



Sodium movement in undisturbed, sodic stripmine spoils with emphasis on unsaturated flow
by Mitchell Mitrey Johns

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Soils

Montana State University

© Copyright by Mitchell Mitrey Johns (1980)

Abstract:

In undisturbed, sodic stripmine spoil and topsoil columns, water, salt, and exchangeable sodium movement with unsaturated flow were measured and expressed as a function of irrigation and chemical treatments. Some saturated flow studies also were carried out. Lithium was applied as a tracer to estimate exchangeable sodium movement.

Water movement through spoil columns, while maintaining a surface moisture tension of 0.08 bars, indicated slow unsaturated water flow with movement being independent of leaching treatment. Water moved faster through topsoil (0.22 cm/day average) than through spoil (0.19 cm/day). Under saturated conditions, distilled water applied to spoil columns resulted in no flow ($K=0$ cm/day) through the entire length of the columns, while gypsum solution applied to spoil columns resulted in flow through 50% of those columns. Either leaching treatment resulted in saturated flow through topsoil columns.

With unsaturated flow, salt and exchangeable sodium movement in spoil columns were independent of leaching treatment. In 222 days, soluble and exchangeable sodium were significantly removed from the surface 10 cm in spoil with movement passing beyond the 20 cm depth. Lithium movement compared favorably with exchangeable sodium movement and it also was independent of treatment. Topsoil showed greater movement of sodium than spoil.

Significant to highly significant correlations were found, using linear regressions, between unsaturated flow and movement of soluble Na and exchangeable Na and extractable Li. For reclamation purposes, this should be useful in predicting the amount of sodium moved under conditions of a low, unsaturated water flux.

STATEMENT OF PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature Mitchell M. Johns
Date 6/13/80

SODIUM MOVEMENT IN UNDISTURBED, SODIC STRIPMINE SPOILS

WITH EMPHASIS ON UNSATURATED FLOW

by

MITCHELL MITREY JOHNS

A thesis submitted in partial fulfillment
of the requirements for the degree

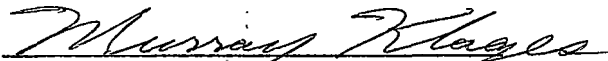
of

MASTER OF SCIENCE

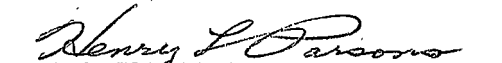
in

Soils

Approved:


Chairperson, Graduate Committee


Head, Major Department


Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

June, 1980

ACKNOWLEDGMENTS

The author would like to thank Drs. M. G. Klages, D. J. Dollhopf, and A. H. Ferguson for their guidance, valuable assistance, and patience throughout the entire project. Also, the author would like to thank Dr. E. P. Smith for his excellent statistical help during the research.

TABLE OF CONTENTS

	<u>Page</u>
VITA	ii
ACKNOWLEDGMENTS.	iii
LIST OF TABLES	vi
LIST OF FIGURES.	viii
ABSTRACT	x
INTRODUCTION	1
LITERATURE REVIEW.	2
Reclamation	2
Water Movement.	6
Tracer, Lithium for Sodium.	11
MATERIALS AND METHODS.	14
Field Site Description.	14
Sampling.	14
Experimental Design	17
Unsaturated and Saturated Leaching.	19
Analysis of Leachate.	22
Analysis of Columns	23
Statistical Models.	26
RESULTS AND DISCUSSION	29
Spoil and Topsoil Characterization.	29
Water Movement.	34
Unsaturated Flow Using Undisturbed Columns	34
Saturated Flow Using Undisturbed Columns	44
Salt Movement with Unsaturated Flow	46
Soluble Sodium Movement as a Function of Unsaturated Water Flux.	51
Exchangeable Sodium Movement with Unsaturated Flow.	54
Exchangeable Sodium Movement as a Function of Unsaturated Water Flux.	59

TABLE OF CONTENTS (cont'd.)

