

Casey and Julie Voigt v. Coyote Creek Mining Company, LLC

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Changes of Sodicity and Salinity in
Soils Reconstructed on Strip-mined Land

Voigt Exhibit 43

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Changes of Sodidity and Salinity in Soils Reconstructed on Strip-mined Land

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Soluble salt and sodium levels in soils spread over strip-mine spoils can and do change, and planning for reclamation should take this into account. At the site of several reclamation experiments in western North Dakota, upward migration of sodium increased the exchangeable sodium of topsoil spread over minespoil. Evidence is presented which indicates that chemical diffusion played an important role in this process.

INTRODUCTION

In the semiarid or arid climates of the West, soluble salt content (salinity) and exchangeable sodium (sodidity) are important quality factors that decision makers must take into account when assessing the suitability of materials for mined-land reclamation. Salinity affects plant growth directly by making soil water less available to plants, whereas sodidity primarily affects plant growth through its effect on physical properties of soils and minespoils.

Salinity and sodidity are changeable qualities. This article will analyze some examples of salinity and sodidity changes that have been observed in reclamation experiments carried out by researchers at the USDA Northern Great Plains Research Center. Special attention will be given to a dynamic aspect of sodidity—the migration of sodium from mine spoil into overspread topsoil at certain sites.

The sodidity of a soil is evaluated in terms of the exchangeable-sodium-percentage (ESP), i.e., the percentage of cation-exchange capacity (CEC) occupied by sodium. The sodium and divalent cations (calcium plus magnesium) in the soil solution are in equilibrium with adsorbed cations, and because less costly measurements can be made of soluble, saturation-extract cations than of exchangeable ones, it is convenient to infer sodidity from the sodium-adsorption-ratio^{1/} (SAR). For most soils and spoils, the ESP value (as a percentage) is approximately the same as the corresponding SAR value. Salinity is commonly expressed as the electrical conductivity of the saturation extract (EC), which involves a water content (saturation percentage, SP) that is roughly double the water content of agricultural soils at the approximate field capacity condition.

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^{1/}SAR = Na / ((Ca + Mg) / 2) where concentrations are expressed in meq/liter.

CHANGES IN SALINITY

In natural soils, salinity patterns follow seasonal or other cycles of change that are in overall equilibrium with climate and water use by plants. In the reconstruction of soil profiles on disturbed land, saline material may be placed in a profile position where it is not in equilibrium with the precipitation pattern; but equilibrium will eventually be established. Data in Table 1 illustrate such a situation, showing changes in soluble cation concentrations that developed after moderately saline subsoil was either placed alone over minespoil or covered with several depths of topsoil. The subsoil was stripped from about the 2- to 8-ft. depths of an unmined soil and randomly placed over the spoil. In no-topsoil plots, the concentration of soluble cations in the upper 12 inches had substantially decreased while concentrations in the 12- to 36-inch depth had increased, indicating that leaching had occurred. Other aspects of the study from which these data are taken have been reported by Power *et al.* (1980). The site, located in Mercer County, was cropped to alfalfa and received an average of 15 inches of precipitation annually. Analyses

Table 1. Saturation extract sodium and calcium-plus-magnesium concentrations in subsoil and in topsoil over subsoil sequences placed over sodic minespoil. Subsoil was 6 ft. thick at the site of samples shown. Samples were taken 2 and 3 years after placement of soils over spoil.

Depth	No topsoil		8 in. topsoil		24 in. topsoil	
	Na	Ca+Mg	Na	Ca+Mg	Na	Ca+Mg
inches	meq/liter					
0-6	7**	7**	1*	6*	1*	7*
6-12	16	11	4	7	2*	6*
12-24	38	40	21	35	28*	27*
24-36	32	41	37	52	28	21
36-48	26	17	36	30	25	21

*Average, initial topsoil values: Na = 1, Ca+Mg = 6.

