SOIL SALINITY AND WATER MOVEMENT DURING IRRIGATION OF A TOPSOIL-COAL SPOIL PROFILE

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Abstract.--This study of the irrigation phase of reclamation was conducted to evaluate the potential for salt accumulation in topsoil placed over a saline-sodic coal spoil under controlled conditions. Topsoil depth and irrigation rate were evaluated for their influence on the concentration and location of salts in the profile.

Four irrigation rates and four topsoil depths over coal spoil were tested in soil lysimeters in a greenhouse. Water was added weekly for 6 summer months (4 in one year, 2 in next). After the final irrigation the cylinders were cut open lengthwise and the profile sampled every 10 cm. The current depth of the wetting front and/or any alteration due to wetting was recorded. Samples from before and after the study were analyzed for EC, soluble and extractable Na, Ca, Mg and the sodium absorption ratio (SAR) computed.

Small increases in SAR and EC were found in the topsoil for most combinations of topsoil depth and watering rate. The most consistent increases were associated with the shallowest depth of topsoil (10 cm). Sodium and other electrolytes accumulated in one case in the 10 cm layer just above the spoil and again at the surface. Both diffusion of salts from the spoil and convection of salts to the surface are possible explanations.

The small increases in salts in the topsoil were well within the salt tolerance of native plants. Although salt migration into reclaimed topsoil from saline-sodic spoil is a possibility, its effect on plant growth is likely minimal.

INTRODUCTION

Topsoiling and irrigation are both included in current reclamation practices on coal mines in the arid portion of New Mexico's San Juan Basin. Irrigation is needed for rapid plant establishment in most areas that receive less than about 25 cm of precipitation (Gould 1978).

Topsoiling is important in enhancing water infiltration and native plant establishment (Gould 1978). Some benefits of topsoil for the San Juan spoils (Fresquez and Lindemann 1983) include the following: 1) good rooting medium, 2) improved infiltration, 3) reduced runoff, 4) source of nutrients, 5) source of native seed, 6) source of microbes activity to improve soil building processes.

Plant yield increases due to topsoiling are greatest where underlying spoils have been sodic and hard to revegetate (Doll et al. 1984). After a few years, however, sodicity can increase in the topsoil over sodic spoil under certain North Dakota conditions (Agricultural Research, USDA-SEA and North Dakota Agricultural Experiment Station staff 1979; Sandoval and Gould 1978). These results showed a progressive deterioration of applied topsoil due to increased concentrations of sodium, presumably by upward migration from sodic mine spoil. With 12 inches of good quality topsoil, sodicity had increased substantially over 4 years with a progressive reduction in productivity.

In contrast, another study from Montana with topsoil over sodic spoil showed no deterioration (Dollhopf et al. 1980; Dollhopf 1983; Dollhopf et al. 1985). For both irrigated and nonirrigated conditions, SAR (sodium absorption ratio) levels remained low in the topsoil, "indicating no upward movement of sodium by either diffusion or convective water flow." Salts were also being leached from the spoil material even without irrigation.

The question of whether salts will migrate upward into a replaced topsoil and cause permanent deterioration is clearly not a simple one. Factors including climate, soil chemistry, physics, and hydrology are all involved.

Proceedings America Society of Mining and Reclamation, 1987 pp 115-124
DOI: 10.21000/JASMR87010115

https://doi.org/10.21000/JASMR87010115

Merrill et al. (1983) have studied two possible mechanisms for upward migration of sodium from underlying sodic spoil: diffusion and convection. Both column and model calculations indicated that considerably more Na migrated upward by salt diffusion than by convective flow resulting from surface evaporation. Application of these results to field conditions in North Dakota indicated that salt diffusion is a significant mechanism for Na accumulation in soil where underlying spoils are dispersed (low hydraulic conductivity) and where a sufficiently steep chemical gradient is present. Their results further indicated that signficant quantities of Na would diffuse only 10 to 15 cm upward under these conditions.

Miyamoto (1983), reviewing work done in the San Juan Basin, has concluded that the potential for upward salt migration is much less there than in North Dakota, primarily because of the relatively dry soil conditions under natural precipitation. Salts could also leach downward following occasional heavy precipitation, especially in winter. A field study in the Basin by Gould (1983), which included both irrigation and several years of natural precipitation, did not show increases in topsoil salinity placed over sodic spoil.

This study was conducted with the following two objectives: 1) to evaluate the potential for salt accumulation and water penetration in topsoil placed over a saline-sodic spoil, and 2) to determine how topsoil depth and irrigation rate influence the concentration and location of salts in the profile. This study was intended to evaluate only the initial irrigation phase of reclamation, and does not include any effects of natural precipitation.