	<u>Page</u>
Exchangeable Lithium Movement.	62
Exchangeable Lithium Movement as a Function of Unsaturated Water Flux.	65
Saturated Flow Experiments.	68
Salt, Li, and Na Content of Leachate from Saturated Flow .	68
Exchangeable Li and Na Movement.	70
SUMMARY AND CONCLUSIONS.	73
LITERATURE CITED	78
APPENDIX	83

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1 Experimental design	18
2 Some physical properties of leached columns (all treatments together)	30
3 Some chemical properties of the spoil and topsoil columns used in leaching experiments.	31
4 Characterization information on spoil and topsoil columns .	33
5 Characterization data for various samples	35
6 Clay mineralogy from X-ray diffraction (approximate values in %)	35
7 Treatment and depth means for volumetric moisture % and its analysis of variance with multiple comparison	37
8 Depth (cm) to wetting front with unsaturated leaching . . .	39
9 Water applied (as ml and cm) to spoil columns receiving various leaching treatments	41
10 Treatment and depth means for indicated parameter for the surface 20 cm in spoil columns after unsaturated leaching .	48
11 Linear regression analyses for movement of soluble Na in spoil and topsoil as a function of water flux	52
12 Treatment and depth means for exchangeable Na and ESP for the surface 20 cm in spoil after unsaturated leaching . . .	55
13 Linear regression analyses between exchangeable Na movement and unsaturated water flux for spoil and topsoil . . .	60
14 Treatment and depth means for extractable Li (meq/100 g) in spoil columns after unsaturated leaching	64
15 Linear regression analyses between extractable lithium movement and unsaturated water flux for spoil and topsoil .	66

LIST OF TABLES (cont'd.)

<u>Appendix Table</u>	<u>Page</u>
16 Bulk density, particle density, and total porosity on spoil and topsoil columns.	84
17 Particle size analysis on spoil and topsoil columns.	87
18 Results of saturation paste and extract for unused, unleached spoil and topsoil columns.	89
19 Extractable Li^+ and Na^+ , exchangeable Na, CEC, and ESP for unused, unleached spoil and topsoil columns.	91
20 Gravimetric and volumetric moisture percentage (P_v) for columns after unsaturated leaching	93
21 Gravimetric and volumetric moisture for unused, unleached spoil and topsoil columns.	100
22 Analysis of the leachate periodically collected from the columns used in unsaturated leaching	102
23 Analysis of leachate from the four columns under saturated leaching successful in collecting leachate	105
24 Results of saturation paste and extract for columns after unsaturated leaching	106
25 Extractable Li^+ and Na^+ , exchangeable Na^+ , CEC, and ESP for columns after unsaturated leaching	110
26 Results of saturation paste and extract for columns after saturated leaching	116
27 Extractable Li^+ and Na^+ , exchangeable Na, CEC, and ESP for columns after saturated leaching	118

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1 View of the West Decker Mine showing sites E (upper left) and A (lower right) where samples were collected . .	15
2 The column-tensiometer make-up for unsaturated leaching in the laboratory.	20
3 Volumetric water content and unsaturated flux (for 222 days) by treatment means for spoil columns	36
4 Volumetric water content and unsaturated flux (for 222 days) for the topsoil columns.	43
5 Hydraulic conductivity of soil columns collecting leachate subjected to saturated flow.	45
6 Electrical conductivity (EC), soluble Na, SAR, and unsaturated water flux (for 222 days) by treatment means for spoil columns.	47
7 Electrical conductivity (EC), soluble Na, SAR, and unsaturated water flux (for 222 days) for topsoil columns.	50
8 Linear regressions of soluble Na displaced and unsaturated water flux	53
9 Exchangeable Na and unsaturated water flux (for 222 days) as a function of different leaching treatments	56
10 ESP for topsoil after unsaturated flow	58
11 Linear regressions of exchangeable Na displaced and unsaturated water flux	61
12 Lithium in spoil and topsoil after unsaturated flow. . . .	63
13 Linear regressions of extractable Li displaced and unsaturated water flux	67

LIST OF FIGURES (cont'd.)