**Average, initial subsoil values: Na = 27, Ca+Mg = 25.

of soil samples collected 1, 2, and 3 years after profile reconstruction showed that the adjustment had occurred during the first year. Leaching of soluble salts from the 6- to 12-inch layer was also evident when 8 inches of nonsaline topsoil was placed over spoil.

Where 24 inches of nonsaline topsoil was placed over the subsoil, the concentration of salt increased in the 12- to 24-inch zone (Table 1). This increase resulted primarily because salts moved upward from depths lower than 24 inches into the nonsaline surface soil.

CHANGES IN SODICITY

Sandoval and Gould (1978) and others (ARS and NDSU staffs, 1977; SEA and NDSU staffs, 1979) observed increases in soluble sodium and SAR in topsoil spread over sodic minespoil. In field plots where 12 inches of good quality soil was spread over minespoils having SAR values over 20, it appeared that upward migration of sodium had deteriorated the quality of the cover soil and contributed to a decline of forage crop yields.

Laboratory Experiments

To determine which physical and chemical mechanisms were responsible for movement of sodium salts from sodic minespoil into overlying soil, a laboratory experiment was conducted. One objective was to determine the effect of slow, upward-movement of water through soil-spoil interface on the upward movement of sodium. In the field, such water flows would be generated by seasonal extraction of water by vegetation from overspread soil. In the laboratory, several types of soil were placed over minespoil (SAR = 19) packed into 5-inch diameter plastic columns. Salt and water movement was observed during 90- to 108-day periods. Some columns were sealed and very little water moved from one part of the column to the other. Other columns were open at one end, causing the evaporation of up to 1.5 inches of water and causing the upward flow of up to 0.5 inch of water through the soil-spoil

interface. The soluble sodium concentration in the spoil was initially over 40 times higher than that in the overlying soil.

After 100 days in the sealed columns, soluble sodium concentration in the 1.6 inches of soil in immediate contact with the spoil increased 20- to 30-fold. In this experiment, however, movement of water through the soil-spoil interface was ineffective in moving sodium because more of this salt migrated upward in sealed columns, without upward water movement, than in open-end columns with evaporation and upward water flows. This apparent anomaly occurred because soil evaporation lowered the soil water content, reducing the liquid cross-section through which chemical diffusion occurs.

A mathematical model of salt and water flow was applied to the column experiments. This model included water flow, salt flow by convection (salt carried by water), salt flow by diffusion (movement of each kind of salt in proportion to differences in concentration), and cation exchange. Calculations using this model showed that upward movement of sodium in the column experiments was mostly due to chemical diffusion.

Application to the Field

Four field sites in Oliver and Mercer counties (ARS and NDSU staffs, 1977) have been examined for sodium migration. At each of these sites, 12 inches of good quality topsoil (predominantly A horizon) was placed over minespoils of various SAR values. Table 2 shows the average, initial properties of the soil and spoil materials used at the different sites. Crested wheatgrass was grown on all sites except S2, which had both crested wheatgrass and cool-season, native grasses. Table 3 shows the changes that occurred in the salt status in each of the 4 sites over a period of 4 years. Accumulation of soluble sodium in the lower 6 inches of the soil zone was considerable at sites S2 and Z, with corresponding increases in this zone's sodicity, as indicated by SAR. Most of these increases occurred during the first or second year. Increases in sodicity of the lower half of the applied soil at sites S1 and B were less than at

Table 2. Initial, average properties of soils and mine spoils at 4 sites.

Site		SAR	EC	Na*	Ca+Mg*	%Clay	Saturation %
S1	Soil	1	0.5	1	4	19	45
	Spoil	12	2.5	22	7	25	83
B	Soil	1	0.6	1	4	20	34
	Spoil	11	5.0	35	21	45	92
S2	Soil	2	0.9	3	6	20	51
	Spoil	25	3.3	30	3	30	134
Z	Soil	3	2.4	9	22	27	42
	Spoil	27	3.9	39	4	46	131

*Concentrations in saturation extracts.

