that an awareness of the problems caused by the application of deicing salts has occurred. Most of these studies, however, have dealt with the effects of salts on the natural roadside vegetation. Only a few studies concerning the concentrations of salts on soil surfaces and depth have been conducted. None of these give evidence as to possible variation of concentrations or effects in different soil types.

The author is unaware of any study which deals with specific soil types in a comparative format. It is known that concentration of sodium is dependent on distance and depth. It is also known that sodium affects the cation-exchange capacity which is in turn affected by the texture and organic content of the soil. It follows therefore, that the cation-exchange capacity of varying soil types will be affected differently by the application of deicing salts. Soil texture and slope will have a definite effect on the distance the salt solution will migrate.

CHAPTER THREE

MODEL AND HYPOTHESES

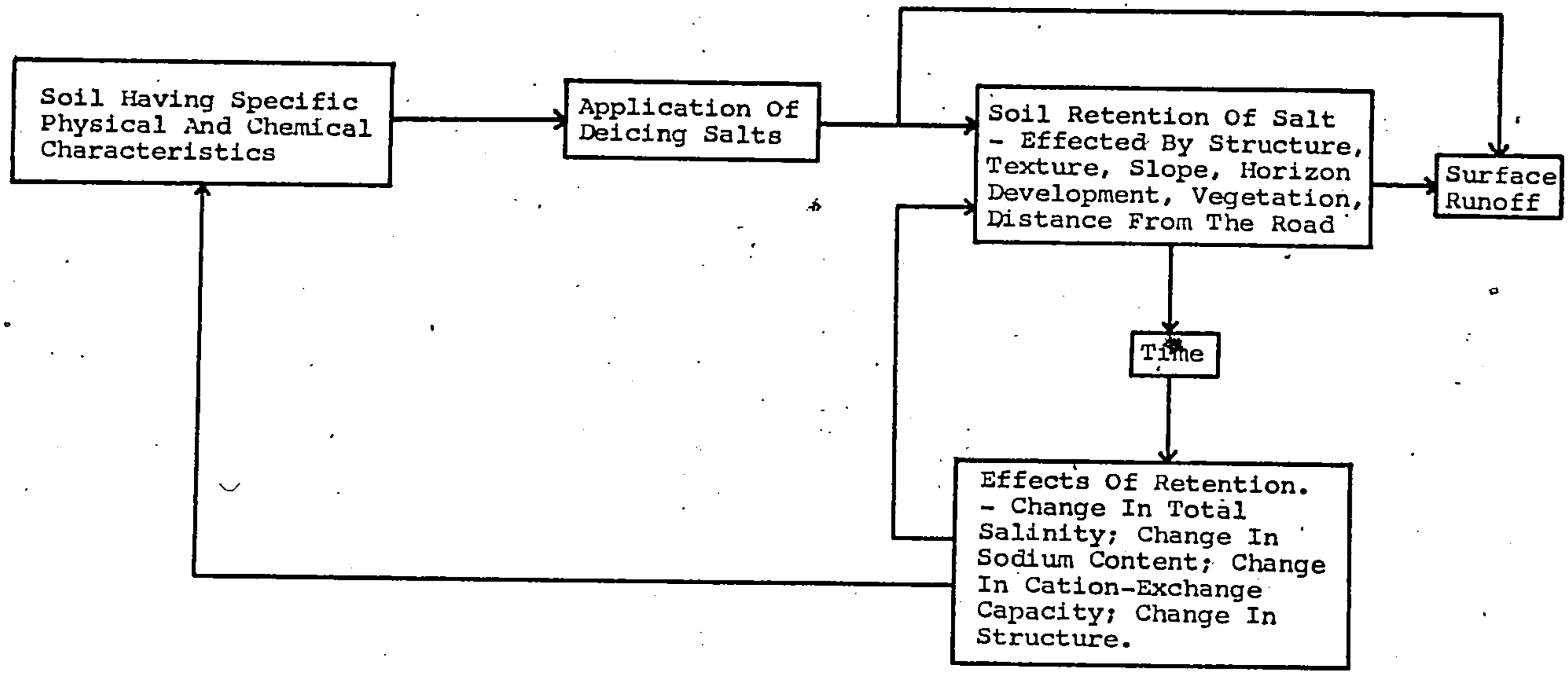
The natural occurrence of events on a roadside soil, after the application of deicing salts may be represented by a simple model (Fig. I). Before salting occurs, each soil type, along a road, has specific physical and chemical characteristics. After salting, a certain portion of the brine solution goes directly into surface runoff. The remainder, excluding the minor portions which enter the atmosphere or transported elsewhere by vehicles, goes into the soil. Once in the soil, the solution is then affected by numerous factors such as texture, structure, horizon development, slope and distance from the road. The salt retained by the soil will, over time, affect other factors such as the total salinity, the sodium content and the cation-exchange capacity. If the total amount of salt added to the soil is sufficient to break down the soil structure, surface runoff will be substantially increased, causing a new set of problems in the roadside environment.

The following hypotheses have been formulated to test the above model.

(1) That for each soil type, total salinity and sodium concentration values will increase at both the surface and at depth over the sampling period (Winter 1975/76), as a result of the addition of deicing salt (sodium chloride).

Figure I

Study Model



(2) That for each soil type cation-exchange capacity will significantly decrease at both the surface and at depth over the sampling period.

(3) That for each soil type, at each sampling interval, total salinity and sodium concentration values will decrease at the surface and depth with distance from the road.

(4) That for each soil type, at each sampling interval, cation-exchange capacity will increase at the surface and at depth with distance from the road.

(5) That for each soil type, at each sampling interval, surface values for total salinity and sodium concentration will be higher than at depth.

(6) That for each soil type, at each sampling interval, surface values for cation-exchange capacity will be significantly lower than those at depth.

(7) That for each soil type, at each sampling interval, there will be a positive relationship between sodium concentration and total salinity values.

(8) That for each soil type, at each sampling interval, there will be a significant negative relationship between sodium concentrations and cation-exchange capacity values.

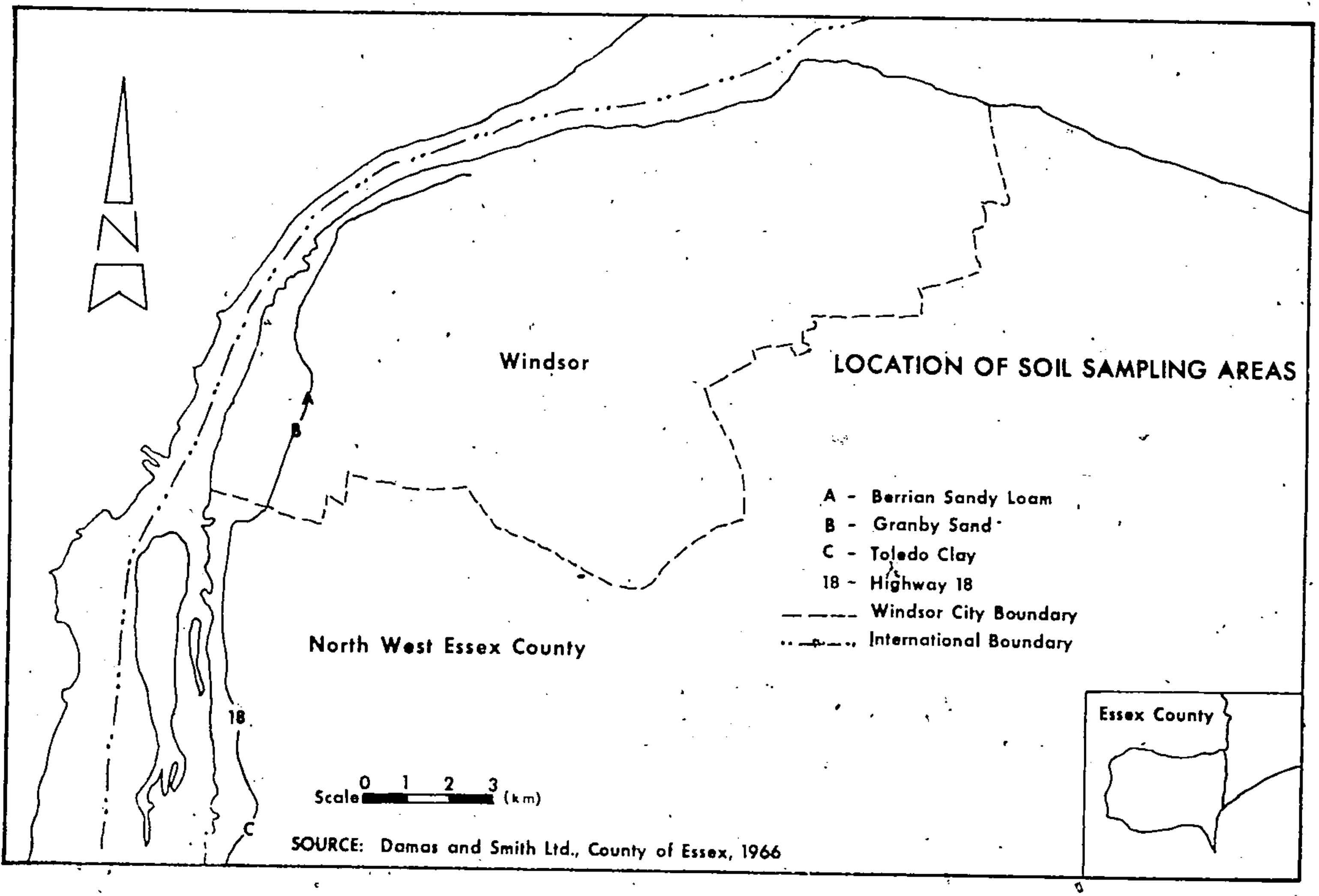
(9) That each soil type, as expressed by the variables; total salinity, sodium concentration, and cation-exchange capacity, will react differently to the addition of deicing salts.

CHAPTER FOUR

STUDY AREA AND SITE DESCRIPTION

The study area was determined by a visual examination of the Soil Survey of Essex County map (Richards, Caldwell, Morwick, 1949), to find three distinct soil types along the same major road. This design justifies the basic assumption that, this road receives approximately the same amount of salt along its entire length during times when snowfall necessitates salting. The Essex County Public Works Department and the Ministry of Transport and Communication were questioned as to whether there was a priority list for road salting. Essex County has priorities for the main arteries into Windsor, such as Walker Road and Howard Avenue, but three different soil types do not exist along these routes. The Ministry of Transport and Communication, responsible for the maintenance of provincial highways, (Highways 401, 18, 3, 2, 98, etc.) do not have priorities. All roads under their jurisdiction are ploughed or salted at approximately the same time, according to the patrol yard network. A major road(i.e. a provincial or county highway) was desired for this study, as these roads are salted more frequently then are the county concession roads.

Highway 18, which runs south from Windsor along the Detroit River and east along Lake Erie was chosen for this study. Along its route, three fairly distinct soil types



SOURCE: Damas and Smith Ltd., County of Essex, 1966

Figure II

were found within a relatively short distance. These soil types are: (1) Berrian Sandy Loam, on Highway 18 just south of Chappus Road; (2) Granby Sand on Highway 18 approximately one-quarter mile north of Sprucewood Drive near the Windsor Raceway; and (3) Toledo Clay on Highway 18 just south of the intersection of Malden Road and Highway 18. It was hoped that a clay, a loam, and a sandy soil could be sampled, but the Berrian Sandy Loam was the closest type to a loam along this section of Highway.

According to the Soil Survey of Essex County (1949), the soils chosen for this study are described as follows:

> (1) Toledo Clay: The Toledo soils developed from fine textured lacustrine materials under a deciduous forest and exhibit the characteristics of the Dark Grey Gleisolic Soils. Toledo Clay occupies approximately 17,500 acres in Essex County. It has a level to slightly undulating topography with poor natural drainage and is classed as slightly alkaline.
>
> (2) Granby Sand: The Granby is the poorly drained member of the Fox catena and exhibits the characteristics of the Dark Grey Gleisolic Soil. Occupying approximately 1000 acres, it occurs chiefly in a large block south of Windsor. The topography ranges from level to depressional, often making it difficult to drain. It is classed as slightly alkaline.
>
> (3) Berrian Sandy Loam: The Berrian Sandy Loam occupies approximately 16,000 acres of Essex County and is generally described as being imperfectly drained. Profiles exhibit characteristics of the Grey-Brown Podsolic soil. The topography is slightly undulating and often resembles the Granby depression conditions. It is classed as being moderately acid.

The actual sites for this research do not vary a great deal (Figure III). Each has a very slight slope, except the Toledo Clay which has a slope of .08m within the first 6.3 meters of the traverse. The Toledo Clay is grass-covered for

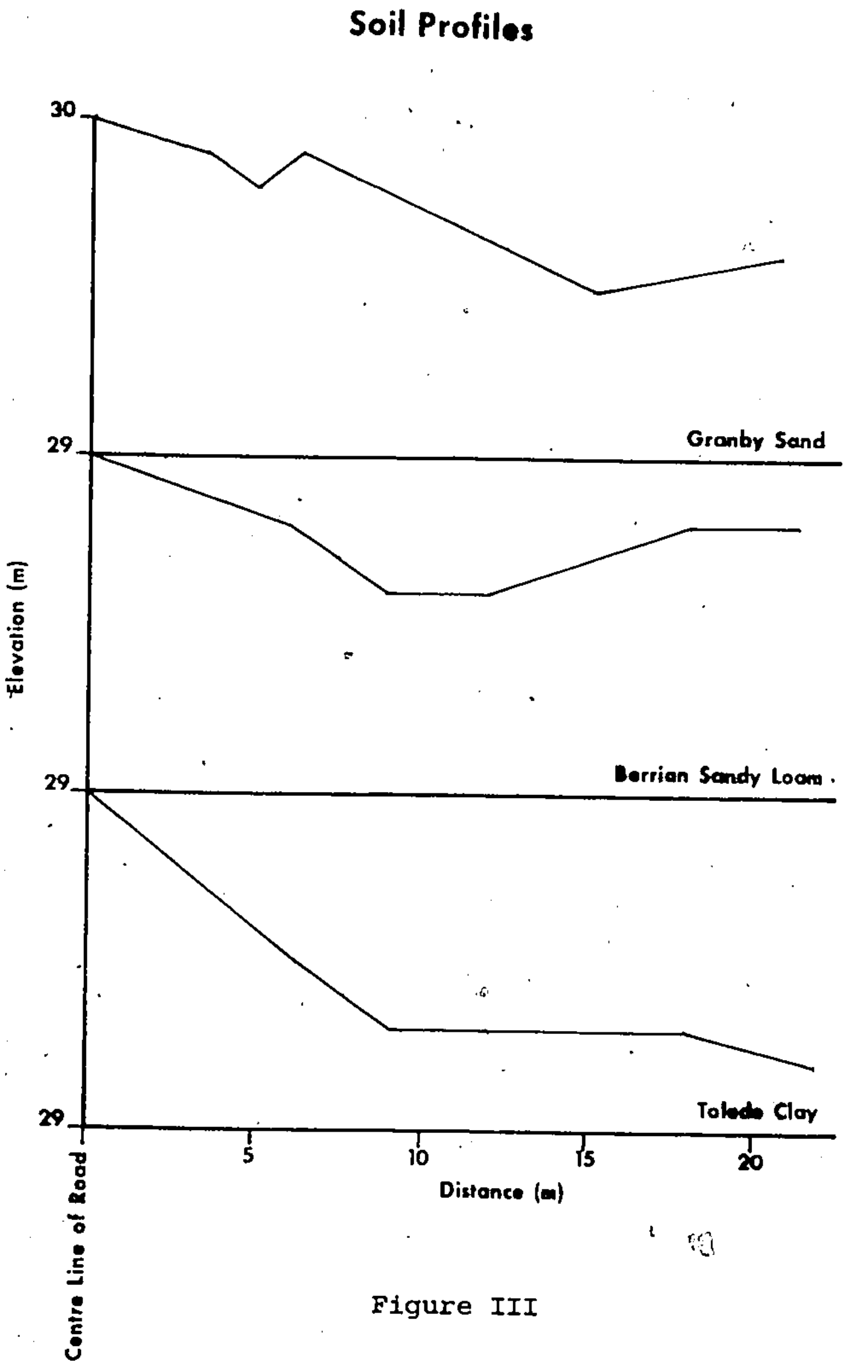

Soil Profiles
30
29
Granby Sand
29
Berrian Sandy Loam
29
Toledo Clay
Elevation (m)
5
10
15
20
Distance (m)
Centre Line of Road

Figure III

the first fifteen feet and is then covered by reeds and cat-tails. Both the Granby Sand and Berrian Sandy Loam are grass-covered. To avoid residential and commerical buildings all sites were located on the west side of Highway 18. Also, areas under cultivation were avoided because fertilizers often contain varying amounts of sodium, and because of the possibilities of soil disturbance due to farming practices.

CHAPTER FIVE

METHODOLOGY

Sampling Procedure:

At each of the three sites, samples were taken along a traverse, at intervals of 0.3, 1.5, 3.0, 6.0, and 12.0 meters from the shoulder of the road. One sample was taken at the surface and depth at each marked distance, except at the 1.5 meter point where three samples were taken.[1] Following Westing's statement (1969), that little if any salt is demonstrable at any time of the year past 30-40 feet, samples were not taken beyond the 40 feet (12.0 meter) distance. Samples were taken at the 0.3 meter (1.0 foot) depth in accordance with the study of Prior and Berthouex (1967), who found the most significant difference in concentrations at that depth.

Sampling Timetable:

The sampling timetable had to be rather flexible to avoid taking samples under frozen ground conditions. The first samples were taken in November, 1975, before any snowfall occurred. The second set of samples was taken during a midwinter thaw in February, 1976, and the third

---

[1] It was originally planned that comparisons of variables between soil types would be conducted using those values at the 1.5 meter distance.

and final set was taken as soon as possible after the last snow melted, which was in early May, 1976. As it turned out, samples were taken almost exactly three months apart.