METHODS

Sample Site

Samples for a greenhouse lysimeter study were collected at the Burnham Mine in the four corners area of Northwest New Mexico. Storage gage data for 1982-1984 indicated an average annual precipitation of 18.5 cm, divided roughly equally between summer and winter. Vegetation in unmined areas consists of desert grasses and shrubs, with low plant density. Soils at the sample site are calcareous loamy sand to sandy loam in the A horizon, with varying levels of clay and $CaCO_3$ accumulation in the B horizon. They are developed from aeolian sands and vary in depth (Gould and Howard 1975). The overburden typically consists of three geologic types (from the surface down) 1) aeolian loamy sands, 2) brown (oxidized) shales, and 3) gray shales. Shale beds may have thin (1 m) layers of sandstone or coal (Scholl 1982).

Spoil samples were taken from the number two blue parting (dark gray poorly consolidated shale) from a depth of 15 m. Under Burnham mining practices, this material was placed on the spoil surface. Topsoil samples were taken as a composite of both the A & B horizons, (Shiprock series) which represents the typical "topsoil" for spreading over spoil surfaces at Burnham mine.

Study Design

The samples of spoil and topsoil were packed (1.45 and 1.42 bulk density respectively) into plastic cylinders. The above density values are common in field conditions except for highly compacted areas. Various amounts of gravel (6 mm dia.) were added to the bottom of the cylinders so that the upper soil surface would be 1 cm below the cylinder top. The spoil (40 cm deep) was then packed onto the gravel. Tópsoil was packed onto the spoil at four different depths (10, 20, 30, 40 cm).

Four irrigation rates were used (0.25, 1.3, 2.0, 2.8 cm per week). The 0.25 cm amount was applied one time each week. The remaining irrigation amounts were divided by 2 and added twice a week. Good quality tap water (EC = 0.8 mmhos, SAR = 2.6) from Albuquerque, N.M. was used. Gould (1983) reported using San Juan River water (EC = 0.5 mmhos, SAR = 1.3). Irrigation was done in four summer months (16 weeks) of one year, then continued for two summer months (8 weeks) of a second year. Each combination of topsoil depth (4) and watering rate (4) was replicated three times in a latin square design. All cylinders were placed together in the center of a greenhouse dedicated to the study. Air flow and temperature were maintained and pan evaporation checked weekly for agreement with field levels. Bare soil was maintained throughout the study.

Two days after the final irrigation, the cylinders were cut open lengthwise and the profile sampled every 10 cm. The depth of the wetting front and/or any alteration due to wetting were determined visually and by feel. Samples from before and after irrigation were analyzed for electrical conductivity (EC), SAR, texture, organic matter, pH, and soluble extractable Na, Ca, and Mg (Sandoval & Powers 1977). Hydraulic conductivity was determined from saturated samples at the above bulk densities (ASA 1965). Water repellency was determined by the drop disappearance test on the 0.2 mm fraction (Scholl 1975). A 0.05 ml drop of water was applied to the surface and the time in seconds for disappearance recorded. Water content at 1/3 bar was determined by the pressure plate method (Richards 1948).

An analysis of variance and Duncan's multiple range test were used to evaluate the results. A least significant difference (LSD) was obtained based on the pair of means (from Duncan's array of mean pairs) that yielded the lowest positive test value. The LSD value was added to or subtracted from the control value (figures 1, 2) so that significantly different