Table 3. Initial and subsequent saturation extract sodium and sodium-adsorption-ratio (SAR) values found in fall (September to November) soil samples from four field sites where 12 inches of soil had been spread over minespoil.

Site	Depth inches	Sodium					SAR				
		Years					Years				
		0	1	2	3	4	0	1	2	3	4
		meq/liter									
S1	0-6	1	2	2	2	1	1	1	1	1	1
	6-12	1	6	7	9	10	1	3	3	4	5
	12-24	22	28	27	25	26	12	9	9	9	10
	24-36	22	20	20	21	21	12	14	13	12	13
B	0-6	1	1	2	1	1	1	1	1	1	1
	6-12	1	8	19	9	12	1	3	6	4	4
	12-24	35	38	39	34	44	11	11	10	10	10
	24-36	35	36	37	37	39	11	11	10	11	11
S2	0-6	3	6	4	3	3	2	4	3	2	3
	6-12	3	18	17	23	16	2	9	10	17	18
	12-24	30	27	29	26	33	25	24	23	21	26
	24-36	30	35	29	33	33	25	29	26	26	25
Z	0-6	9	11	17	12	12	3	3	5	4	4
	6-12	9	25	42	40	41	3	7	15	14	12
	12-24	39	41	40	39	31	27	28	29	27	27
	24-36	39	35	33	37	39	27	32	30	27	28

sites S2 and Z and were probably not significant in terms of degradation of the quality of the topsoil zone. At sites S2 and Z, however, SAR values in the 6- to 12-inch zone increased to 10 or more, and physical properties of the soil were probably adversely affected. There were indications that forage yields declined at some of the sites (Sandoval and Gould, 1978; ARS and NDSU staffs, 1977).

Calculations representing just the diffusion and ion-exchange parts of our mathematical model were applied to the field data. The application of the model to the field sites was approximate because average water content and soil temperature values were used. The data from site S2 were used for a comparison between calculated and measured sodium concentrations. The results, expressed as relative values based on the initial concentration in the spoil chosen as 100, are shown in Table 4. These data indicate that the diffusion calculation accounted for about half of the sodium migration occurring at site S2. When the same calculation was applied to the other 3 sites, results for site Z were similar to those found for site S2 (Merrill *et al.*, 1980). The results for sites B and S1 showed that the relative amount of sodium accumulation in the soil at these sites was less than at sites S2 and Z.

Table 4. Relative soluble sodium concentration measured at site S2 compared to calculated values.

	Depth, inches	Years			
		0	1	2	3
MEASURED:	0-6	0	4	1	4
	6-12	0	18	17	27
	12-24	100	90	94	84
CALCULATED:	0-6	0	0	0	1
	6-12	0	8	12	14
	12-24	100	91	87	84

The hydraulic conductivity of spoil materials at sites S1 and B should have been greater than at sites S2 and Z. For example, at sites S1 and B, the SAR of the spoil was lower (83 and 92% as compared to 134 and 131%), which indicates less swelling and dispersion. Spoil from near site S2 had a very low measured, unsaturated hydraulic conductivity of 6 inches per year or less. Based on these

considerations, it is likely that there was some periodic, downward leaching of sodium at sites S1 and B. Under the prevailing climatic conditions, mobile sodium salts can be moved to a depth of 12 inches or more from a soil surface position in non-sodic soil materials. Apparently the hydraulic conductivities need only be larger than some rather low value to overcome the very slow process of chemical diffusion in this system.

Clay mineralogy also affects the hydraulic flow properties of minespoils. In a Montana experiment, Dollhopf *et al.* (1980) observed very little accumulation of sodium or increase of SAR value in 28 inches of sandy loam spread over a sodic minespoil (average SAR = 23) which had kaolinite as the most abundant constituent of the clay fraction. The saturation percentage of the minespoil was about 75%. Materials dominated by kaolinite (a nonswelling clay) are much less sensitive to the effects of sodium accumulation than are materials dominated by montmorillonite (swelling clay). The clay fractions of minespoils at sites S1, B, S2 and Z were dominated by montmorillonite (Bauer *et al.*, 1976).