Data Collection:

Data for texture analysis were collected using the Bouyoucos Hydrometer Method as outlined in Appendix I, to determine, if in fact the samples taken fall within the soil classification units allotted by the Essex County Soil Survey (1949). Total salinity data (Table I) were collected using electrical conductivity, whereby the conductance of the filtrate of each sample was measured for total salt content, by direct reading from a nomogram for salt concentrations (Appendix II). Cation-exchange capacity data (Table II) were collected using the method outlined in Appendix II. Due to equipment facility problems and the author's timetable, all samples were sent to a contract laboratory for the determination of sodium concentrations. Results were obtained by Atomic Absorption (Table III). The soil column construction was completed by the author. Data from the column procedures (Table IV) were collected using the same standard laboratory methods stated in Appendices II and III. Detailed sodium chloride concentration calculations and column procedure, are given in Appendix IV.

Statistical Testing Procedures:

To test for statistically significant differences over

TABLE I

Total Salinity (ppm)

Granby Sand

Distance (meters)	November	February	May
Surface			
0.3	8.8	7.0	4.8
1.5	6.2	7.0	8.0
1.5	5.1	7.2	3.7
1.5	27.0	7.0	5.1
3.0	7.0	5.4	5.1
6.0	7.0	4.2	3.7
12.0	4.8	3.7	3.2
Depth (0.3m)			
0.3	7.0	7.0	4.8
1.5	4.2	7.0	4.8
1.5	5.1	7.2	5.1
1.5	5.1	6.2	5.1
3.0	3.7	4.8	3.7
6.0	4.2	3.7	3.2
12.0	3.7	4.8	3.2

Berrian Sandy Loam

Distance (meters)	November	February	May
Surface			
0.3	7.2	13.0	56.0
1.5	9.2	4.2	5.4
1.5	10.0	7.2	9.2
1.5	10.0	8.8	14.0
3.0	8.8	5.1	6.2
6.0	5.1	7.0	7.0
12.0	5.1	2.7	2.2

Table I cont'd.

Berrian Sandy Loam

Distance (meters)	November	February	May
Depth (0.3m)			
0.3	7.0	12.3	16.0
1.5	8.0	6.2	5.1
1.5	8.8	8.0	5.4
1.5	7.2	7.2	7.2
3.0	5.1	4.2	4.8
6.0	2.2	5.4	3.2
12.0	2.7	2.2	1.6
Toledo Clay			
Surface			
0.3	7.0	7.2	6.2
1.5	7.0	7.0	8.0
1.5	7.2	7.0	7.0
1.5	8.0	7.0	9.2
3.0	7.0	6.2	7.0
6.0	8.0	7.0	5.4
12.0	5.4	4.8	4.8
Depth (0.3m)			
0.3	7.0	10.0	8.8
1.5	8.8	8.0	10.0
1.5	9.2	7.0	7.2
1.5	7.0	8.8	10.0
3.0	5.1	6.2	6.2
6.0	6.2	15.3	5.4
12.0	5.4	8.0	4.8

TABLE II

Cation-Exchange Capacity (me/100g)

Granby Sand			
Distance (meters)	November	February	May
Surface			
0.3	19.0	9.0	3.4
1.5	2.4	7.6	5.0
1.5	30.4	8.0	4.8
1.5	34.4	11.6	4.4
3.0	27.0	9.4	4.4
6.0	3.2	6.6	4.0
12.0	4.6	6.8	4.0
Depth (0.3m)			
0.3	1.0	7.0	5.6
1.5	1.0	6.0	6.0
1.5	20.0	14.2	7.2
1.5	0.8	16.6	4.6
3.0	16.4	16.2	5.2
6.0	14.4	17.4	8.0
12.0	16.0	17.8	6.0
Berrian Sandy Loam			
Surface			
0.3	16.8	8.4	5.2
1.5	22.4	13.0	6.6
1.5	15.8	13.4	8.2
1.5	7.4	14.0	7.0
3.0	9.0	13.6	8.8
6.0	11.6	15.0	6.8
12.0	10.4	14.4	12.2

Table II cont'd.

Berrian Sandy Loam

Distance (meters)	November	February	May
Depth (0.3m)			
0.3	4.4	8.8	11.0
1.5	2.2	7.8	7.4
1.5	3.0	8.8	5.4
1.5	5.0	8.6	5.6
3.0	3.8	11.4	4.8
6.0	3.8	10.6	8.0
12.0	7.4	10.8	6.4

Toledo Clay

Surface			
0.3	17.0	9.6	14.0
1.5	29.0	15.4	19.6
1.5	47.0	18.6	20.2
1.5	13.0	16.8	20.8
3.0	14.0	15.8	20.2
6.0	20.0	19.2	21.6
12.0	19.0	18.4	22.6
Depth (0.3m)			
0.3	28.0	16.8	19.4
1.5	28.0	16.2	17.0
1.5	28.0	17.8	18.0
1.5	22.0	18.6	19.6
3.0	24.0	16.0	18.4
6.0	22.0	18.6	19.6
12.0	24.0	19.6	18.8

TABLE III

Sodium Concentration (ppm)

Granby Sand

Distance (meters)	November	February	May
Surface			
0.3	17	40	21
1.5	10	34	41
1.5	8	46	26
1.5	12	38	32
3.0	17	34	23
6.0	11	15	3
12.0	12	13	4
Depth (o.3m)			
0.3	36	36	28
1.5	29	33	25
1.5	32	39	33
1.5	15	34	32
3.0	26	26	14
6.0	6	12	2
12.0	4	8	1

Berrian Sandy Loam

Surface			
0.3	19	58	230
1.5	26	19	11
1.5	41	40	27
1.5	29	48	41
3.0	20	26	38
6.0	12	43	36
12.0	3	8	3

Table III cont'd.

Berrian Sandy Loam			
Distance (meters)	November	February	May
Depth (0.3m)			
0.3	35	60	90
1.5	32	27	21
1.5	41	36	33
1.5	38	45	45
3.0	19	21	23
6.0	8	22	22
12.0	4	7	1
Toledo Clay			
Surface			
0.3	7	40	22
1.5	24	40	24
1.5	23	32	34
1.5	23	34	41
3.0	25	28	26
6.0	23	30	25
12.0	22	21	19
Depth (0.3m)			
0.3	20	36	52
1.5	35	31	52
1.5	35	28	41
1.5	29	37	51
3.0	20	27	32
6.0	17	37	34
12.0	19	25	18

TABLE IV

Soil Column Data

Depth (cm)	One-Half	Full	Double
	Concentrations		
	Total Salinity (ppm) Before = 5.4ppm		
0.0	5.4	8.0	14.0
10.2	5.1	7.0	9.2
20.4	5.1	7.0	11.0
30.6	6.2	7.0	10.0
	Sodium Concentration (ppm) Before = 16ppm		
0.0	30	54	60
10.2	19	32	42
20.4	17	28	39
30.6	21	40	57
	Cation-Exchange Capacity (me/100g) Before = 7.60 me/100g		
0.0	2.60	1.60	1.00
10.2	3.20	2.40	1.40
20.4	1.80	2.20	1.40
30.6	2.60	2.80	1.60

time in hypotheses number one and two, the Ordered Hypotheses for Multiple Treatments (Page, 1963) is employed. Using the November samples as a control sample, to which the February and May samples are defined as treatments, the Ordered Hypotheses test computes an L-statistic, which when used against the given tables, denotes whether rejection of the null hypotheses or acceptance of the stated alternative hypotheses is admissible. The L-test can only be used when a reasonable basis for ordering treatments is known. The signifance level for this test and all other tests performed for this research is .05, to allow the greatest leeway for acceptance or rejection of a hypothesis due to the small sample sizes involved. The L-test was chosen rather than the Analysis of Variance and the Student's t-test primarily because of the small sample sizes involved and because of direct application to the data.

Simple linear regression and correlation is used to test those relationships predicted in hypotheses 3, 4, 7, and 8. The significance of the correlation coefficient is then tested at the .05 significance level using tables (Barnes and Noble, 1950). Rejection occurs if the computed correlation coefficient is less than the critical r-value in the tables.

The Wilcoxon Rank-sum test for Identical Populations (Bradley, 1968) is employed to test hypotheses 5, 6, and 9. The test statistic is computed by calculating the sum of the ranks of the smaller-sized sample, or when n = m, the smaller of the two sums, and comparing this value to the W-critical value in the given tables. Rejection occurs when W-observed is less than or equal to W-critical.

The assumptions of random sampling and independence of samples are fulfilled in each case. The problem of tied observations or tied rands, is dealt with using midranks as outlined in Bradley (1968).

CHAPTER SIX

STATISTICAL ANALYSIS OF FIELD DATA

The first step in the analysis was to provide data concerning the proportions of sand, silt and clay in the November samples, to determine if they were, in fact, the soil types designated in the Soil Survey of Essex County (1949). The calculations in the bouyoucos hydrometer method provided crude but reliable estimations of the sand, silt and clay proportions of each sample. The Berrian Sandy Loam soil has 18.9 percent clay, 19.1 percent silt and 62.0 percent sand, which confirms its designation as a sandy loam. The Granby Sand samples, however, were found to have 18.1 percent clay, 13.0 percent silt and 68.9 percent sand, which does not classify it as a sand, but rather a sandy loam. The continued use of the "Granby Sand" designation of its samples is based on the author's desire to sutdy the possible differences, or similarities, between it and the Berrian Sandy Loam. It is conceivable that any significant differences between the samples, could be related, not so much to soil type or texture, but to other local factors, such as the slope of the site or the actual site location. The Toledo Clay samples were found to have 43.7 percent clay, 29.2 percent silt and 28.0 percent sand, which confirms its classification as a clay soil.[1]

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[1] The proportions of sand, silt and clay are mean values of all the samples taken at each site. It is felt that the mean values are more representative of the soil types, than values derived from single determinations.

Therefore, the texture analysis confirmed the classification of the Toledo Clay and the Berrian Sandy Loam soils, but classed the Granby Sand as actually being a sandy loam.

Analysis of Hypotheses:

In the statement of hypothesis number one, it was predicted that total salinity and sodium concentrations would increase significantly over the sampling period. The mean values for total salinity, as derived from Table I, are plotted to illustrate the changes in total salinity in each soil type over the sampling period (Figure IV). The graphs seem to indicate that significant changes did occur in the Granby Sand and Berrian Sandy Loam surfaces, and also at depth in the Toledo Clay samples.[1] Despite the indications of significant change, the changes were not significant at the .05 significance level (Table V).

The curves in Figure V, derived from calculations of mean values for sodium concentrations (Table III), seem to indicate, again, significant changes over time at each surface and depth. In all cases, however, changes that did occur were not significant at the .05 significance level (Table VI).

Similar conclusions may be drawn for the results of both total salinity and sodium over time. It may be that

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[1] It must be noted that mean total salinity values for surface and depth samples are plotted. Extremely high or low values tend to weight the mean value. Plotting the means, however, best illustrates changes over time. The problem of misrepresentative means is overcome by ranks in the L-test.

Mean Monthly Total Salt Concentrations (TS) For Each Soil Type

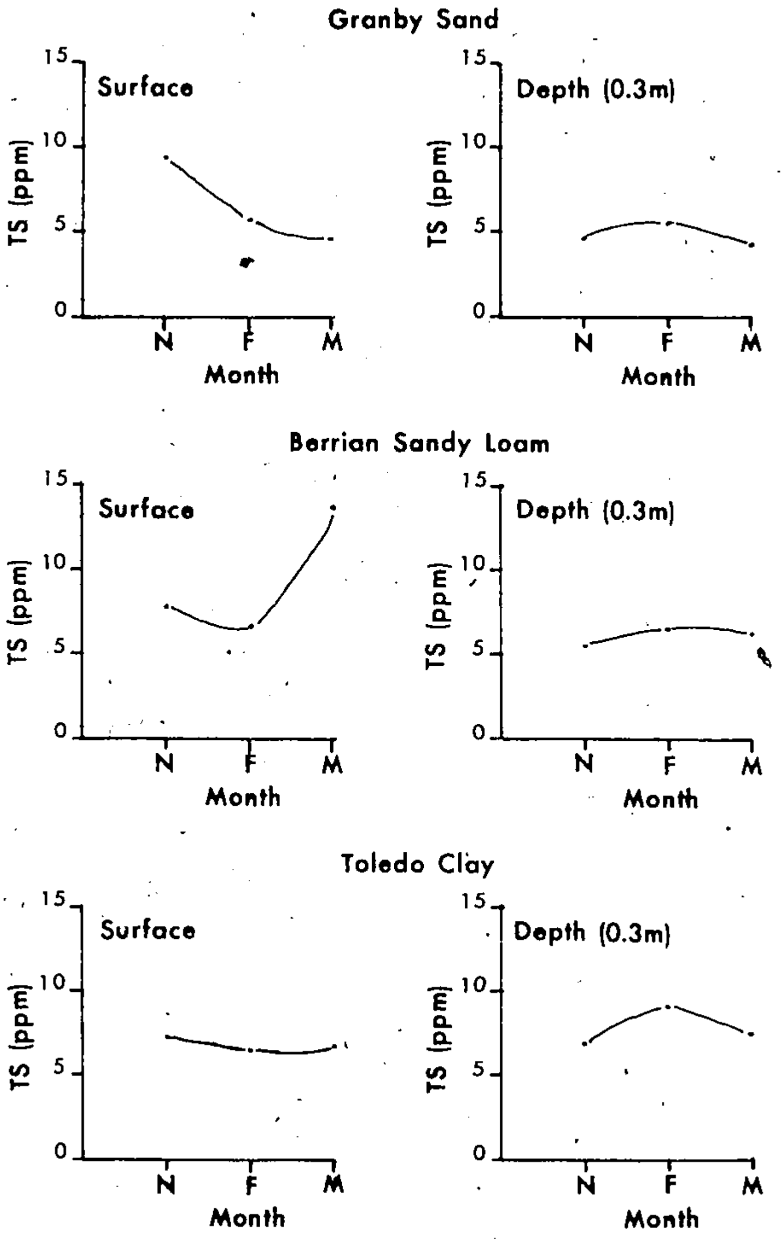


Figure IV

TABLE V

Results Of L-test For Total Salinity Over Time

Sample	L-observed	Significance
Granby Sand		
-Surface	54	No
-Depth	51	No
Berrian Sandy Loam		
-Surface	57	No
-Depth	62	No
Toledo Clay		
-Surface	51	No
-Depth	55	No

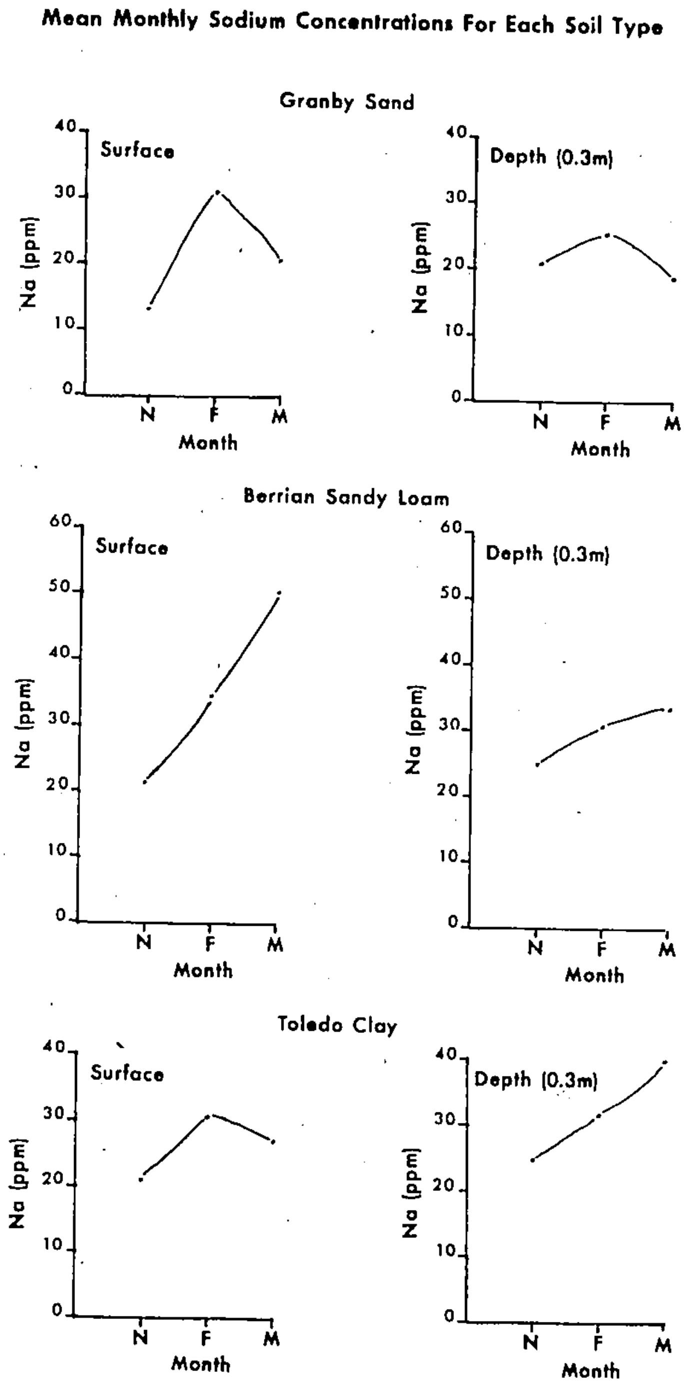
Level of Significance = .05
Significant if L ≥ L' = 66

TABLE VI

Results Of L-test For Sodium Concentrations Over Time

Sample	L-observed	Significance
Granby Sand		
-Surface	61	No
-Depth	53	No
Berrian Sandy Loam		
-Surface	62	No
-Depth	60	No
Toledo Clay		
-Surface	62	No
-Depth	64	No

Level of Significance = .05
Significant if L ≥ L' = 66



Mean Monthly Sodium Concentrations For Each Soil Type

Granby Sand

Berrian Sandy Loam

Toledo Clay

Figure V

the total amount of deicing salt that was retained by the soil over the sampling period was not sufficient to significantly change the total salinity value or the sodium concentration in the soil. Alternatively, during the thaw in February, enough snow may have melted to produce sufficient runoff to leach the soil of the deicing salt it may have accumulated between November and February. If this were the case, the values actually received may be the result of incomplete leaching. In conclusion therefore, hypothesis number one must be rejected and the null hypothesis, that there is no significant change in total salinity and sodium over time at the surface or at depth must be accepted.