<u>Figure</u>		<u>Page</u>
14	Leachate EC, Li, Na, and SAR periodically collected from soil columns subjected to saturated flow conditions. . . .	69
15	Lithium, distribution after saturated leaching	71

ABSTRACT

In undisturbed, sodic stripmine spoil and topsoil columns, water, salt, and exchangeable sodium movement with unsaturated flow were measured and expressed as a function of irrigation and chemical treatments. Some saturated flow studies also were carried out. Lithium was applied as a tracer to estimate exchangeable sodium movement.

Water movement through spoil columns, while maintaining a surface moisture tension of 0.08 bars, indicated slow unsaturated water flow with movement being independent of leaching treatment. Water moved faster through topsoil (0.22 cm/day average) than through spoil (0.19 cm/day). Under saturated conditions, distilled water applied to spoil columns resulted in no flow ($K = 0$ cm/day) through the entire length of the columns, while gypsum solution applied to spoil columns resulted in flow through 50% of those columns. Either leaching treatment resulted in saturated flow through topsoil columns.

With unsaturated flow, salt and exchangeable sodium movement in spoil columns were independent of leaching treatment. In 222 days, soluble and exchangeable sodium were significantly removed from the surface 10 cm in spoil with movement passing beyond the 20 cm depth. Lithium movement compared favorably with exchangeable sodium movement and it also was independent of treatment. Topsoil showed greater movement of sodium than spoil.

Significant to highly significant correlations were found, using linear regressions, between unsaturated flow and movement of soluble Na and exchangeable Na and extractable Li. For reclamation purposes, this should be useful in predicting the amount of sodium moved under conditions of a low, unsaturated water flux.

INTRODUCTION

The demands for Western coal will obviously increase in response to the increasing energy needs of the Nation. Almost all of this Western coal is surface-mined which results in substantial amounts of land being disturbed. In order to restore productivity to this mined land, and thus maintain a quality environment, the need for adequate reclamation is apparent.

Current surface-mining methods tend to invert the soil profile that naturally existed above the deepest mined layer. In the northern Great Plains, the spoil material coming from above the deepest mined layer is generally moderately saline and sodic (Sandoval et al. 1973). This situation is typified by the West Decker Coal Company located at Decker, Montana. Here the quality of the 60 cm of topsoil placed over the spoil material is fairly good but the spoil immediately below is often sodic and moderately saline.

This research focuses on soil water and salt movement in spoils and topsoil with saline-sodic conditions under laboratory conditions. The objective is the determination of sodium translocation patterns as a function of irrigation and chemical amendments with emphasis on unsaturated flow. A limited amount of saturated leaching was carried out also. Hopefully, the results presented here will contribute to the formulation of specific recommendations for saline-sodic spoil reclamation.

LITERATURE REVIEW

Reclamation

Sodium can render stripmine spoils extremely unstable, highly impermeable, and erodible to water (Sandoval et al. 1973). Therefore, perhaps the greatest concern with chemical reclamation is permeability. Maintaining a stable permeability while reclaiming a sodic soil generally depends upon three factors: (a) clay type, (b) adsorbed sodium, and (c) electrolyte concentration. Some generalizations can be made (Lutz and Kemper 1959). Smectite clay has the lowest permeability of all the clays especially with clays having adsorbed sodium. Clays with adsorbed sodium are less permeable to both water and electrolytes than clays having either calcium or hydrogen. The greater the electrolyte concentration, the greater the permeability. Increasing the electrolyte concentration apparently suppresses the electric double layer and either destroys the water structure, or reduces its thickness around the clay particles. Concerning soil permeability and aggregate stability, the worst condition would be to have a high proportion of smectite clays associated with a high level of exchangeable sodium (El-Swaify and Henderson 1967). Applying an irrigation water with low salt concentration would create destructive swelling pressure forces which would cause a breakdown of soil aggregates and consequent deterioration of soil structure. These high swelling pressures result in the high water retention capability of a Na-smectite soil.