The Role of Diffusion

Application of the calculations to field data indicates that chemical diffusion at least played a major role in sodium migration at all the North Dakota sites discussed here, and was probably the predominant mechanism of salt transport between spoil and soil. None of the sites received significant runoff water from higher slope positions, so the mechanism of capillary rise, responsible for sodium accumulation and physical deterioration in many dryland and irrigation situations, was not involved. Accumulations of sodium by diffusion will dominate where the hydraulic conductivity of the spoil is very low and where the soil-spoil interface is far enough below the soil surface so that seasonal leaching does not predominate.

What is the potential extent of this type of sodium accumulation? Fig. 1 shows a calculation of soluble sodium concentrations in the soil and spoil solution after 1 to 8 years of elapsed time. The calculation indicates that approximately 6 to 8 inches out of a total of 12 inches of soil above the spoil zone will accumulate significant amounts of sodium. The same method of calculation as used for the Table 4 comparison was used for Fig. 1. If soluble calcium-plus-magnesium is not transported to the affected soil zone, or increased by ion exchange, the calculated increases of soluble sodium indicate proportional increases in sodicity (as SAR). This applies to sites S2 and Z.

With greater depths of cover soil, Fig. 1 and other calculations indicate that the zone of sodium accumulation will eventually become thicker than when only 12 inches of cover soil is present. The calculated soluble sodium content increased significantly at the surface of the 12-inch thick soil zone only after 4 years. Thus, the results shown in Fig. 1 would apply reasonably well during the first 4 years for thicker layers of respread soil.

The process of diffusion is very slow and self-limiting by its very nature. Its rate is proportional to the square root of elapsed time and this rate declines as the concentration gradient which drives diffusion becomes exhausted. Because of the limited reach of sodium accumulation by chemical diffusion, this phenomenon is likely to have the greatest potential for degrading overspread soil where

unstable, dispersed minespoils possessing SAR (or ESP) values of 20 or more are found and where only 12 inches or less of high quality soil material is available for use in reclamation. If soil material of sufficiently great salinity is spread over sodic spoil, there will be no concentration gradient in sodium, and thus, sodium accumulation of the type discussed here will not occur.

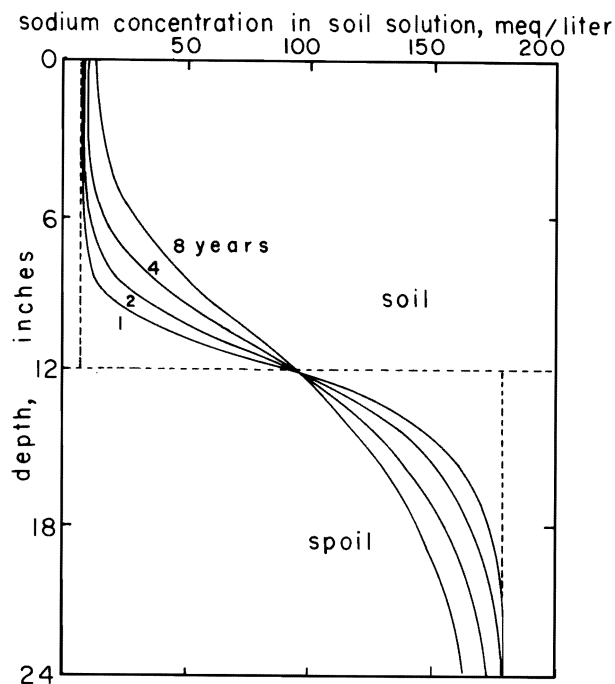


Figure 1. Calculated changes in soil solution sodium concentrations occurring in 12 inches of cover soil spread over minespoil as the result of the processes of chemical diffusion and ion exchange.

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