In the statement of hypothesis number two it was predicted that cation-exchange capacity values would decrease significantly over the sampling period as sodium chloride was added to the soil. Figure VI illustrates the changes that occurred both on the surface and at depth at the three study sites, as derived from the data in Table II. The graphs indicate that a number of changes in cation-exchange capacity did occur. The results of the L-test (Table VII) however, show that in all cases no changes significant at the .05 significance level exist.

It is interesting to note that in every case, with the exception of a the Berrian Sandy Loam depth data, the mean cation-exchange capacity is lower in May than in November. It would seem therefore, that over the sampling period the

Mean Monthly Cation-Exchange Capacity Values For Each Soil Type

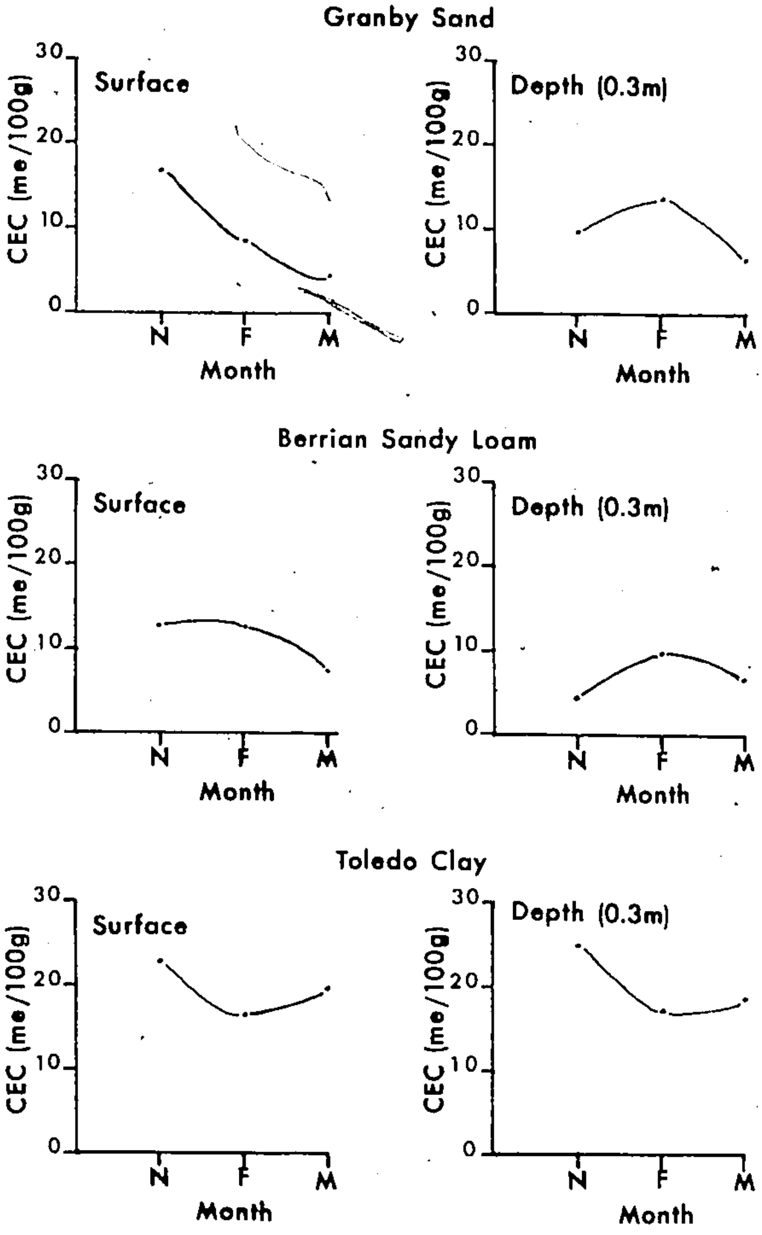


Figure VI

TABLE VII

Results Of L-test For Cation-Exchange Capacity Over Time

Sample	L-observed	Significance
Granby Sand		
-Surface	54	No
-Depth	58	No
Berrian Sandy Loam		
-Surface	55	No
-Depth	64	No
Toledo Clay		
-Surface	62	No
-Depth	54	No

Level of Significance = .05

Significant if L ≥ L' = 66

cation-exchange capacity generally decreased, but not to such a degree that the changes could be shown to be significant. The lack of significant change in the cation-exchange capacity may be explained by the thaw-induced leaching of sodium in February. In conclusion therefore, the hypothesis that cation-exchange capacity values would significantly decrease over the sampling period must be rejected and the null hypothesis that, there is no significant change over the sampling period, accepted.

Hypothesis number three states that total salinity values and sodium concentrations should decrease with distance away from the road. The edge of the road is the first area that receives any salt due to splashing by automobiles bouncing of salt from the salting vehicle, and from snow which has been previously salted and later ploughed to the side. This trend is also expected because of the change in slope from the center of the highway to the road's edge. Salt will also reach greater distances if slope increases away from the road.

Figures VII to XII illustrate the changes in total salinity and sodium with distance. Visual examination of the curves (Figures VII to IX) would seem to indicate that, in general the hypothesized relationship between total salinity and distance can be accepted.[1] The correlation coefficients (Table VIII), however, show the relationship to be significant in five out of eighteen cases at the .05 significance level. The relationship is consistent between months; February to May on the Granby Sand surface, and February to May at the 0.3m depth of the Berrian Sandy Loam. The relationship is not consistent at the coinciding depth or surface. Even though both soils are, by definition, sandy loams, it cannot be stated that there is a possible overall trend of decreasing salinity with distance. Nor can this be stated for the Toledo Clay samples. It may be, that the amount of deicing salt retained by the soil was not sufficiently

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[1] The value plotted at the 1.5m distance is the mean value of three samples taken at that point. The mean value also represents that distance in the regression analysis.

Changes In Total Salinity With Distance - Granby Sand

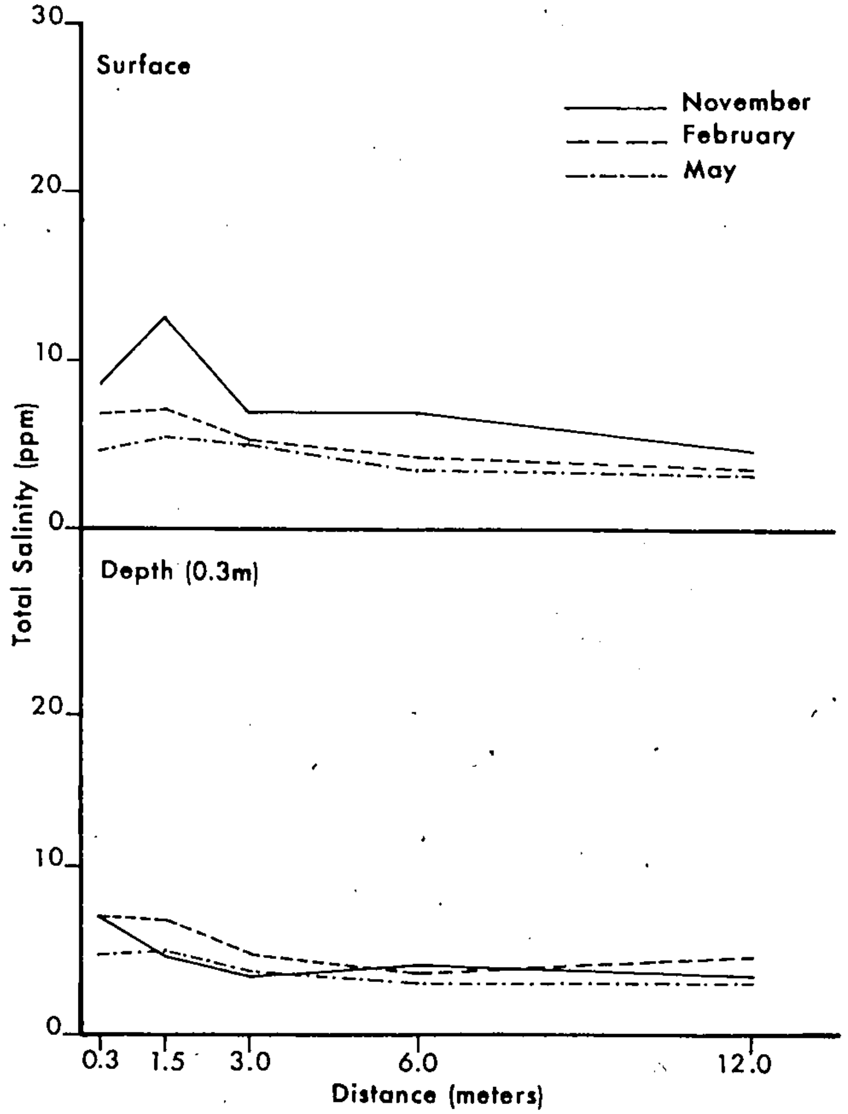


Figure VII

Changes In Total Salinity With Distance - Berrian Sandy Loam

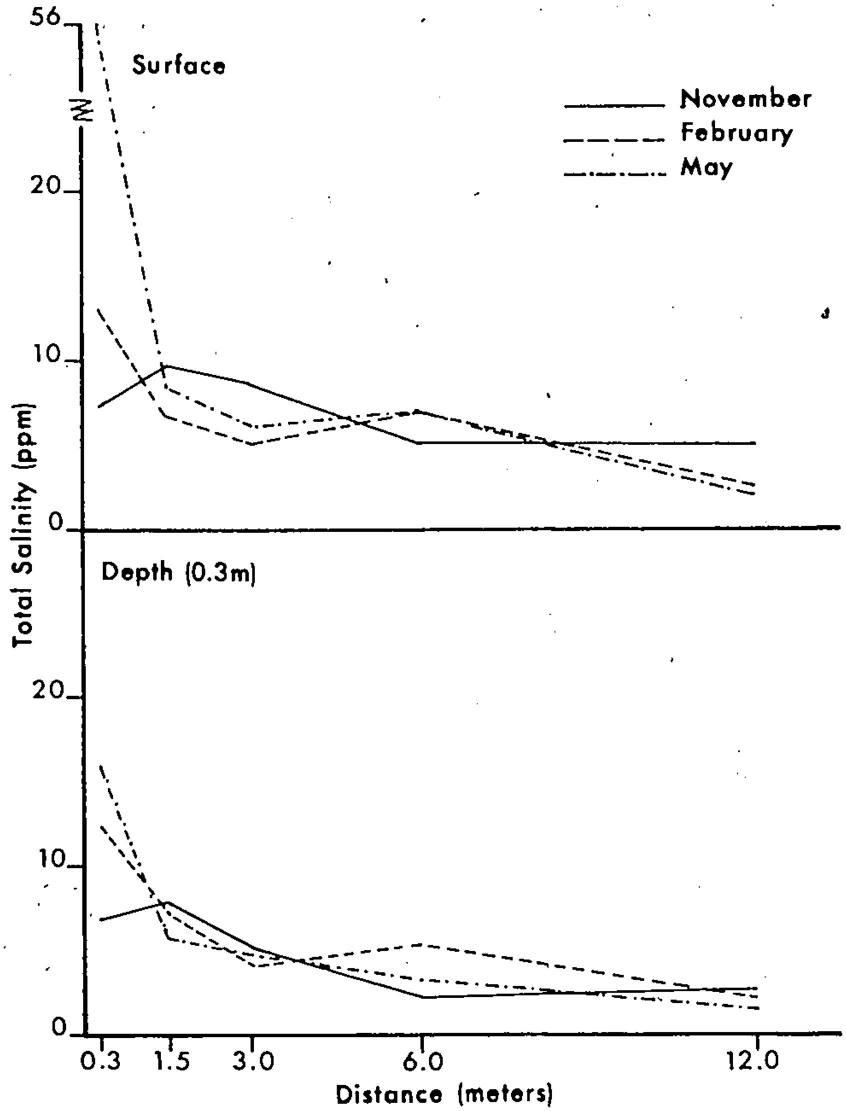


Figure VIII

Changes In Total Salinity With Distance - Toledo Clay

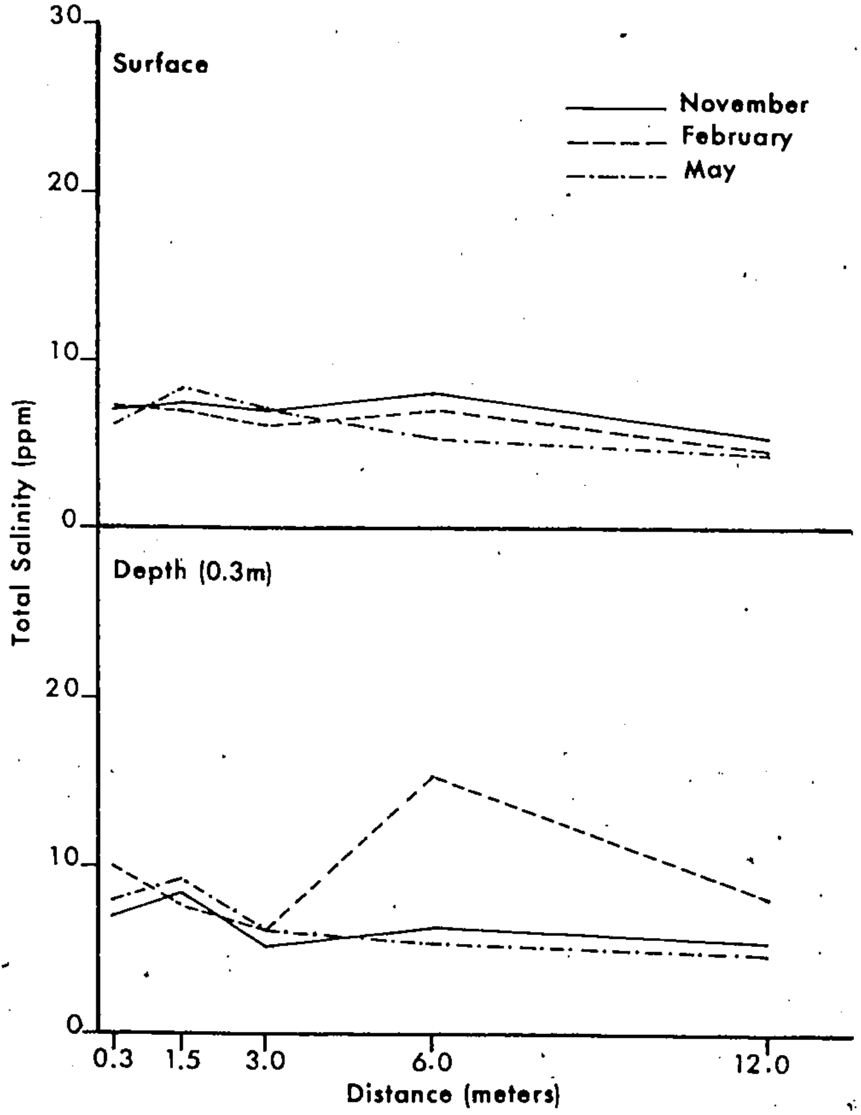


Figure IX

TABLE VIII

Results Of Regression Analysis Between Total Salinity (y) And Distance (x)

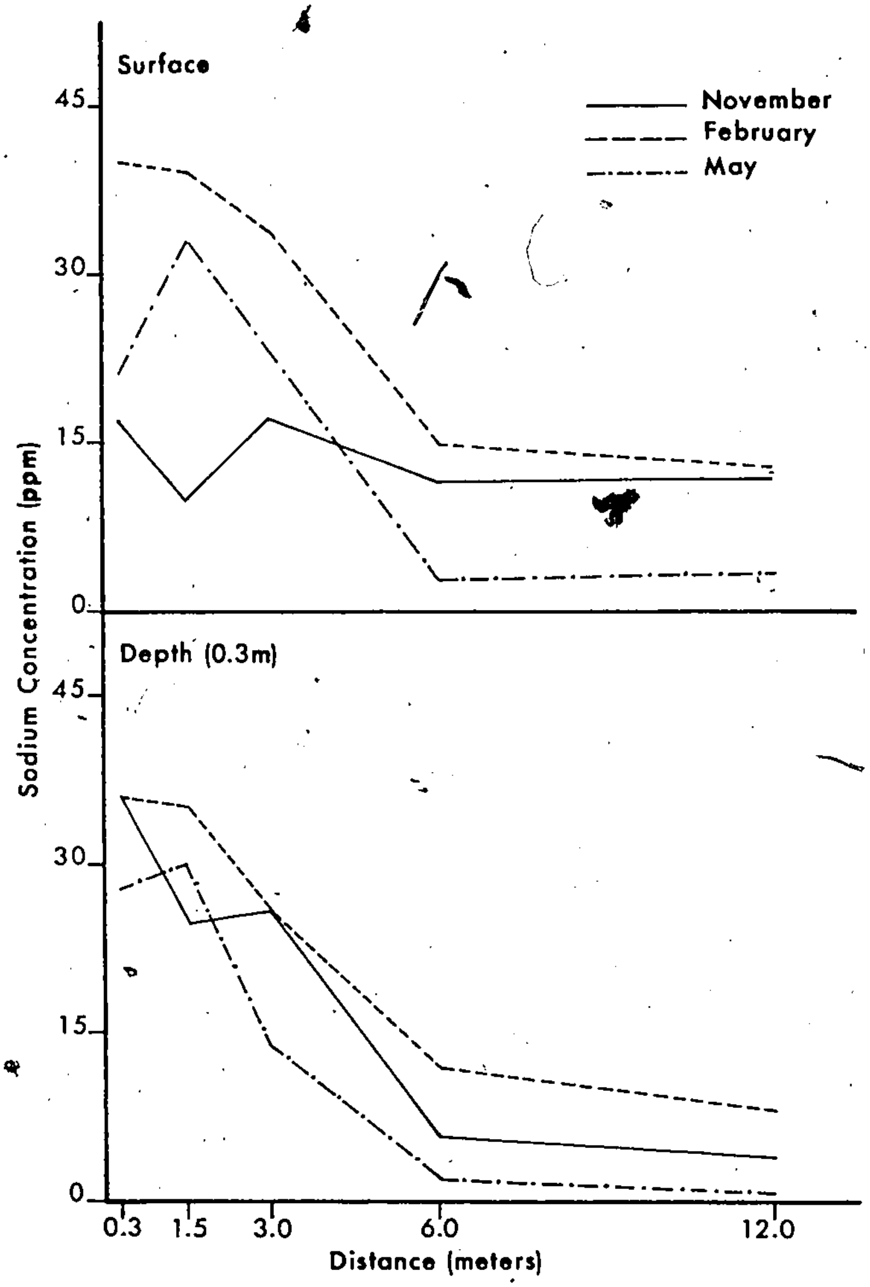
Sample	Regression Coefficient	Best Fit Line Equation	Correlation Coefficient	Coefficient Of Determination
Granby Sand				
November - Surface	-0.03	$y = -0.03x + 1.01$	-0.838	0.702
February - Surface	-0.03	$y = -0.03x + 0.84$	-0.931*	0.867
May - Surface	-0.02	$y = -0.02x + 0.73$	-0.905*	0.819
November - Depth	-0.02	$y = -0.02x + 0.73$	-0.672	0.453
February - Depth	-0.02	$y = -0.02x + 0.79$	-0.607	0.369
May - Depth	-0.02	$y = -0.02x + 0.67$	-0.824	0.678
Berrian Sandy Loam				
November - Surface	-0.02	$y = -0.03x + 0.94$	-0.764	0.584
February - Surface	-0.05	$y = -0.05x + 0.99$	-0.856	0.732
May - Surface	-0.09	$y = -0.09x + 1.35$	-0.829	0.688
November - Depth	-0.04	$y = -0.04x + 0.84$	-0.809	0.655
February - Depth	-0.05	$y = -0.05x + 0.97$	-0.894*	0.799
May - Depth	-0.07	$y = -0.07x + 1.00$	-0.918*	0.843
Toledo Clay				
November - Surface	-0.01	$y = -0.01x + 0.88$	-0.691	0.478
February - Surface	-0.01	$y = -0.01x + 0.87$	-0.869	0.755
May - Surface	-0.02	$y = -0.02x + 0.86$	-0.807	0.652
November - Depth	-0.01	$y = -0.01x + 0.85$	-0.577	0.333
February - Depth	0.002	$y = 0.002x + 0.95$	0.064	0.004
May - Depth	-0.02	$y = -0.02x + 0.93$	-0.887*	0.787

*Significant at the .05 significance level. Degrees of freedom = 3. Total salinity values were transformed to log values to straighten curves evident in Figures VII to XII.

high to significantly increase the total salt content of the soil. The results of a more rigorous test, the non-parametric Total Number of Runs Up and Down (Bradley, 1968), also showed the absence of a significant trend between total salinity and distance (Appendix V). This test showed only one case in eighteen to be significant - the Berrian Sandy Loam depth in May. The hypothesis that total salinity decreases with distance from the road must be rejected.