Quirk and Schofield (1955) showed that the saturated permeability of a given soil decreases with increasing sodium percentage provided that the electrolyte concentration is below a critical level (threshold level). Gardner et al. (1959) measured the effect of electrolyte concentration and exchangeable sodium percentage (ESP) on diffusivity (0 to 15 bar range) in Pachapps sandy loam and Yolo loam soils. They concluded that when the ESP is above about 25, the diffusivity is reduced as much as a thousandfold as the electrolyte concentration is decreased from 300 to 3 milliequivalents per liter. Working with a sodic soil, Reeve and Tammaddoni (1965) found that leaching with an initial electrolyte concentration tended to temporarily "fix" the general level of permeability with the soil with respect to subsequent electrolyte concentrations. Their results indicate that the permeability with subsequent solutions depended upon the degree of flocculation or dispersion that occurred with the application of the initial solution.

Christenson and Ferguson (1966) found that swelling was a factor in water movement in a smectite soil, while it was not a factor in a dickite soil. Using a 0.015N calcium chloride solution eliminated swelling in the smectite soil of ESP 5.5, but only reduced swelling in the 13.6 ESP soil. In their calculations of water diffusivities, use of 0.015N calcium chloride instead of distilled water increased water diffusivity by a factor of 1.8 in all soils except for the 13.6 ESP smectite soil.

Frendel et al. (1978) showed that plugging of soil pores by dispersed clay particles is a major cause of reduced permeability in smectitic, vermiculitic, and kaolinitic soils affected by varying ESP and electrolyte concentrations. The exact levels of ESP and electrolyte concentration at which permeability is reduced varied with mineralogy, clay content, and bulk density.

To measure the effect of mixed Na-Ca solutions on the hydraulic properties of unsaturated soils, Russo and Bresler (1977) developed functional relationships over a wide range of water contents, soil solution concentrations, and Na:Ca ratios. Their results show that diffusivity (D) and hydraulic conductivity (K) are independent of electrolyte concentration in a Ca-saturated system. In mixed Na-Ca systems, K and D functions are highly dependent on the kind and concentration of the electrolyte solution in addition to their dependence on soil water content. Further, they stated that the negative effect of a combination of a high Na:Ca ratio and low electrolyte concentration on K are directly related to the degree of water saturation of the soil. Under unsaturated conditions, low soil water content values can compensate for the negative effect of high Na:Ca ratios and low electrolyte concentrations.

The basic principle of chemical reclamation of a sodic stripmine spoil is the same as for a sodic soil. It requires replacing adsorbed sodium with an acceptable divalent ion, preferably calcium. This

released sodium can then be leached downward deeper in the profile. The reaction between a calcium amendment and exchangeable sodium is an equilibrium reaction, and, therefore, does not entirely go to completion. The extent to which this reaction goes to completion is determined by the interaction of several factors, among which are the differences in the replacement energies of calcium and sodium, the exchangeable sodium percentage, and the total cation concentration of the soil solution (U. S. Salinity Laboratory 1954).

Sulfuric acid, calcium chloride, and gypsum were studied for use in sodic soil reclamation by Prather et al. (1978) on two soils high in ESP and cation exchange capacity. Their laboratory results with saturated leaching showed that sulfuric acid was more effective than gypsum and it resulted in a more desirable ESP profile than calcium chloride. However, the calcium chloride treatment removed the greatest amount of sodium per unit volume of leachate.

With field plots and ponding, Reeve and Doering (1966) studied reclaiming a highly sodic soil (ESP = 75) with a high-salt-water dilution method and conventional methods. The high-salt-water dilution method was effective in maintaining high permeability. However, this method is limited since it depends heavily upon having high-salt waters with divalent cation concentrations of 30% or more of the total salt concentration. A saturated gypsum solution (0.038N) and a concentrated calcium chloride solution (0.6N) were two of the conventional methods.

The saturated gypsum solution was not effective in reclaiming this highly sodic soil, even by leaching for a period of 228 days. Reclamation failure was attributed to the adverse physical condition of the highly sodic soil which developed because of the application of a low electrolyte water. The concentrated calcium chloride solution was effective. Comparative reclamation times to a soil depth of 90 cm were 3 days and 7 years for calcium chloride and gypsum, respectively.

From their laboratory experiments, Doering and Willis (1975) concluded that high electrolyte concentrations (greater than 0.5N Ca solutions) are desirable in order to establish and maintain an acceptable saturated hydraulic conductivity with a high ESP stripmine spoil. Therefore, the use of concentrated solutions for reclamation saves time and water. But as the ESP is lowered, use of concentrated solutions becomes increasingly less efficient and uneconomical.