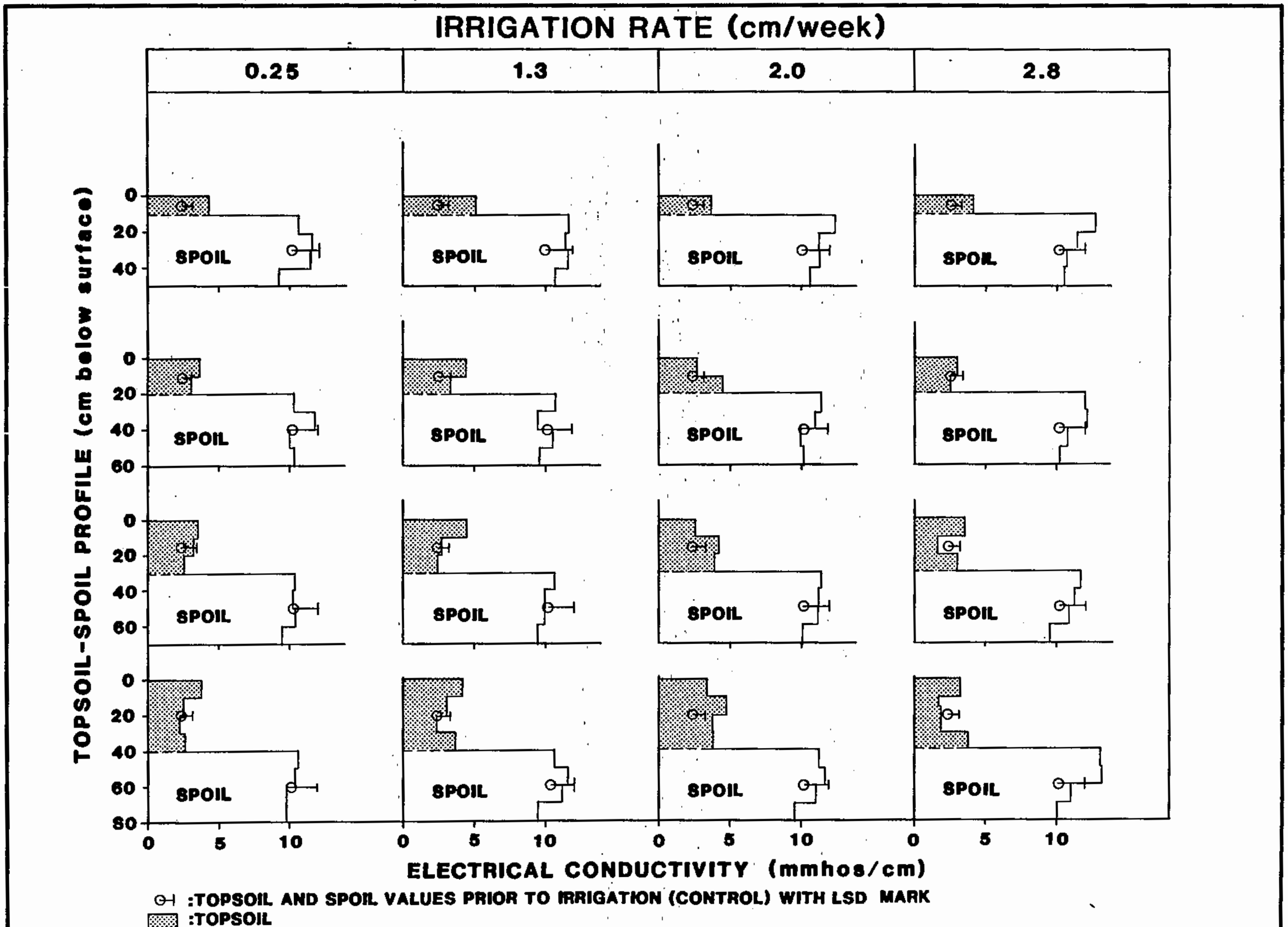

FIGURE 1-- Electrical conductivity of an irrigated topsoil-spoil profile.