Hypothesis three also predicts that sodium concentrations will decrease with distance from the road. Correlation coefficients (Table IX) confirm this hypothesis, particularly with respect to the sandy loam soils, where nine out of twelve cases are significant. With the Toledo Clay samples, in only one instance is the hypothesis upheld. Figures X to XII illustrate the change in sodium with distance from the road. The expected trend is most apparent in the sandy loam soils. The disparity of values 6m from the road in the Berrian Sandy Loam (Figure XI) may be related to the presence of a minor surface depression on the site serving as a runoff reservoir, and tending to increase sodium values. It seems evident therefore, that the amount of salt retained by the soil, although not sufficient to change the total salinity values close to the road, was sufficient to change the sodium content values so as to establish a trend with regard to distance from the road.

The results of the total number of Runs test, however,



Change in Sodium Concentrations With Distance - Granby Sand

Figure X

Change In Sodium Concentrations With Distance - Berrian Sandy Loam

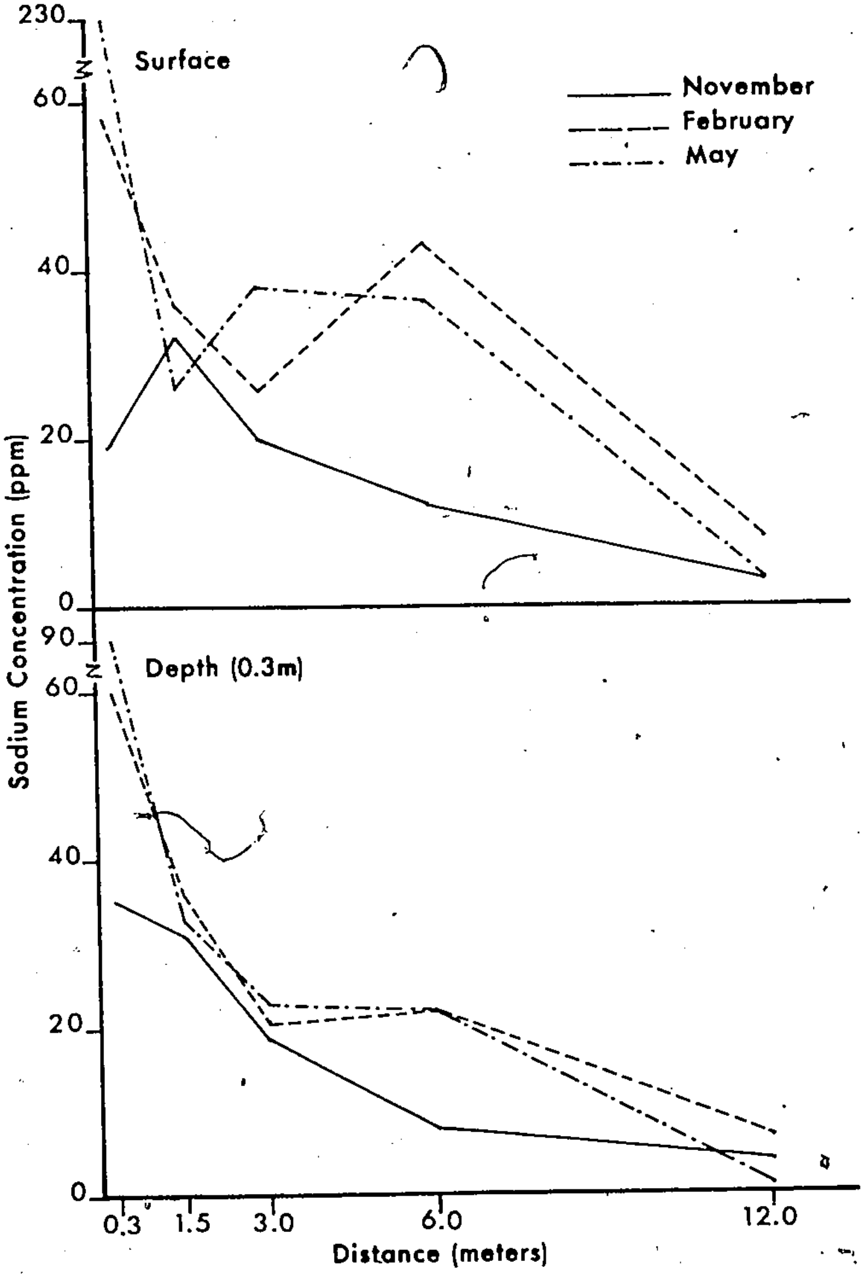


Figure XI

Changes In Sodium Concentrations With Distance - Toledo Clay

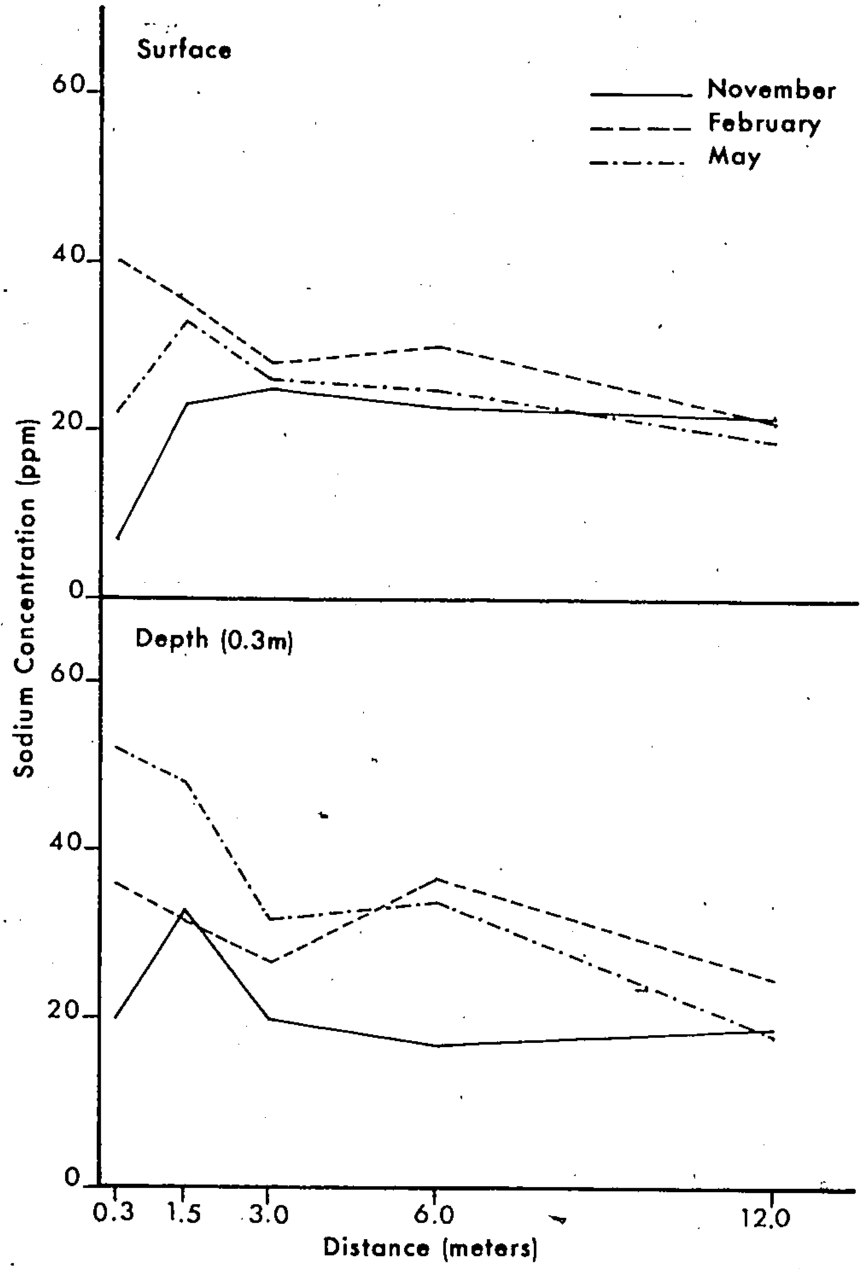


Figure XII

TABLE IX

Results Of Regression Analysis Between Sodium Concentration (y) And Distance (x)

Sample	Regression Coefficient	Best Fit Line Equation	Correlation Coefficient	Coefficient Of Determination
Granby Sand				
November - Surface	-0.01	y = -0.01x + 1.15	-0.343	0.118
February - Surface	-0.05	y = -0.05x + 1.62	-0.922*	0.849
May - Surface	-0.08	y = -0.08x + 1.43	-0.807	0.652
November - Depth	-0.09	y = -0.09x + 1.54	-0.938*	0.879
February - Depth	-0.06	y = -0.06x + 1.58	-0.963*	0.928
May - Depth	-0.14	y = -0.14x + 1.50	-0.945*	0.893
Berrian Sandy Loam				
November - Surface	-0.08	y = -0.08x + 1.49	-0.948*	0.898
February - Surface	-0.06	y = -0.06x + 1.74	-0.868	0.754
May - Surface	-0.13	y = -0.13x + 2.06	-0.883*	0.779
November - Depth	-0.09	y = -0.09x + 1.58	-0.968*	0.937
February - Depth	-0.07	y = -0.07x + 1.69	-0.954*	0.910
May - Depth	-0.15	y = -0.15x + 1.92	-0.960*	0.922
Toledo Clay				
November - Surface	0.02	y = 0.02x + 1.16	0.452	0.204
February - Surface	-0.02	y = -0.02x + 1.58	-0.930*	0.865
May - Surface	-0.01	y = -0.01x + 1.45	-0.627	0.393
November - Depth	-0.01	y = -0.01x + 1.37	-0.448	0.200
February - Depth	-0.01	y = -0.01x + 1.53	-0.576	0.331
May - Depth	-0.04	y = -0.04x + 1.71	-0.955	0.912

*Significant at the .05 Significance Level. Degrees of freedom = 3.

conflict with the regression analysis (Appendix V). In only three out of eighteen cases does sodium show a significant decline with distance. It would seem that this test may be too rigorous,,as significance at the .05 level occurs only if there is one run in a sample size of five. This does not allow for the slightest variation up or down in values except in the predicted direction. Therefore, that part of hypothesis three regarding the relationship of sodium concentration to distance is accepted for the sandy loam soils and rejected for the clay.

Hypothesis number four states that as the distance away from the road increases the cation-exchange capacity should also increase significantly because of a progressive reduction in the addition of deicing salts. Cation-exchange capacity is effected primarily by clay colloids and organic matter, each of which serves as reservoirs for cation-exchange activity. It is therefore reasonable to assume that each sample will naturally have different cation-exchange capacities, the clay soils having the highest. Acceptance of this fact does not change the nature of the hypothesis stated above. The influx of sodium providing an abundance of sodium ions into the soil system, should effect the exchange capacity. This imbalance results in a decrease in the total exchange capacity. It is closest to the road, that the exchange capacity values should be lowest, increasing with distance from the road.

Figures XIII to XV illustrate the cation-exchange capacity of the three soil types. Few trends are evident from visual inspection and this is confirmed by the correlation coefficients (Table X) as well as the Runs test (Appendix V). In not one case does the hypothesized relationship become evident. The fact that some of the regression coefficients are positive and some negative, also indicates the absence of a relationship. It seems evident therefore, that factors other than distance and indirectly sodium, affect the cation-exchange capacity. Hypothesis eight directly tests the relationship between sodium and cation-exchange capacity. It is known that clay and organic colloids directly affect the exchange capacity. It is also possible that frozen-soil conditions affect cation activity. Neither of these possibilities, however, can be substantiated in the present study, therefore; one must reject the hypothesis that cation-exchange capacity increases with distance as a result of decreasing sodium concentration.

The Wilcoxon rank-sum test was used to determine whether there is a significant difference between total salinity and sodium values in samples taken at the surface and at a depth of 0.3m. It was expected that surface values for total salinity and sodium would be higher than the depth values in accordance with the observations of Prior and Berthouex (1967) and Zelazny and Blaser (1970). The results in Table XI