Water Movement

It is generally believed that a significant amount of water movement can occur in soil macropores. Consequently, it has been reported that when much of the water from rainfall or irrigation flows in macropores, the usual occurrence is that of only a partial displacement of soil water (Elrick and French 1966, Ritchie et al. 1972, McMahon and Thomas 1974, Quisenberry and Phillips 1976). In their excellent review, Thomas and Phillips (1979) state that one of the consequences of water

flow in macropores is that some of the surface salts will be moved to a much greater depth by a rain or irrigation than predicted by piston displacement. On the other hand, much of the salt will be by-passed and remain near the soil surface. Further, they note that if rain or irrigation water added to the soil moves primarily through macropores, it will interact with solutes to only a limited extent since much of the smaller pores will be by-passed.

Leaching soils during unsaturated conditions brings about the following changes: (1) decreased the relative volume of water passing through larger pore sequences (they are partially empty), (2) increases the mixing between soil pores caused by molecular diffusion associated with the generally smaller flow velocity values, and (3) alters the tortuosity and extent of nearly stagnant pores (Nielsen et al. 1972).

The effectiveness of leaching is usually judged on the basis of redistribution of salt within the profile resulting from a known quantity of surface-applied water. According to Biggar and Nielsen (1967), this efficiency of leaching may be significantly increased by controlling the degree of water saturation and the rate of water movement through the soil profile. In their review, it was shown that for soil water contents less than saturation but greater than one-fifth bar, both laboratory and field data show leaching efficiencies to be greater than for saturated conditions.

Nielsen et al. (1966) attributed better leaching efficiencies under unsaturated flow conditions to greater mixing of the applied treatment solution with the soil solution. This additional mixing is caused principally by ionic diffusion. The contribution of diffusion to mixing depends in part upon the pore-velocity distribution which in turn depends upon the water filled soil-pore structure. In his introduction, Kirda et al. (1974) noted that the apparent diffusion coefficient depends not only on the average pore water velocity but also on the microscopic characteristics of the medium such as pore size, pore sequence channel length, random arrangement of channels within the porous medium, and the molecular diffusion coefficient. It was suggested that for slowly permeable soils, especially those that are sodic, one means of increasing the penetration of water is to allow the soil surface to dry and crack between periods of wetting.

Kirda et al. (1974) indicated that a given quantity of water applied by continuous ponding yields relatively large water contents confined initially to the upper portion of the soil profile and thereby displaces salts relatively short distances. By contrast, frequent small quantities of intermittently applied water produced deeper penetration of salt and water on an equal time basis to ponding. Water application methods giving rise to small water contents coupled with small pore water velocities provide the most efficient mode of leaching. Warrick et al. (1971) concluded that the advance of the wetting front

is slower and that solute displacement was greater at lower initial soil moisture contents. The cumulative infiltration is greater at lower soil moisture contents and this increases solute displacement.

Although the ultimate goal of water movement studies is to be able to determine water behavior in the soil-plant-atmosphere continuum in the field, the majority of these experiments have been restricted to laboratory models and conditions. In applying the Darcy flow equation or its derivations to unsaturated soil water movement, the use of a homogeneous, porous medium is quite frequent (Bruce and Klute 1956, Gardner and Miklich 1962, Flocker et al. 1968, Watson 1966). This need for homogeneity arises from the fact that quantitative measurements require that the pore size distribution be everywhere geometrically similar. In the natural state, most soils have unequal porosities and are not geometrically similar.

Arnold (1976) measured solute and unsaturated water movement on stripmine spoils in the field. He applied a mathematical model developed by Sisson (1972) for measuring unsaturated water flow. He found that the quantity of soil water movement in native range was approximately 1.5 times greater than in spoils. The lower amount of soil water movement was attributed to bulk density, which was 54% higher than native range, and to higher contents of silt and clay. Due to the short time span of Arnold's study (1 year) no definite trends in solute movement were found.