Change In Cation-Exchange Capacity With Distance - Granby Sand

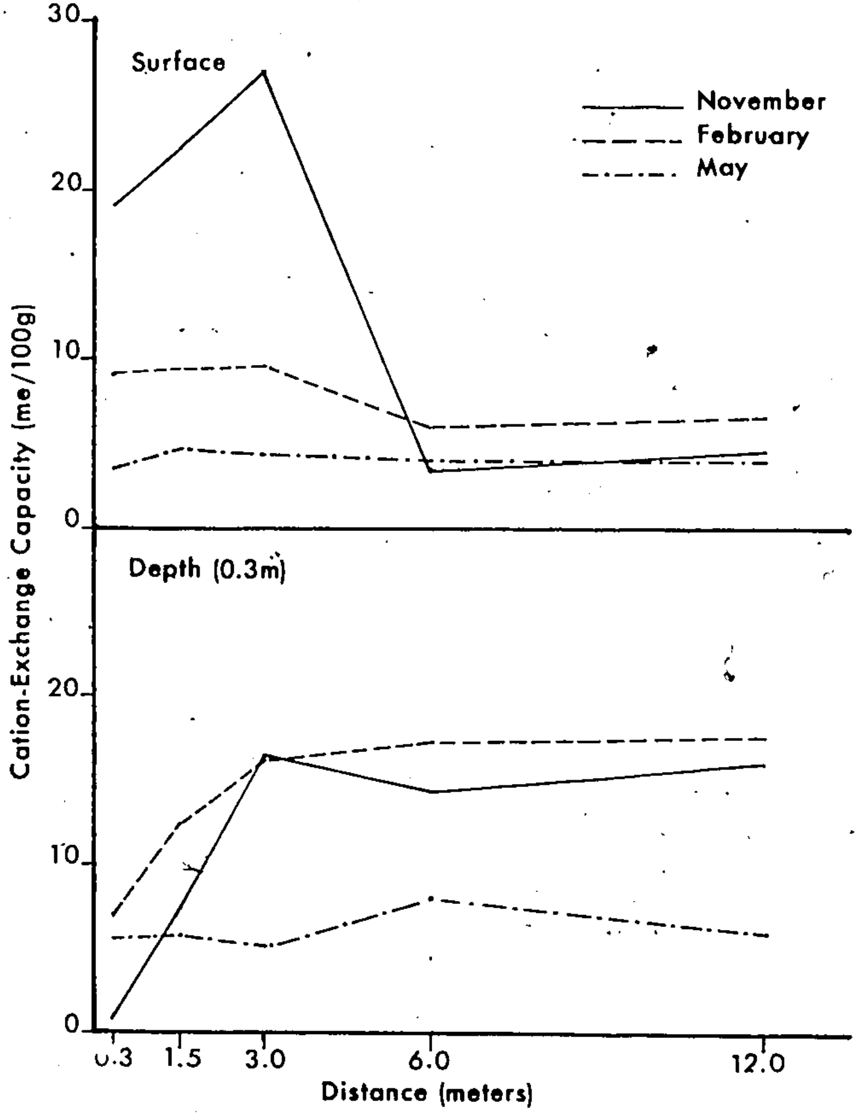


Figure XIII

Change In Cation-Exchange Capacity With Distance - Berrian Sandy Loam

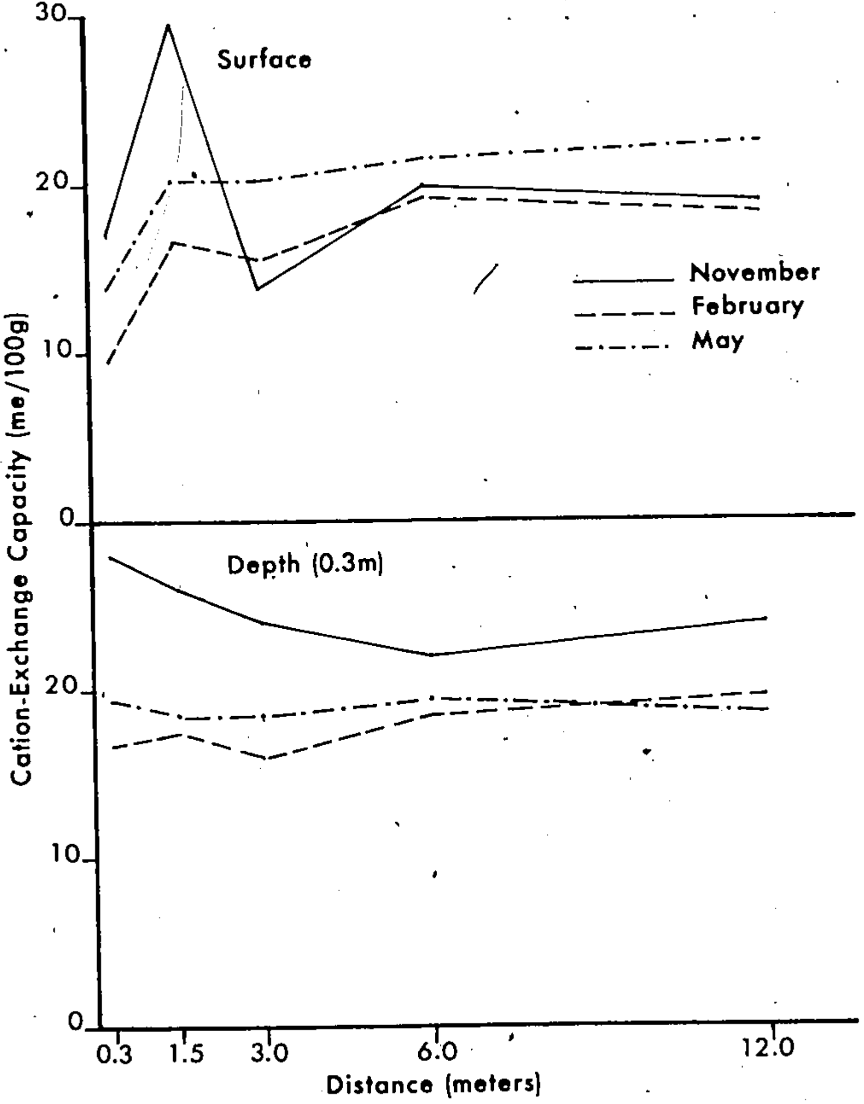


Figure XIV

Change In Cation-Exchange Capacity With Distance - Toledo Clay

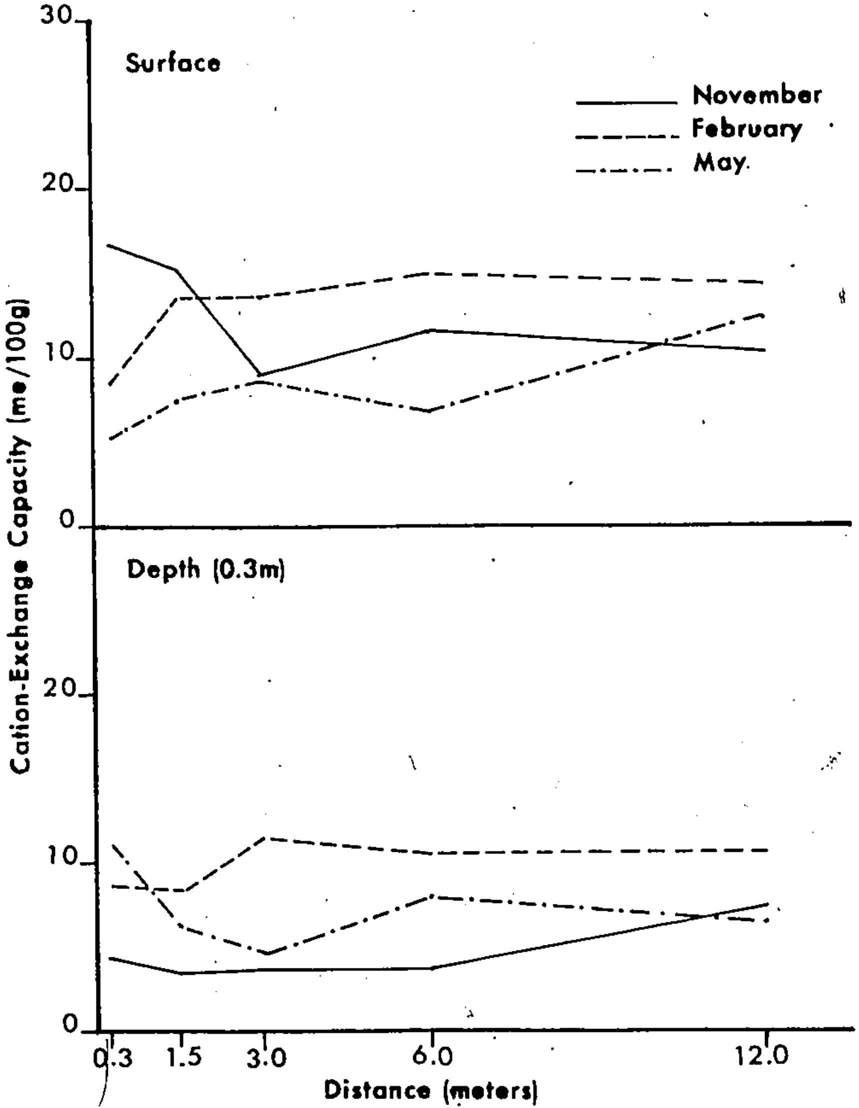


Figure XV

TABLE X

Results Of Regression Analysis Between Cation-Exchange Capacity (y) And Distance (x)

Sample	Regression Coefficient	Best Fit Line Equation	Correlation Coefficient	Coefficient Of Determination
Granby Sand				
November - Surface	-0.07	$y = -0.07x + 1.37$	-0.768	0.589
February - Surface	-0.01	$y = -0.01x + 0.97$	-0.815	0.664
May - Surface	0.0001	$y = 0.0001x + 0.61$	0.016	0.0003
November - Depth	0.07	$y = 0.07x + 0.57$	0.631	0.398
February - Depth	0.03	$y = 0.03x + 1.01$	0.715	0.511
May - Depth	0.005	$y = 0.005x + 0.76$	0.315	0.099
Berrian Sandy Loam				
November - Surface	-0.01	$y = -0.01x + 1.15$	-0.579	0.336
February - Surface	0.01	$y = 0.01x + 1.04$	0.601	0.361
May - Surface	0.02	$y = 0.02x + 0.78$	0.824	0.679
November - Depth	0.02	$y = 0.02x + 0.53$	0.812	0.659
February - Depth	0.01	$y = 0.01x + 0.96$	0.606	0.367
May - Depth	0.01	$y = 0.01x + 0.88$	0.241	0.058
Toledo Clay				
November - Surface	-0.002	$y = -0.002x + 1.29$	-0.063	0.004
February - Surface	0.02	$y = 0.02x + 1.11$	0.636	0.404
May - Surface	0.01	$y = 0.01x + 1.23$	0.702	0.493
November - Depth	-0.01	$y = -0.01x + 1.42$	-0.601	0.361
February - Depth	0.01	$y = 0.01x + 1.22$	0.825	0.679
May - Depth	0.0003	$y = 0.0003x + 1.27$	0.078	0.006

*Significant at the .05 Significance Level. Degrees of freedom = 3.

indicate an absence of significant differences. In the nine comparisons of total salinity only two cases are significant, the Granby Sand in November and the Toledo Clay in February. Only in the Granby Sand, however, does the surface have the higher values; the higher values being at the 0.3m depth in the Toledo Clay. As a result, only one comparison is acceptable under the stated hypothesis.

It is conceivable that percolation, occurring throughout the winter months, played a more important role in creating a homogeneous profile, with regard to total salinity, than did the February thaw. If percolation did continue throughout the winter, the results would concur with those of Zelazny and Blaser (1970), who suggested that brine solutions are capable of percolating through frozen soils. It must be concluded that total salinity values were not significantly higher at the surface than at the 0.3m depth.

The results of the sodium comparisons between samples collected at the surface and at the 0.3m depth are similar to those for total salinity. In only one case are the surface values significantly higher than those at depth. Again, percolation through frozen soil seems to be the only plausible explanation. One must therefore, reject the hypothesis that total salinity and sodium concentrations will be higher in samples collected at the surface than at the 0.3m depth.

Cation-exchange capacity values may be expected to be lower at the surface than at depth because of the higher

TABLE XI

Results Of Wilcoxon Rank-Sum Test For Monthly Surface-Depth Comparisons Of Total Salinity And Sodium Concentrations

Soil Type	Month	Smallest Rank-Sum (W_n)	Significant
		Total Salinity	
Granby Sand	November	35.0	Yes
	February	51.0	No
	May	48.0	No
Berrian Sandy Loam	November	40.0	No
	February	50.0	No
	May	42.5	No
Toledo Clay	November	48.5	No
	February	36.5	Yes
	May	47.5	No
		Sodium Concentrations	
Granby Sand	November	44.0	No
	February	44.0	No
	May	50.5	No
Berrian Sandy Loam	November	48.0	No
	February	50.0	No
	May	49.0	No
Toledo Clay	November	52.0	No
	February	49.5	No
	May	39.0	Yes

Significance Level .05
Significant if $L \leq L' = 39$

sodium retention at the soil surface. The results generated by the rank-sum test in hypothesis five however, would seem to indicate that, because there was only one significant difference in sodium, there would be no variation in the exchange capacity values. In the nine comparisons (Table XII) however, significant differences are evident in four cases, although only in the Granby Sand - May comparison are the exchange values lower at the surface. In the other three cases, exchange values are higher at the surface. None of the four comparisons having significant differences, correspond to significant differences in the sodium comparisons. It would seem evident therefore, that because the exchange values do not differ significantly, factors other than sodium (such as clay and organic matter) are more important to cation activity. It is also possible that insufficient sodium was available to effect the exchange value because of percolation through the 0.3m depth. The actual relationship between sodium and cation-exchange capacity is dealt with later in the paper.

In conclusion therefore, because only one comparison is significant, the hypothesis that cation-exchange capacity values are lower at the surface than at depth, must be rejected.

Hypothesis seven predicts that a positive relationship exists between sodium and total salinity, such that as sodium increases the total salinity also increases. Using regression and correlation techniques, this hypothesis was

TABLE XII

Results Of Wilcoxon Rank-Sum Test For Monthly Surface-Depth Comparisons Of Cation-Exchange Capacity

Soil Type	Month	Smallest Rank-Sum (W_n)	Significance
Granby Sand	November	41.0	No
	February	40.0	No
	May	30.0	Yes
Berrian Sandy Loam	November	28.5	Yes
	February	34.0	Yes
	May	45.0	No
Toledo Clay	November	36.0	Yes
	February	45.5	No
	May	42.0	No

Level of significance = .05
Significant if $W_n \leq W_n' = 39$

tested first for each month and for each soil type, combining the surface and the 0.3m depth data (Table XIII). It is evident from the results, that in every month, for each soil type, with the exception of Granby Sand and Toledo Clay in November, the hypothesized relationship is significant at the .05 significance level. There are two results for the Berrian Sandy Loam because of extreme values in sodium and total salinity, at the surface and depth, 0.3m from the shoulder of the road in May. The analysis was done first with then without, the extreme values, to determine if those values had an effect on the regression coefficient and correlation coefficient. The results show an increase in the slope and correlation coefficient when the extremes are eliminated. Such high values, i.e. 230ppm-surface and 90ppm depth, when compared to the other values can only be a

TABLE XIII

Results Of Regression Analysis Between Total Salinity And Sodium Concentration For Each Month

Sample	Regression Coefficient	Best Fit Line Equation	Correlation Coefficient	Coefficient Of Determination
Granby Sand				
November	-0.01	$y = -0.01x + 6.51$	-0.028	0.001
February	0.10	$y = 0.10x + 2.86$	0.899*	0.809
May	0.07	$y = 0.07x + 3.13$	0.955*	0.911
Berrian Sandy Loam				
November	0.15	$y = 0.15x + 3.19$	0.770*	0.593
February	0.19	$y = 0.19x + 0.55$	0.971*	0.943
May	0.14	$y = 0.14x + 1.93$	0.729*	0.531^{a}
	0.24	$y = 0.24x + 0.67$	0.988*	0.974^{b}
Toledo Clay				
November	0.07	$y = 0.07x + 5.31$	0.384	0.147
February	0.27	$y = 0.27x - 0.49$	0.558	0.311
May	0.12	$y = 0.12x + 2.94$	0.850	0.722

*Significant at .05 significant level. Degrees of freedom = 12.
a = extreme values included.
b = extreme values excluded.

chance occurrence. It is not suprising not to find a correlation between the variables in November for Granby Sand and Toledo Clay, as the samples represent pre-winter or pre-salting conditions. One may conclude therefore, that there is a strong positive relationship between sodium and total salinity on a monthly basis.

The data were tested a second time combining all values regardless of month, surface, or depth (Table XIV). Only in the Berrian Sandy Loam and Toledo Clay soils was the relationship found to be significant and moderately strong. Berrian Sandy Loam data were again tested without the extreme sodium and total salinity values, lowering the regression and correlation coefficients considerably. The relationship was found to be almost non-existent in the Granby Sand data. It is conceivable that percolation efficiency was highest in the Granby Sand throughout the winter, thereby not allowing the sodium ions to significantly change the total salinity values. This is also evident in the lack of change in total salinity over time (Figure IV). It must be concluded therefore that there is a moderately strong relationship between total salinity and sodium, in the Berrian Sandy Loam and Toledo Clay soils, but not in the Granby Sand.

Finally the data for total salinity and sodium were combined regardless of soil type, surface or depth location, distance, or month to formulate a general conclusion regarding the hypothesized relationship over the study period. Again

TAB[illegible] XIV

Results Of Regression Analysis Between Total Salinity And Sodium Concentration For Each Soil Type

Sample	Regression Coefficient	Best Fit Line Equation	Correlation Coefficient	Coefficient Of Determination
Granby Sand	0.04	$y = 0.04x + 5.02$	0.128	0.016
Berrian Sandy Loam	0.22	$y = 0.22x + 0.48$	0.962*	0.926^a
	0.15	$y = 0.15x + 2.34$	0.789*	0.623^b
Toledo Clay	0.11	$y = 0.11x + 4.09$	0.564*	0.318

*Significant at .05 significance level. Degrees of freedom = 40
a = extreme values included.
b = extreme values excluded.

the regression analysis was conducted, first including the extreme values (A) and secondly excluding those values (B) (Table XV). It is reasonable to conclude that the correlation coefficient r = 0.151 is more representative of the data than is the value r = 0.324 when the extremes are considered. The presence of extremely high and unaccountable values tends to increase the correlation and regression values thereby reducing confidence in the final results.

TABLE XV

Results Of Regression Analysis Between All Values Of Total Salinity And Sodium

Test	Regression Coefficient	Best Fit Line Equation	Correlation Coefficient	Coefficient Of Determination
A	0.20	$y = 0.20x + 1.49$	0.324*	0.105
B	0.11	$y = 0.11x + 3.66$	0.151	0.023

*Significant at .05 Significance Level
Degrees of freedom = 125
Critical r = .174

When the extreme values are included, the correlation coefficient is significant at the .05 significance level but the relationship is very weak; when the extreme values are eliminated the correlation is insignificant. The coefficient of determination in test A states that only 10.5 percent of the change in total salinity is explained by the sodium concentration. One must therefore, reject the hypothesis that total salinity is related to sodium over the study period.

It is predicted in hypothesis eight that a significant negative relationship exists between sodium and cation-exchange capacity, such that as sodium increases, the exchange capacity decreases. The data were tested in the same three phases as were the data for hypothesis seven (Tables XVI XVII XVIII). Hypothesis four, concerning the change in cation-exchange capacity with distance, was an indirect test for the relationship between sodium and cation-exchange. The results of this test (i.e. regression analysis) confirm the implications of the results of tests in hypothesis four, that there is no significant relationship between sodium and cation-exchange capacity. This was found to be true on a monthly basis (Table XVI) and with regard to each soil type when monthly data were combined. The regression analysis and the combined-data test were run a second time for Berrian Sandy Loam in May but showed no major change. In not one case, did the hypothesized relationship prove to be significant.

The hypothesized relationship, however, was found to be significant at the .05 significant level (Table XVIII) when all values were combined, regardless of month, soil type, surface or depth location, or distance. Both tests were run, (A including extremes and B excluding extremes) but the results differed only slightly. Despite the significance of the correlation coefficients, the coefficients of determination show that in test A, only 5.0 percent and

TABLE XVI

Results Of Regression Analysis Between Cation-Exchange Capacity And Sodium For Each Month

Sample	Regression Coefficient	Best Fit Line Equation	Correlation Coefficient	Coefficient Of Determination
Granby Sand				
November	-0.29	$y = -0.29x + 17.90$	-0.334	0.112
February	-0.14	$y = -0.14x + 14.75$	-0.399	0.159
May	-0.02	$y = -0.02x + 5.44$	-0.189	0.036
Berrian Sandy Loam				
November	-0.04	$y = -0.04x + 9.30$	-0.098	0.009
February	-0.06	$y = -0.06x + 13.32$	-0.925	0.181
May	-0.01	$y = -0.01x + 8.10$	-0.245	0.060^{a}
	-0.05	$y = -0.05x + 8.83$	-0.263	0.069^{b}
Toledo Clay				
November	0.22	$y = 0.22x + 17.78$	0.294	0.086
February	-0.25	$y = -0.25x + 24.71$	-0.530	0.281
May	-0.02	$y = -0.02x + 19.78$	-0.076	0.006

*Significant at the .05 significance level. Degrees of freedom = 12.
a = extreme values included.
b = extreme values excluded.

TABLE XVII

Results Of Regression Analysis Between Cation-Exchange Capacity And Sodium For Each Soil Type

Sample	Regression Coefficient	Best Fit Line Equation	Correlation Coefficient	Coefficient Of Determination
Granby Sand	-0.10	$y = -0.10x + 12.06$	-0.155	0.024
Berrian Sandy Loam	-0.02 -0.01	$y = -0.02x + 9.69$ $y = -0.01x + 9.51$	-0.132 -0.045	0.017[a] 0.002[b]
Toledo Clay	-0.11	$y = -0.11x + 23.41$	-0.189	0.036

*Significant at the .05 significance level. Degrees of freedom = 40.
a = extreme values included.
b = extreme values excluded.

TABLE XVIII

Results Of Regression Analysis Between Sodium And Cation-Exchange Capacity

Test	Regression Coefficient	Best Fit Line Equation	Correlation Coefficient	Coefficient Of Determination
A	-0.02	$y = -0.02x + 13.74$	-0.223*	0.050
B	-0.01	$y = -0.01x + 12.83$	-0.254*	0.064

*Significant at the .05 significance level
Degrees of freedom = 125
Critical r = .174

in test B, 6.4 percent of the variation in cation-exchange capacity is explained by variation in sodium concentration. The remaining variation is explained by other factors, most probably the clay and organic fractions of the soil.

It must be concluded therefore that cation-exchange capacity is not related to the sodium retained by the soil, even though the correlation coefficient is significant when all values are combined.

Hypothesis number nine states that each of the three soil types will be significantly different at the surface and at depth, for each of the three variables. Soil types have thus far been discussed on an individual basis. Hypothesis nine brings together each soil type and statistically compares them using the Wilcoxon rank-sum test for Identical Populations. To determine significance, the smallest rank-sum is compared to the critical value of W_n provided in tabular form. If the observed W_n is less than W_n' the compared values cannot be considered to be from the same population, and are therefore significantly different. The data for each soil type are plotted (Figures XVI to XIX) for November, February, and May. Each variable will be discussed separately below.

i) Total Salinity:

Figures XVI and XVII present total salinity values both for the surface and the 0.3m depth for each soil type, for each month during the sampling period. Significant differences in total salinity values might be expected to occur between November and February, when most of the deicing salt is laid down. However, the greatest variation in total salinity occurs in May on the soil surfaces and at the 0.3m depth (Table XIX). On the surface there are significant differences in only two instances: (1) between the Granby Sand and the Berrian Sandy Loam in May; and (2) between the Granby Sand and the Toledo Clay in May. In each case the total salinity values are higher for the Berrian Sandy Loam and the Toledo Clay than for the Granby Sand.

In the depth samples (Figure XVII), it would appear that the Toledo Clay values are significantly higher than the other soil types.[1] The results in Table XIX substantiate this observation only between Toledo Clay and Granby Sand.

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[1] It must be noted here that the values for total salinity as well as sodium and cation-exchange capacity are treated as groups of values; i.e. Toledo Clay - November as opposed to Toledo Clay at each distance from the road in November. The data have been grouped this way to facilitate statistical procedures otherwise impossible to perform on single values.

Monthly Comparison Of Total Salinity At The Surface, By Soil Type

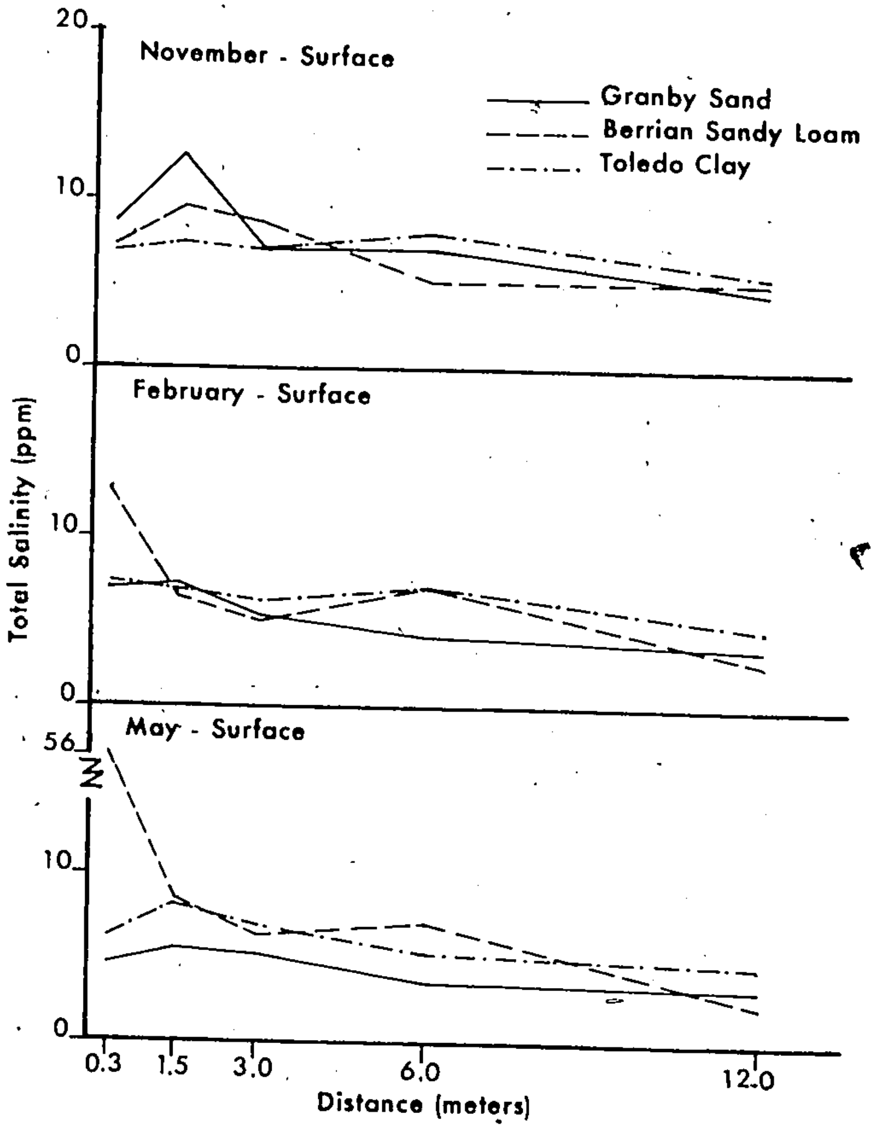


Figure XVI

Monthly Comparison Of Total Salinity At The 0.3 Meter Depth, By Soil Type

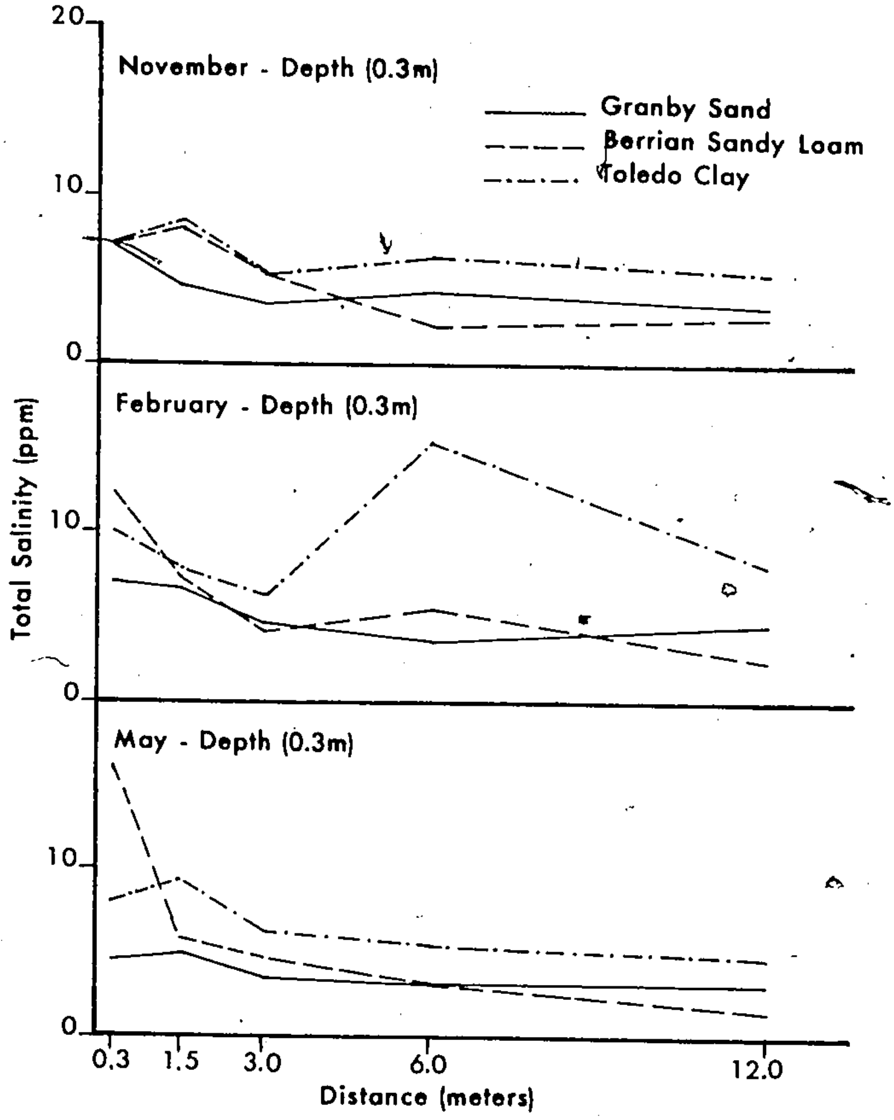


Figure XVII

The clay values are significantly higher than the Granby Sand (sandy loam) values in November, February, and May. At no point does the Berrian Sandy Loam differ significantly from the other two soils at the 0.3m depth.

A possible explanation for the results can be offered in terms of percolation efficiency. More efficient percolation and resultant leaching probably occurred in the sandy loam soil (designated Granby Sand), than in the Toledo Clay, which tended to absorb more of the incomming brine solution, particularly in February and May. It can only be suggested that the percolation efficiency in the Berrian Sandy Loam soil may have been insufficient to produce total salinity values comparable to the other sites.

Each soil type was compared six times (one comparison for each month for surface and depth data). In the comparisons between Granby Sand and Berrian Sandy Loam, a significant difference in total salinity values occurred only once. One must therefore reject the hypothesis that these two soil types differ significantly. Granby Sand and Toledo Clay were compared with significant differences occurring in four out of six cases. According to the Binomial Frequency test (Bradley, 1968), all cases must be significant to prove an overall significance at the .05 significance level when six cases are abailable. In the case of Granby Sand and Toledo Clay, one must refect the hypothesis that the soil types differ significantly with respect to total salinity, as only four cases are significant.

TABLE XIX

Results Of Wilcoxon Rank-Sum Test For Comparison Of Surface And Depth Between Soil Types For Total Salinity

Month	Soils Compared	Smallest Rank-Sum (W_n)	Significant
	Surface		
November	Granby Sand-Berrian Sandy Loam	46.5	No
	Granby Sand-Toledo Clay	48.0	No
	Berrian Sandy Loam-Toledo Clay	44.5	No
February	Granby Sand-Berrian Sandy Loam	48.5	No
	Granby Sand-Toledo Clay	43.5	No
	Berrian Sandy Loam-Toledo Clay	51.5	No
May	Granby Sand-Berrian Sandy Loam	38.0	Yes
	Granby Sand-Toledo Clay	36.0	Yes
	Berrian Sandy Loam-Toledo Clay	48.5	No
	Depth		
November	Granby Sand-Berrian Sandy Loam	44.5	No
	Granby Sand-Toledo Clay	33.0	Yes
	Berrian Sandy Loam-Toledo Clay	48.0	No
February	Granby Sand-Berrian Sandy Loam	50.0	No
	Granby Sand-Toledo Clay	32.5	Yes
	Berrian Sandy Loam-Toledo Clay	39.5	No
May	Granby Sand-Berrian Sandy Loam	45.0	No
	Granby Sand-Toledo Clay	31.0	Yes
	Berrian Sandy Loam - Toledo Clay	41.5	No

Significant at the .05 significance level.
Significant if $W_n \leq W_n' = 39$.

Berrian Sandy Loam and Toledo Clay were similarly compared a total of six times, but no significant differences could be identified. One must therefore reject the hypothesis that the three soil types differ significantly with respect to total salinity over the sampling period It is suggested that the lack of significant differences in total salinity between soil types could be attributed to the effects of percolation. It is conceivable that percolation was consistent in each soil type, thereby producing similar results in respect to the amount of sodium available to affect the total salinity values.

ii) Sodium:

Figures XVIII and XIX represent the sodium data for each soil type per month for surface and depth samples. Visual examination suggests that in numerous cases, significant differences in sodium concentration do occur. However, the results generated from the Wilcoxon rank-sum test (Table XX), show that only three out of eighteen comparisons are significant. These are: (1) Granby Sand and Berrian Sandy Loam in November at the surface; (2) Granby Sand and Toledo Clay in November at the surface; and (3) Granby Sand and Toledo Clay in May at 0.3m depth. In each of the three comparisons, the Granby Sand samples are significantly lower than the other types to which they are compared.

The only reasonable explanation of the absence of significant differences between soil types, is that the amount of sodium retained by the different soils may not be

Monthly Comparison Of Sodium Concentrations At The Surface, By Soil Type

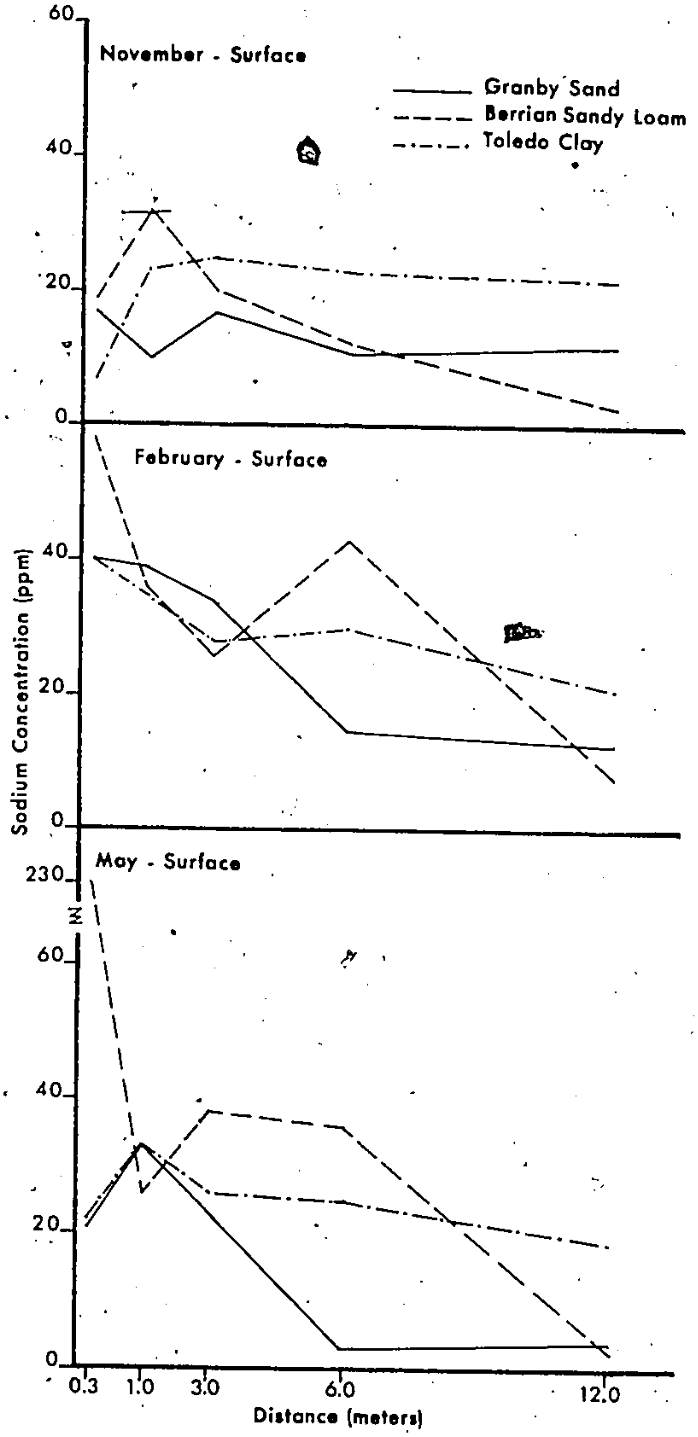
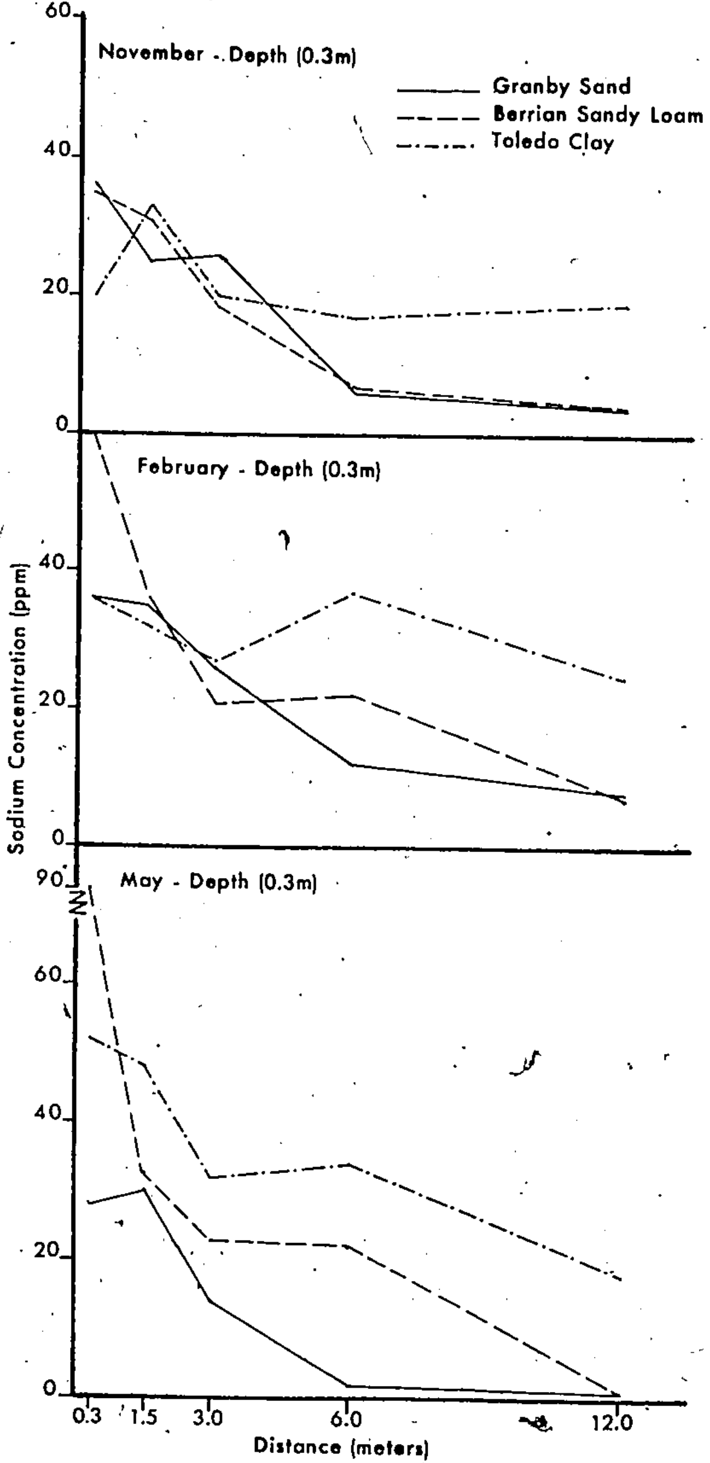