When a solution moves in the liquid phase in soils under unsaturated conditions, the effect of salt sieving may be of some importance since this solution must flow through thin films which connect the wedge-shaped volumes of solution (Kemper 1960). However, as pointed out by Nielsen et al. (1972), when soil-water pressure differences are small (less than 0.1 bar), the resultant convective flow may be of the same order of magnitude as diffusive flow, and under such conditions salt sieving in soils will be practically negligible. Any appreciable salt sieving may require soil-water pressure differences as large as 10 bars, which probably occurs infrequently in natural systems.

The rate of water movement through undisturbed cores can be strikingly different than the rate it moves in the field. In a swelling clay soil, Ritchie et al. (1972) compared hydraulic conductivities between field basins and undisturbed cores. Their results showed that the saturated conductivity of the undisturbed cores were much less than that of the field. These rate differences were due to the core walls which cut off some large continuous pores associated with the soil structure that exists in the field.

In sodic reclamation, the process of ion exchange is just as important as the leaching process. Rible and Davis (1955) adapted chromatographic theory of DeVault to ion exchange processes in soil columns. It involved the use of a salt-free, homogeneous, homoionic Yolo fine sandy loam soil. Of considerable interest is the exchange of

sodium with calcium. Upon leaching a sodium saturated column with a known amount of calcium in solution, theory predicted a sharp boundary where the upper zone should be saturated with calcium while the lower zone remains sodium saturated. It is evident that 100% exchange was assumed. Fair agreement with theory was obtained through experimentation. However, although they found calcium in dilute salt solutions readily replaced most of the sodium in the surface layer, calcium did not adequately penetrate the subsoil.

Tracer, Lithium for Sodium

The tracing of sodium movement with lithium can only be justified through the evidence which shows that both cations react similarly, chemically and physically, in soils. In this regard, the tracer should not change the properties of the leaching fluid or the transmission characteristics of the medium in a manner different from that which it is tracing (Biggar and Nielsen 1962).

The similarity of lithium and sodium with respect to replacement and displacement was noted by Bear (1964). The replaceability (replacing power) from an exchange material grows in the order $Li < Na < K < Mg < Ca$ when these ions function separately as complementary ions. The order of difficulty of displacement is approximately $Ca > Mg > Na > Li$ but the relative position in such a series varies with the concentration in the solution and the nature of the exchange active material.

Shainberg and Kemper (1966a) stated the order of difficulty of displacement as $K > Na > Li$ for these monovalent ions. They consequently showed that the observed relative mobilities (in Stern layer position and relative to their mobilities in bulk solution) of these monovalent ions is the highest for adsorbed lithium, intermediate for adsorbed sodium, and lowest for adsorbed potassium. As would be expected from their relative mobilities in the Stern layer, Shainberg and Kemper (1966b) showed that the fraction of ions in the diffuse layer (completely hydrated) for Li, Na, and K are 0.84, 0.64, and 0.51, respectively.

Husted and Low (1954) studied ion diffusion in bentonite. They indicated that the diffusion rate of potassium depended on the rate of the counterdiffusing ion, and that the diffusion rate of the counterdiffusing ions was in the order $NH_4 > Na > Li$. This is the order of their mobilities in solution. In another experiment, the amount of ions transferred from a cation-bentonite film to a H-bentonite film were in the order $Li > Na > K$. But the amount of these ions reaching the terminal end of the hydrogen film were in the reverse order. The obvious conclusion is that within the H-bentonite films the diffusion rate of the ions, and hence the diffusion coefficients, was in the order $K > Na > Li$. This is the order observed for diffusion in bentonite and for diffusion (but of a greater magnitude than clays) in solution.

In terms of swelling, lithium and sodium show similarities. Baver et al. (1972) cited that the swelling of Putman clay (beidellite)

varies with nature of the adsorbed cations as follows: $\text{Li} > \text{Na} > \text{Ca}$. On the other hand, the order of swelling for bentonite (smectite) is $\text{Na} > \text{Li} > \text{K} > \text{Ca}$. In terms of swelling (cm^3 per gram of colloid), Li and Na are 10.77 and 11.08, respectively, for bentonite. In Putman clay, Li and Na are 4.97 and 4.02, respectively.