Figure XVIII



Monthly Comparisons Of Sodium Concentrations At The 0.3 Meter Depth, By Soil Type

Figure XIX

TABLE XX

Results Of Wilcoxon Rank-Sum Test For Comparison Of Surface And Depth Between Soil Types For Sodium

Month	Soils Compared	Smallest Rank-Sum (W_n)	Significant
	Surface		
November	Granby Sand-Berrian Sandy Loam	38.0	Yes
	Granby Sand-Toledo Clay	34.5	Yes
	Berrian Sandy Loam-Toledo Clay	52.0	No
February	Granby Sand-Berrian Sandy Loam	47.5	No
	Granby Sand-Toledo Clay	50.0	No
	Berrian Sandy Loam-Toledo Clay	49.0	No
May	Granby Sand-Berrian Sandy Loam	44.0	No
	Granby Sand-Toledo Clay	47.0	No
	Berrian Sandy Loam-Toledo Clay	46.5	No
	Depth		
November	Granby Sand-Berrian Sandy Loam	46.0	No
	Granby Sand-Toledo Clay	48.5	No
	Berrian Sandy Loam-Toledo Clay	50.5	No
February	Granby Sand-Berrian Sandy Loam	50.5	No
	Granby Sand-Toledo Clay	48.5	No
	Berrian Sandy Loam-Toledo Clay	48.0	No
May	Granby Sand-Berrian Sandy Loam	47.0	No
	Granby Sand-Toledo Clay	33.5	Yes
	Berrian Sandy Loam-Toledo Clay	44.0	No

Significant at the .05 significance level.
Significant if $W_n \leq W_n' = 39$.

sufficient to produce significant differences even though it may have been sufficient to change the total salinity values in a number of cases. Nevertheless, hypothesis number nine must be rejected.

iii) Cation-Exchange Capacity:

According to general theory cation-exchange capacity is influenced primarily by the clay and organic colloids in the soil. It is expected therefore that cation-exchange values would differ significantly between soil types. It has already been shown that (a) the exchange values do not change significantly over time for any one soil type and (b) that changes in sodium were not strongly related to changes in cation-exchange capacity. The results of the Wilcoxon rank-sum test are given in Table XXI. As was expected, 15 out of 18 comparisons provided significant differences; the clays in almost every case having higher exchange values than the other soils. The significant difference was found between the Granby Sand samples and the Berrian Sandy Loam samples in three cases out of six; which is not however unexpected since the Granby Sand is actually a sandy loam.

In conclusion, hypothesis number nine can be accepted with regard to the cation-exchange capacity values.

TABLE XXI

Results Of Wilcoxon Rank-Sum Test For Comparison Of Surface And Depth Between Soil Types For Cation-Exchange Capacity

Month	Soils Compared	Smallest Rank-Sum (W_n)	Significant
	Surface		
November	Granby Sand-Berrian Sandy Loam	50.0	No
	Granby Sand-Toledo Clay	46.0	No
	Berrian Sandy Loam-Toledo Clay	37.0	Yes
February	Granby Sand-Berrian Sandy Loam	31.0	Yes
	Granby Sand-Toledo Clay	29.0	Yes
	Berrian Sandy Loam-Toledo Clay	34.0	Yes
May	Granby Sand-Berrian Sandy Loam	28.0	Yes
	Granby Sand-Toledo Clay	28.0	Yes
	Berrian Sandy Loam-Toledo Clay	28.0	Yes
	Depth		
November	Granby Sand-Berrian Sandy Loam	49.0	No
	Granby Sand-Toledo Clay	28.0	Yes
	Berrian Sandy Loam-Toledo Clay	28.0	Yes
February	Granby Sand-Berrian Sandy Loam	42.0	No
	Granby Sand-Toledo Clay	38.0	Yes
	Berrian Sandy Loam-Toledo Clay	28.0	Yes
May	Granby Sand-Berrian Sandy Loam	47.0	No
	Granby Sand-Toledo Clay	28.0	Yes
	Berrian Sandy Loam-Toledo Clay	28.0	Yes

Significant at the .05 significance level.
Significant if $W_n \leq W_n' = 39$.

CHAPTER SEVEN

SOIL COLUMN ANALYSIS

The purpose of the soil column experiment was to establish a controlled situation where changes in total salinity, sodium concentration, and cation-exchange capacity could be studied using known concentrations of sodium chloride. The soil column experiment is representative of those changes occurring in these parameters at the 1.5m distance from the shoulder of the highway.

The column consisted of a waterproofed wooden box, divided into four compartments or columns, each sealed from the other (Figure XX). Holes were bored through one side of each column, at specific depths, through which samples were extracted. Samples were taken at the surface, 10.2cm, 20.4cm, and at the bottom of the column, after the screen was removed. During the experiment the column was wedged into a galvanized steel bucket to collect the filtrate.

The Granby Sand samples were chosen at random for the column experiment. The November surface and depth samples were mixed thoroughly, producing a homogenous soil throughout the column. Measurements of total salinity (5.4ppm), sodium content (16ppm), and cation-exchange capacity (7.6 me/100g) were taken on the non-treated soil. Three concentrations of sodium chloride were filtered, each through its own column.

Soil Column Construction

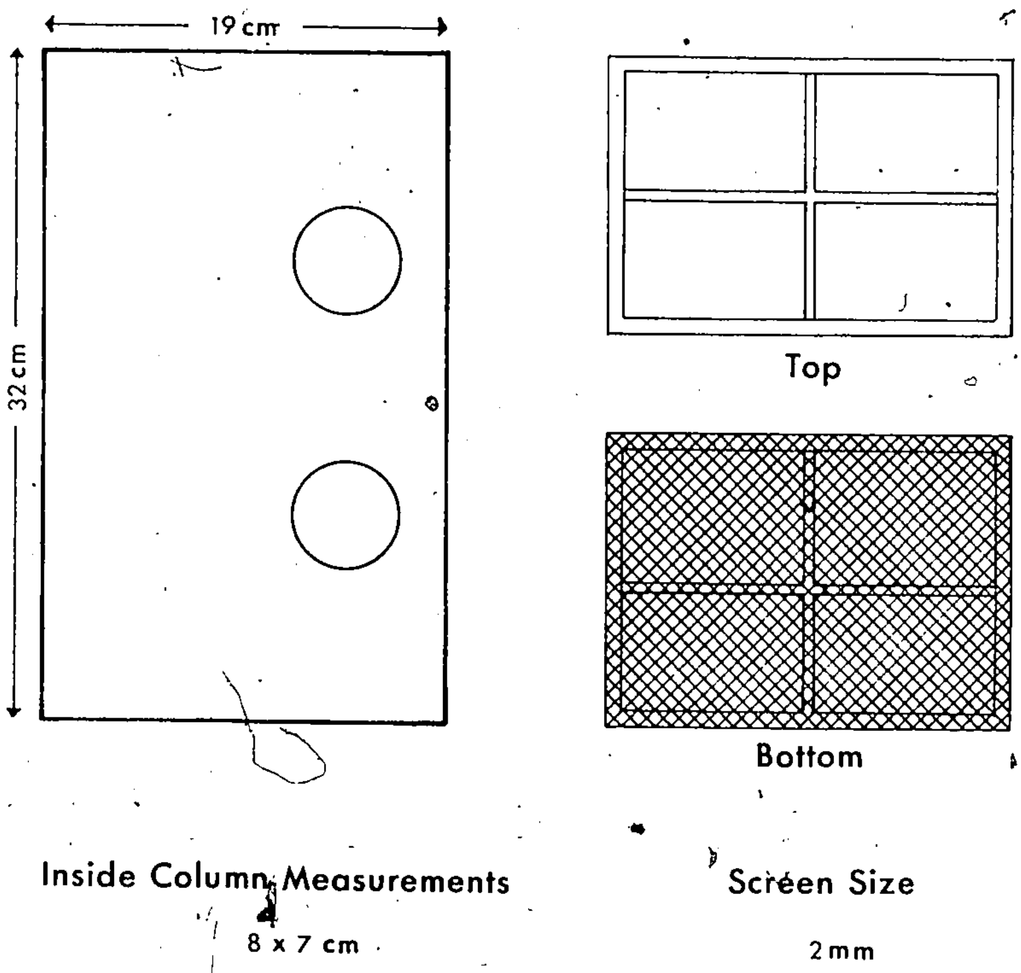


Figure XX

The relevant computations for the salt solutions are given in Appendix IV. Full concentration was based on the total amount of salt put down during the study period. Measurements of total salinity, sodium, and cation-exchange were then taken of the samples from each column (Table IV), using the standard methods previously outlined.

The L-test was used to determine whether a significant increase occurred in total salinity and sodium content as a result of treatments by sodium chloride. A visual examination of the curves (Figure XXI) would indicate that both variables increased significantly after treatment. The L-statistic for total salinity was calculated to be 117.5 and the L' value at the .05 significance level is 111. Because L-observed is greater than L-critical, it is accepted that total salinity values changed significantly at each depth, with each succeeding treatment of sodium chloride. The L-statistic for sodium is 120 which exceeds the L-critical value of 111. Again the results show that, that amount of sodium retained by the soil, changed significantly with each succeeding treatment of sodium chloride.

The same test was applied to the cation-exchange capacity data to show a significant decrease with treatment of sodium chloride. The L-statistic was calculated to be 82 which is lower than the L-critical value of 111. Therefore cation-exchange capacity did not decrease significantly with successive treatments of sodium chloride.

Soil Column Treatment Results Of Sodium Chloride On Total Salinity, Sodium Content And Cation Exchange Capacity

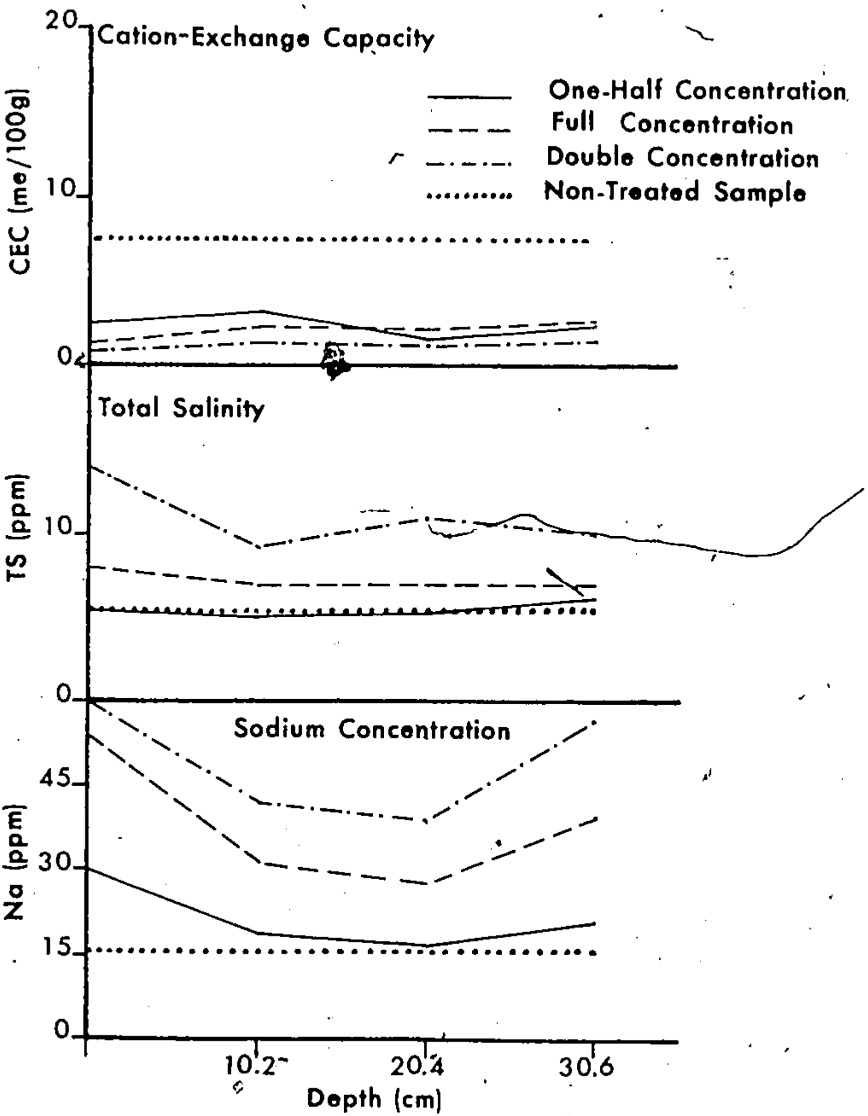


Figure XXI

Regression analysis was used to determine whether the hypothesized relationships between sodium and total salinity, and sodium and cation-exchange capacity are evident under controlled situations. The curves generated from the laboratory data (Figure XXI), seem to indicate a significant correlation for both hypothesized trends. The correlation coefficient for sodium against total salinity is 0.818 and is significant at the .05 significance level, where r-critical = 0.576 with 10 degrees of freedom. The regression coefficient is 0.15 and 67.2 percent of the variation in total salinity is explained by the variation in sodium. These results are not radically different from those computed on a monthly basis (Table XIII) for the sandy loam soils. One may conclude therefore that the hypothesized relationship between sodium and total salinity is confirmed in the column experiment by a moderately high correlation and coefficient of determination.

The correlation between sodium and cation-exchange capacity was found to be moderate at 0.679 with only 46.2 percent of the variation in cation-exchange explained by the variation in sodium. The slope, 0.03 compares favourably to the slope of the regression lines for the sandy loam soils, when analyzed on a combined-monthly basis. Although the correlation is significant at the .05 significance level 53.8 percent of the variation in cation-exchange capacity is left unexplained. It is probable that the clay and organic matter contents of the soil make up the bulk of the unexplained variation. Both the correlation and the coefficient of determination are much higher than in the field data analysis, which would indicate that even though the relationship is moderate, further detailed study under controlled conditions would provide more substantial information as to the hypothesized relationships.

It is impossible to determine significant changes in total salinity from the surface to the 0.3m depth, comparing one value against another with each added concentration. The only test available is the Run's test at the 0.1 significance level, but this significance level is inconsistent with the other tests performed previously in this study. A qualitative analysis would indicate that total salinity values are consistently higher at the surface for each added concentration (Figure XXI). Decreases tend to occur between the surface and the 20.4cm depth. It is suspected that this is because of uneven compaction within the soil column. This would explain the higher values at the bottom of the column, where compaction against the screen is high, thereby increasing the residency period of the salt solution. These curves compare favourably with the statements of Prior and Berthouex (1967) and Zelazny and Blaser (1970) that higher values of salinity and sodium are always found at the surface.

A similar trend is evident in the change in sodium values

(Figure XXI), only with greater consistency. Sodium concentrations retained by the soil decrease consistently to the 20.4cm depth and then increases toward the bottom of the column. Again, high compaction is cited the probable cause for this increase.

In summary, total salinity and sodium concentrations at each sampled depth in the soil columns were found to increase significantly with the addition of sodium chloride solutions. For both variables values were higher at the surface and decreased to the 20.4cm depth, where, because of high soil compaction, they tended to increase as a result of inefficient percolation. The results of the regression analysis showed a moderate correlation between sodium and total salinity, significant at the .05 significance level.

The correlation between cation-exchange capacity and sodium content was found to be significant, but the amount of unexplained variations tends to lower the reliability of the correlation value. It was concluded that even though the correlation was found to be significant, much further analysis is necessary to confirm the hypothesized trend particularly since 53.8 percent of the variation in cation-exchange is left unexplained.

CHAPTER EIGHT

CONCLUSIONS

It was the primary aim of this research to study the impact of deicing salt, namely sodium chloride (NaCl), on the soil adjacent to Highway 18, in Essex County. Three soil types; Granby Sand, Berrian Sandy Loam and Toledo Clay were studied to determine if they reacted in different ways to the addition of sodium chloride.

Changes in total salinity, sodium concentration, and cation-exchange capacity were studied over time, over distance from the highway, and over depth in the soil. These variables were also used to provide a comparison of the soil types both at the surface and at the 0.3m depth. It was found that the three variables did not differ significantly in any of the soil types between the months of November, February and May. It is suggested that the expected differences were not achieved because of the effects of percolation during the February and spring thaws. It is also possible that percolation through frozen soil was achieved by the brine solution, thereby removing the sodium ions necessary to increase total salinity and sodium concentration, and to decrease the exchange capacity values.

Percolation is also cited as a plausible explanation for the general absence of significant differences between the surface and depth samples of each soil type.

It was also hypothesized that total salinity would decrease with distance from the highway. Results of regression analysis and run's tests, however have shown that there was no significant relationship. Had the samples been taken in conditions other than thaw, the problem of percolation may have been avoided, possibly permitting a significant trend to be identified. The hypothesis that cation-exchange capacity would increase with distance was also rejected citing percolation as a plausible explanation.

A significant relationship was found between sodium and distance. It is evident that the amount of sodium retained by the soil, although not sufficient to consistently change the total salinity content, was high enough to change the sodium content particularly in the sandy loam soils.

It was predicted that the increase in sodium retained by the soil would be positively related to increases in total salinity. This hypothesis was accepted when regression analysis was performed on the data on a monthly and a combined-monthly basis for each soil type. The relationship was found to be particularly strong in the sandy loam soils. However, when all the data were combined regardless of soil type, distance, surface or depth, and month, the correlation was found to be significant when extreme values were included and not significant when they were excluded. It is concluded therefore, that total salinity and sodium are positively related on a monthly basis, but not over the study period in general.

Cation-exchange capacity was expected to decrease as sodium content increased. This hypothesis was rejected on a monthly and a combined-monthly basis for each soil type. When all data were combined the regression analysis showed a significant negative relationship having a very weak correlation. The hypothesis, however, had to be rejected as the coefficient of determination showed only 5.0 percent (extremes included), and 6.4 percent (extremes excluded) of the variation in cation-exchange explained by the variation in sodium content.

The correlations between sodium and total salinity, and sodium and cation-exchange capacity were lower than expected. This is probably due to the validity of the sodium data, resulting from different sample preparation procedures. Samples sent to the contract laboratory for sodium content analysis were sieved using an 80 mesh screen; whereas the preparation of samples for the other laboratory tests did not include sieving. The sodium tests, were then performed using a sample with surface area greater than the original unsieved sample, therefore producing values higher than normally expected. Because of this difference in laboratory preparation, the validity of the regression and correlation is somewhat weakened.

The soil types were found to react in similar ways to the addition of deicing salts. Total salinity and sodium concentrations did not differ significantly on a monthly basis, between each soil type. Cation-exchange capacity did differ significantly between soil types due primarily to differences in clay and organic matter content, rather than because of the additional sodium chloride.

Both total salinity and sodium concentrations were found to increase significantly, as a result of treatment by sodium chloride in the column experiment. Cation-exchange capacity however was not found to decrease significantly under the same treatment conditions.

Regression analysis performed on the soil column data generated a significant positive correlation between sodium and total salinity values. Cation-exchange capacity was also found to be negatively correlated to sodium content. It is suggested however, that further detailed analysis be conducted concerning the negative correlation between sodium and cation-exchange capacity as only 46.1 percent of the variation in cation-exchange is explained by the variation in sodium.

There are a number of factors which may be cited as having possibly influenced the results of this research. One such factor already mentioned is the sample preparation procedure used by the contract laboratory which, as a result, produced higher sodium values than expected thereby reducing the validity of any regression analysis in which the sodium values were involved.

A second factor, which could significantly change the results of the research, is the length of the study period. This research was concerned with specific changes in the soil due to the addition of sodium chloride for a very short period of time, that is, from just before the winter to just after the spring thaw. A more complete synthesis of the soil conditions might have been rendered had the sampling period been extended to include an entire year. Had this been possible, it is conceivable that upward capillary action could bring salt that was applied in the winter months up to the surface soil in the summer months. The effect of percolation could also be studied in more detail with the absence of frozen soil conditions.

The results of the statistical analysis showed no significant difference between soil types with respect to total salinity and sodium concentration. It is possible that these values did not differ according to soil type because of the use of fill in road construction, which would change the original designation of the soil types involved. Granby Sand for example, was shown to be a sandy loam soil rather than a sandy soil due possibly to the use of fill. The existence of fill may have affected the values in both surface and depth samples to an undetermined distance from the highway.

A fourth factor which may have affected the variables studied is the presence of other chemicals in the roadside soil received from other sources sources such as exhaust emissions from automobiles or even atmospheric fallout from local industries.

It is possible that other chemicals set up reactions in the soil, producing results in those variables measured which may not be representative of the actual changes due solely to the addition of sodium chloride. It is not within the scope of this research to determine the existence of these reactions but their possibility must be cited as a basis for a potential source of error.

In conclusion, the detrimental impact of deicing salts on the three roadside soils under study was not as severe as expected. The variables studied were not appreciably changed, nor did the soil types react differently to the salt. It seems evident that the soil system was able to maintain its salinity balance by percolation during the study period. It must be emphasized, however, that this research relates only to short-term effects and cannot be considered capable of long-term predictions.

Having completed this preliminary investigation, the author wishes to recommend areas of future research into the effects of deicing salts on roadside soils. The study of the effects of deicing salts to determine whether changes are occurring over a longer period of time, is the basis for further research. It is also recommended that a detailed study be conducted to examine the movement of brine solutions through frozen soils and that laboratory simulation play a more important role in deicing salt research. In the laboratory situation, factors, uncontrollable in nature, such as percolation, slope, compaction, and salt additions, can be controlled in an effort to determine the maximum allowable concentrations that can be applied, before toxicity levels can develop.

APPENDIX I

The Bouyoucos Hydrometer Method

1. Weigh 50 grams of soil into a beaker.
2. Pour soil into a dispersing cup. Fill the cup with distilled water to 1½ inch from the top.
3. Add 10 cc. of 1 Normal sodium hexametaphosphate (calgon). If the soil is highly calcareous use sodium carbonate.
4. If the soils are dry, let soak for 15 minutes before dispersing. Place dispersing cup on the mixer for 5 minutes for sandy soils and 10 minutes for other soils.
5. Pour and wash contents from cup into 1000 ml. soil cylinder and fill to 1 litre with distilled water.
6. Place stopper over end of cylinder and shake contents vigourously, turning cylinder upside down and back several times.
7. Place on table and note the time. Place the hydrometer in gently and record the reading at the end of 40 seconds.
8. Remove the hydrometer. Record the temperature. Repeat steps 6 to 8 several times to obtain more accuracy.
9. At the end of 2 hours, take another reading and record the temperature.

The hydrometer is calibrated at temperatures 67 - 68°F. Therefore a correction of 0.2 graduation on the hydrometer reading is made for every 1°F above or below the given temperature, but subtracted for temperatures below the given range.

$$\frac{\text{First reading corrected}}{\text{50 grams}} \times 100 = \text{\% of material still in suspension at the end of 40 sec. (silt and clay)}$$

This percentage is subtracted from 100; the result is the percent of material settled in 40 sec. or the approximate percent of sand.

$$\frac{\text{Corrected reading at 2 hrs.}}{\text{50 g. (soil sample wt.)}} \times 100 = \text{\% of clay (approximate)}$$

The percent of silt is obtained by subrtacting the sum of percent sand and clay from 100.

After the percentage of sand, silt, and clay is determined, the texture of the soil (class name) is obtained from the texture triangle.

Source: B. Sabey, (1967), pp. 17-22.

APPENDIX II

Total Salinity By Electrical Conductivity And Instrument Specifications

1. Mix soil:water to a specific ratio.
   - soil:water ratio was 1:10 as results for chloride salts are only slightly effected by moisture content.
   - vaccuum equipment was not available for lower ratio.
2. Mix soil:water ratio and filter by gravity.
3. Take conductivity reading on filtrate (mmhos/cm^2).
4. Correct for temperature (-3.5 percent).
5. Convert conductivity to total salts concentration (ppm) using nomogram and multiply according to soil:water ratio to get ppm soil.

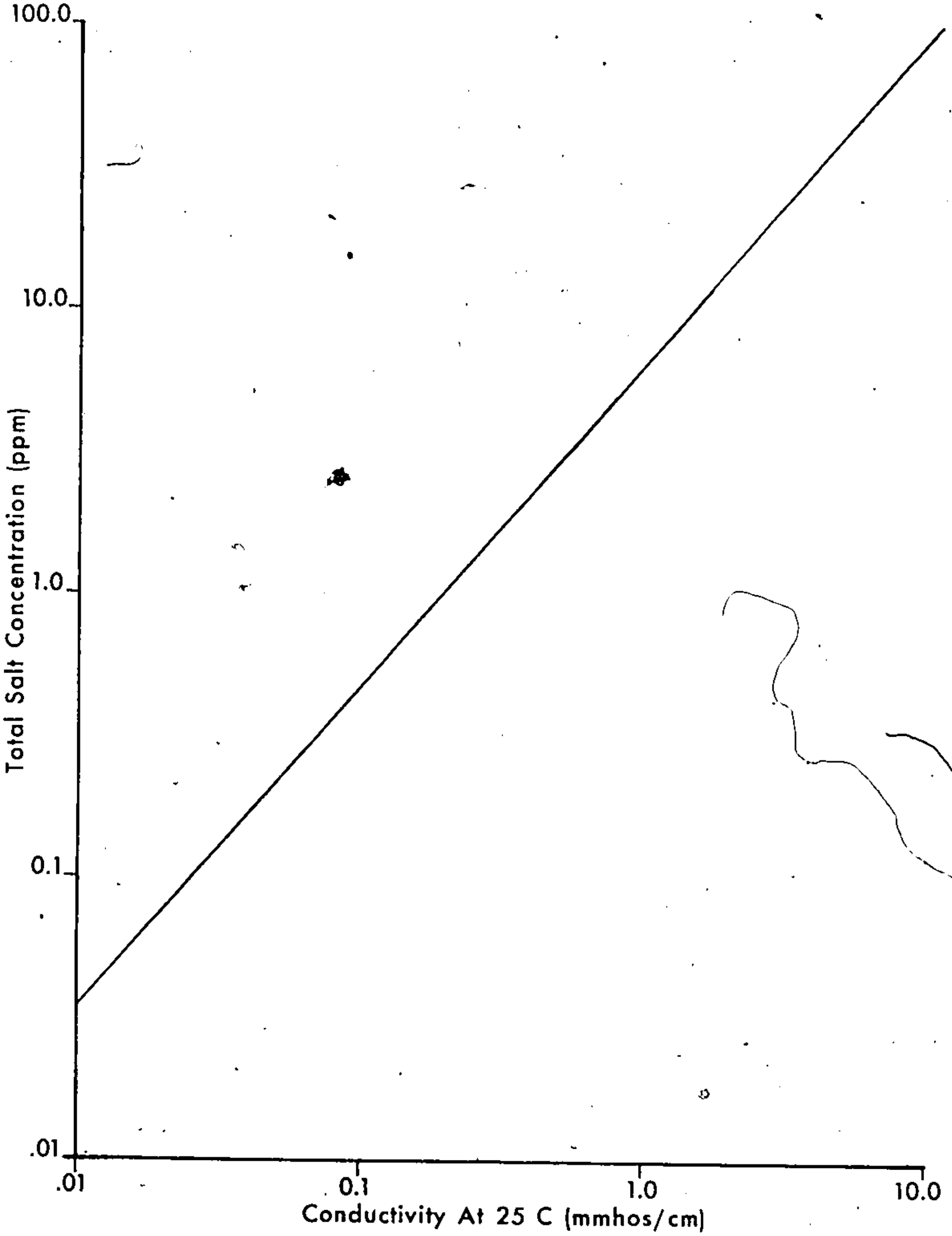
The principle of the conductivity meter is that of an ohmmeter. In fact the conductivity of the conductivity cell is read directly from the indicating meter, and the specific conductivity of the test liquid at the specified temperature is had by correcting the conductivity read with a small correction percentage which is engraved in the socket of the conductivity cell.

The type CDM^2 conductivity meter has direct reading and because of this it operates considerably faster than a bridge type instrument which uses headphones or a magic eye as zero indicator. In most cases the higher accuracy which in theory can be had with a precision bridge is unimportant in practice, because the precision bridge requires an exact temperature control (because the electrolytes have a temperature coefficient of approximately 2 percent per °C).

Specifications:

Measuring ranges:	0 - 1.5 - 5 - 15 - 50 - 150 - 500 S 0 - 1.5 - 5 - 15 - 50 - 150 - 500 mS
Cell constant:	about 1.
Measuring accuracy:	1 percent of full-scale deflection on the ranges from 0-50 S to 0-150 mS. On the other ranges it is 2 percent.
Test voltage:	about 0.25 volt.

Total Salinity Concentration By Electrical Conductivity Using Sodium Chloride As The Control



Measuring frequency:	3000 cps at conductivities above 150 S, and 70 cps at lower conductivities.
Recorder output:	0.2 mA f.s.d. Recorder resistance 5 .
Power supply:	110 - 127 - 150 - 200 - 240 volts, 50 - 60 cycles. Consumption about 15 watts.
Tubes:	2 type ECC81 or 12AT7.

Source: Operating Instructions for the CDM2e Conductivity Meter, p. 0-1.

APPENDIX III

Determination Of Cation-Exchange

1. Place a 5-gram soil sample into a 250-ml. Erlenmeyer flask.

2. Add 25ml. of 1.0N ammonium acetate. Mix and let stand for 30 minutes with an occasional swirling.

3. Filter the contents of the flask. Transfer as much of the soil as possible to the filter paper.

4. Add a second 25ml. ammonium acetate to the flask. Mix and let stand for 10 to 15 minutes before filtering.

5. Wash the sides of the flask with a small portion of 70 percent methyl alcohol. Transfer this solution and as much of the soil as possible to the filter paper. Continue until all the soil has been transferred to the filter paper.

6. Wash the soil on the filter paper with successive portions of 70 percent methyl alcohol until the filtrate is free of NH_3 (ammonium ions). Nessler's solution will turn from brown to a light yellow when the ammonium ions are absent.

7. Transfer the soil and filter paper to a 500 ml. Kjeldahl flask. Add a spoonful of magnesium oxide and 150 ml. of water.

8. Measure exactly 25 ml. of 0.1N HCl from a burette into a 250 ml. Erlenmeyer flask. Add 4 drops of methyl red indicator to the flask and place under the receiver of the distillation apparatus.

9. Connect the Kjelkahl flask to the still, light the flame and distill over approximately 125ml. of solution.

10. Titrate the excess acid in the Erlenmeyer flask using 0.1N NaOH.

11. Calculate the cation exchange capacity in me/100g of soil. The following formula is used:

$$\text{me/100g} = \frac{\text{me acid} - \text{me base}}{\text{weight of sample}} \times 100$$

where me acid = ml. acid x N acid
me base = ml. base x N base
100 = 100 grams of soil

Source: D.A. Russel, (1958), pp.2-6.

APPENDIX IV

Soil Column Procedure And Calculations

1. Mix soil thoroughly to get a homogeneous sample.

2. Take desired measurements on non-treated sample,
   i.e. - Total Salinity (ppm)
   - Sodium Concentration (ppm)
   - Cation-Exchange Capacity (me/100g)

3. Put soil into columns while adding distilled water and shaking the column to resemble approximate field conditions.

4. Pour into columns, solutions having known concentrations.

5. After solutions have passed through columns, take samples at specific depths by boring through the sides of each column where previously cut holes are provided (Figure 2).

6. Perform variety of laboratory procedures on samples as desired, making sure each sample is properly labelled.

Calculations:

1. Calculation of total salt for winter of 1975/76.

- According to the verbal communication with Ministry of Transport and Communication (Chatham) the Operation Policy of snow control is identical to that of the City of Windsor.

- Level-of-service for major traffic routes. (Class 1 streets)
  0" - 2" salting only
  2" - 4" ploughing and salting
  4" - 6" ploughing and removal

- For number of saltings (one pass by salting vehicle) per snowfall according to University of Windsor Weather Station Precipitation data
  0" - 2" snow = 1 salting
  2" - 4" snow = 2 saltings if over 3"
  4" - 6" snow = 3 saltings if over 5"

Number of saltings: November = 4, December = 14, January = 13, February = 8, March = 3, April = 2. Total number of saltings = 45.

- Policy states that a maximum of 451 lb./mi. is distributed per salting.

  Therefore, the total salt for Winter 1975/76
  = 451 x 45 = 20,295 lb./mi.

- Salt/foot for Winter 1975/76 = 3.84 lb. or 96.09 g/0.3m.

2. Calculation of solution concentration for 5.o foot distance from the road.

   - based on area under February-surface curve for sodium concentration (Figure).

   - area determined by square counting method.
   - determined that 5.0' distance (4.5' - 5.5') contained 4.48 percent of total sodium.
     Therefore, if 4.48% of total salt added stays at the 5.0' distance then;

   full concentration = 4.48% of 96.09 g (Total salt/ft.)
   = 4.30 g NaCl in the total precipitation for Winter of 1975/76.

   Total precipitation (rain and snow) = 18.18 inches
   or 46.18 cm.

   Volume of precipitation/soil column = (area of column surface)(depth of precipitation)
   = 2696.14 ml
   NB. 2700 ml used in solution mixtures.

   Therefore, concentration are,
   Column #1 = ½ concentration = 2.15g NaCl in 2700ml distilled water.

   Column #2 = full concentration = 4.30g NaCl in 2700ml distilled water.

   Column #3 = double concentration = 8.60g NaCl in 2700ml distilled water.

APPENDIX V

Results of Total Number of Runs Up And Down For Total Salinity Over Distance

Sample	November #r	November P	February #r	February P	May #r	May P
Granby Sand						
- surface	2	.2500	2	.2500	2	.2500
- depth	3	.7333	2	.2500	2	.2500
Berrian Sandy Loam						
- surface	2	.7333	3	.7333	3	.7333
- depth	3	.7333	3	.7333	1*	.0167*
Toledo Clay						
- surface	4	1.0000	3	.7333	2	.2500
- depth	4	1.0000	3	.7333	2	.2500

Level of Significance = .05
*Significant if P < .05
#r = number of runs
P = Probability

Results of Total Number of Runs Up And Down For Sodium Concentrations Over Distance

Sample	November #r	November P	February #r	February P	May #r	May P
Granby Sand						
- surface	4	.1000	1*	.0167*	3	.7333
- depth	3	.7333	1*	.0167*	2	.2500
Berrian Sandy Loam						
- surface	2	.2500	3	.7333	3	.7333
- depth	2	.2500	3	.7333	1*	.0167*
Toledo Clay						
- surface	2	.2500	3	.7333	2	.2500
- depth	3	.7333	3	.7333	3	.7333

Level of Significance = .05
*Significant if P < .05
#r = number of runs, P = Probability

Results of Total Number of Runs Up And Down For Cation-Exchange Capacity Values Over Distance

Sample	November		February		May	
	#r	P	#r	P	#r	P
Granby Sand						
- surface	3	.7333	3	.7333	2	.2500
- depth	3	.7333	1*	.0167*	4	.1000
Berrian Sandy Loam						
- surface	3	.7333	2	.2500	3	.7333
- depth	2	.2500	4	.1000	3	.7333
Toledo Clay						
- surface	4	.1000	4	.1000	1*	.0167*
- depth	2	.2500	3	.7333	3	.7333

Level of Significance = .05
*Significant if $P < .05$
#r = number of runs
P = Probability

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