As pointed out by Norrish (1954), in the initial stages of interlayer swelling for Li- and Na-smectite, their stepwise hydration forms interlayer spacings of 22.5 and 19.0 Angstroms for Li and Na, respectively. Upon osmotic swelling, the interlayer spacings for both Li- and Na-smectite may reach 130 Angstroms (Baver et al. 1972).

A brief summary seems appropriate. In comparison to sodium, lithium has a larger diffuse layer and somewhat less replacing power, but due to a greater hydration, it has, consequently, a lower molecular diffusion rate. Generally speaking, the degree of swelling is quite similar between the two cations.

MATERIALS AND METHODS

Field Site Description

The sampling area is located at the Decker Coal Mine near Decker, Montana (Figure 1). Decker, Montana is located 12 miles (19 km) north of Sheridan, Wyoming at an elevation of 3,530 feet (1076 m). The Decker Coal Mine is adjacent to the Tongue River Reservoir. Montana State Highway 314 separates the West Decker Mine from the East Decker Mine. The Decker area is characterized by rolling dissected hills and broad, nearly flat valley floors. Sparse vegetation cover and impeded soil drainage create severe erosion problems (Sindelar et al. 1973). Saline-sodic soils limit forage productivity and restrict vegetation to tolerant adapted species. Big sagebrush and western wheatgrass dominate the rangeland vegetation. The overburden derives from the Paleocene, Fort Union, Tongue River formation and it is composed of sandstone, stratified sands, siltstone, and clay and silt shales. Also, the overburden generally contains saline and/or sodic materials.

At the West Decker Mine, undisturbed topsoil and spoil cores were collected for laboratory study from sites that had been recontoured. In September 1977, topsoil and spoil cores were collected in sites E and A, respectively (Figure 1).

Sampling

Present reclamation practice involves placing approximately 60 cm of topsoil, which had been stockpiled from the initial stripmining

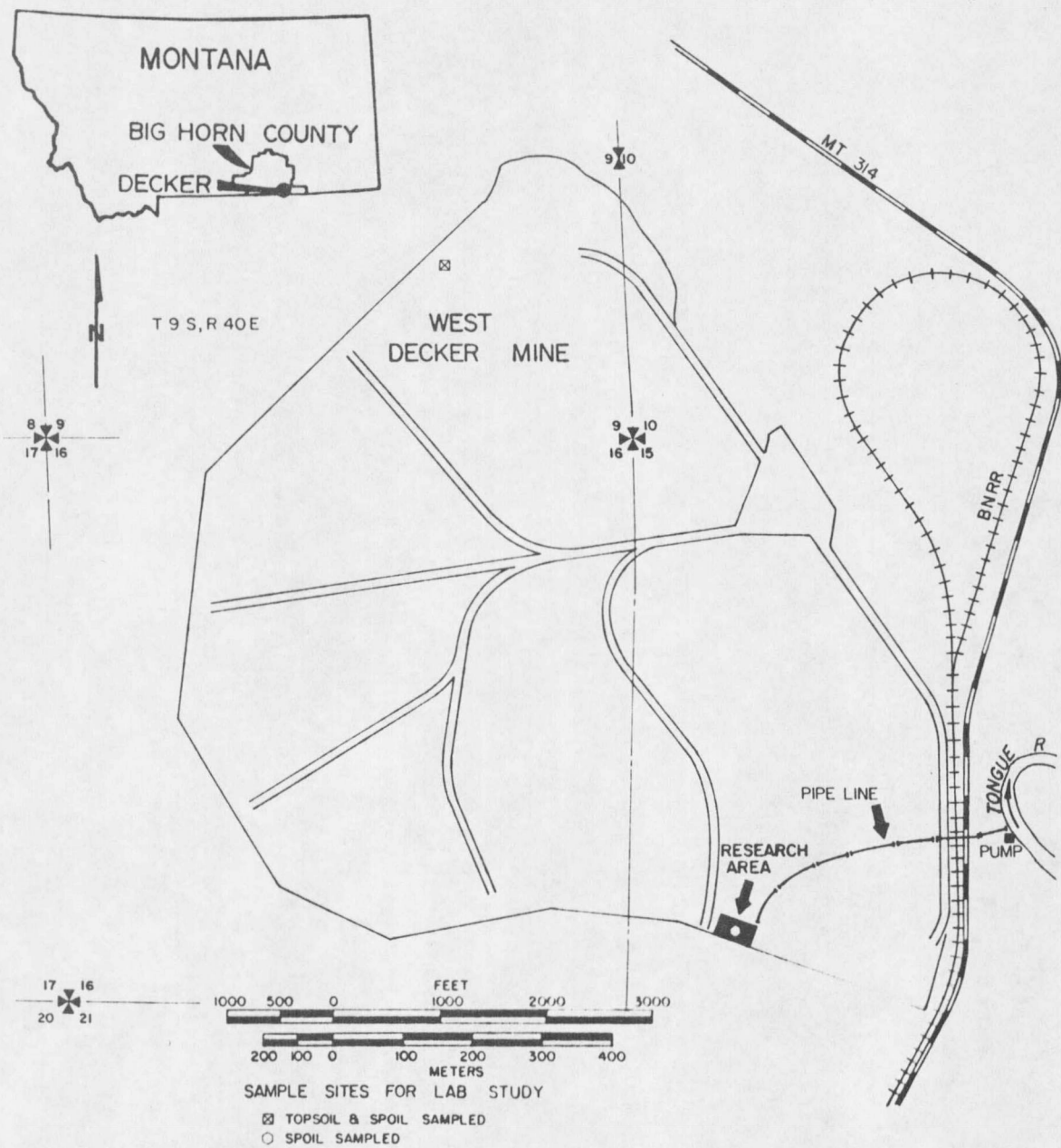


Figure 1. View of the West Decker Mine showing sites E (upper left) and A (lower right) where samples were collected.

process, atop spoil material. It was the intention of the author to gather topsoil and spoil cores from one site. However, the sampler used for collecting undisturbed cores was unable to penetrate into the spoil material at site E (Figure 1). At site A, which had not yet been topsoiled, spoil columns were collected successfully after some unsuccessful attempts.

Topsoil and spoil core columns were gathered by use of a specially designed King tube attached to the Giddings hydraulic soil sampler. The cutting edge of this King tube was bevelled to displace soil to the outside of the tube to reduce compaction when pushed into the soil. Heat shrink tubing 55 cm long (purchased from the Radar Electric Company, Seattle, Washington) was inserted into this King tube. Upon use, the soil sample slipped into this plastic tubing within the King tube. The tubing plus soil core was removed from the King tube and the tubing was shrunk by applying heat to the outside surface of the column. The soil column then fit snugly within the tubing and was held intact. The end result was a relatively undisturbed topsoil or spoil column having a diameter of 4 cm. These columns were collected in 55 cm lengths down to a depth ranging from 110 to 165 cm. All columns were sealed to prevent moisture loss.

Past experience indicated that stripmine spoils had extreme soil chemical variability within very small distances. With this in mind, samples were collected in 1 m^2 stations located within site areas.

Cores were taken as close as possible to each other within these stations. It was hoped that these small distances would reduce as much as possible any variation between columns. Topsoil columns were collected from one station (station E) in site E (Figure 1). Spoil columns were collected from two stations (stations A₁ and A₂) in site A.

Experimental Design

The main emphasis of this study dealt with unsaturated leaching. However, a limited experiment with saturated leaching was included. The design is shown in Table 1. Since spoil cores were collected from two different stations and from two different depths within each station, a randomized complete-block design was used (Steel and Torrie 1960). The leaching treatments studied were distilled water, a saturated gypsum solution (0.03N), a calcium chloride solution (0.06N), and a combination solution containing gypsum (0.026N), ammonium sulfate (0.0015N), and calcium chloride (0.003N). In the unsaturated leaching experiments, all four treatments were tested using four replications per treatment for spoils and no replication for topsoil. Topsoil and spoil columns subjected to saturated flow were leached with only gypsum solution and distilled water using four replications per treatment for spoil and no replication for topsoil.