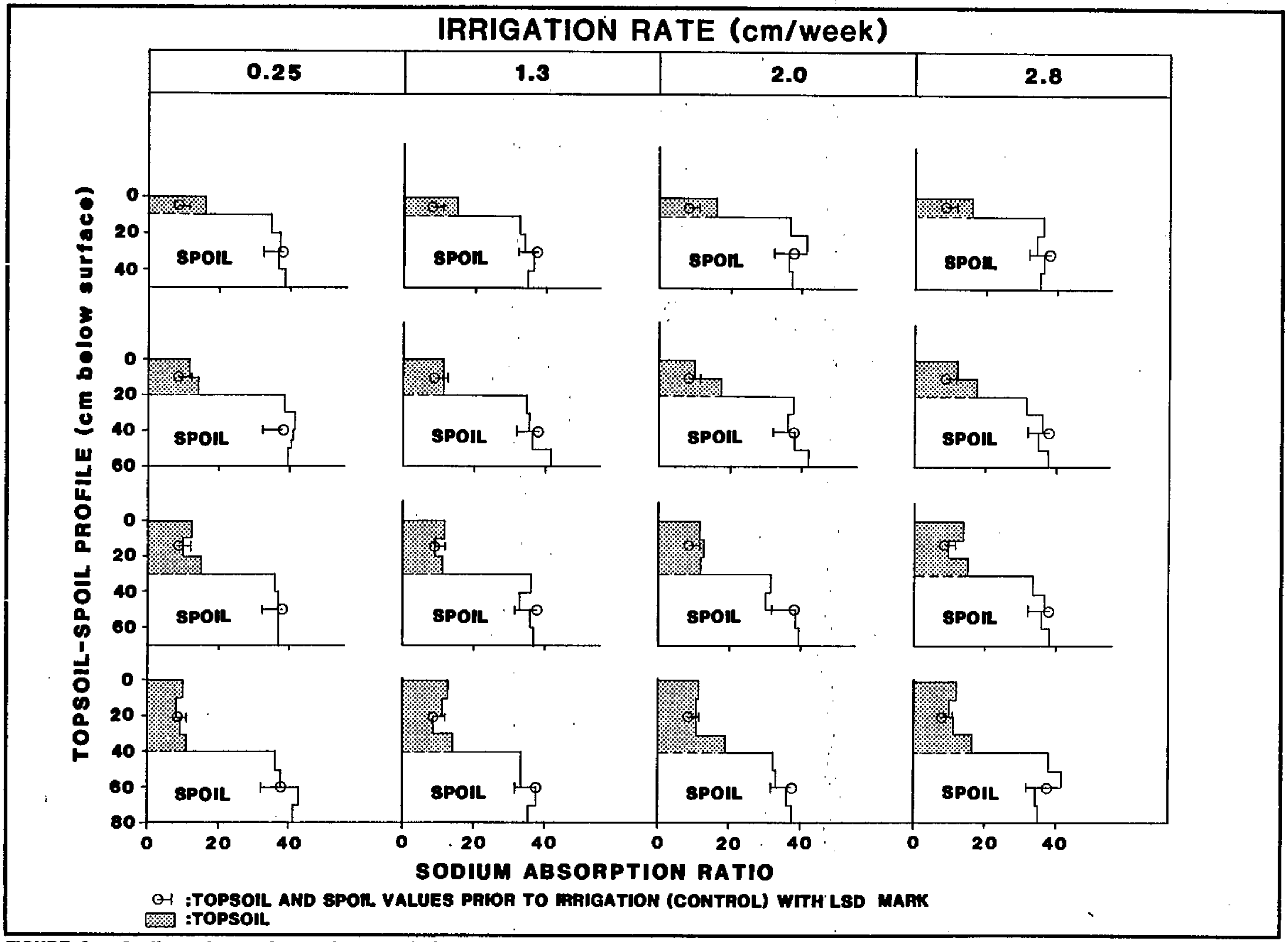

FIGURE 2-- Sodium absorption ratio of an irrigated topsoil-spoil profile.

topsoil or spoil values would lie outside the LSD bracket. The small vertical line connected to the right or left of the data point (control value) indicates the range of values that are not significantly different.

RESULTS AND DISCUSSION

Results of this study apply only to controlled conditions that attempt to duplicate summer irrigation and do not include effects of natural precipitation.

Salts and Water Movement

The contrasting differences between topsoil and spoil, prior to irrigation, are shown in Table 1. The spoil has much higher SAR, EC and clay content as compared with the topsoil. The spoil has very low hydraulic conductivity and tends to be water repellent when dry, but once wetted, holds (at 1/3 Bar) more than 3 times the water that the topsoil does. The soluble salts (Na, Ca, Mg) are dominated by Na in both materials, but much more so in the spoil.

Spoil under the two lower irrigation levels (all topsoil depths) showed no evidence of wetting (Table 2). The depth of wetting of spoil under the two higher rates was dependent on amount of water and the depth of topsoil. Water penetrated farthest at the highest watering rate, and generally with the least topsoil. The two deeper topsoils (30 and 40 cm) apparently stored (at least temporarily) enough water to reduce the flux of water into the spoil.

Topsoils at the two higher watering rates were still moist two days after watering. Topsoils at the lower rates showed only light cementation, likely due to wetting in the period prior to sampling.

The spoils wetted under topsoil did not show the typical swelling, slaking, and massiveness associated with water saturation of spoil. They remained loose and porous and the shale fragments showed little sign of slaking. Saturation, therefore, was not likely complete. Spoils that are not completely hydrated could behave quite differently (chemically and physically) from fully saturated spoils. Unsaturated spoils may have less soluble salts, with improved air and water movement (Miyamoto 1983; Russo and Bresler 1977a, 1977b).

Salinity (EC) was consistantly higher than the control in profiles with the least topsoil (10 cm total depth) (figure 1 and Table 3). The shallow topsoil, regardless of watering rate, accumulated salts rich in sodium, as shown by higher SAR values in figure 2. Salt accumulation at the two lower watering rates may be due to salts added with the water, as upward migration from the spoil or leaching from the topsoil was precluded by the dry spoil. Any salts added with the water would therefore remain in the topsoil.

Salts also accumulated in the surface layers (0-10 cm) of the three deeper topsoils (Figure 1) 20, 30, 40 cm depth), two lower watering rates).

At the two higher watering rates, where the spoil was wetted, both upward additions from the spoil and losses by leaching are possible. At both high watering rates, the topsoil layer in contact with the spoil generally (two exceptions) showed increases in salts (Table 3). The highest rate (2.8 cm/week), however, also had elevated salts in the surface layer (30 and 40 cm of topsoil, figure 1).

Because diffusion functions over relatively thin layers (<15 cm) and steep concentration gradients, it is a possible explanation for the increases in salts at the spoil contact. Convection, on the other hand, may explain some of the increases in surface layers. Changes in solubility of salts added in the water, or in the soil itself, may also have been involved. Further work under New Mexico conditions is needed, however, to confirm these mechanisms.

Electrical conductivity, mainly at the highest watering rate, was elevated in the wetted spoils. One explanation for the effect is that additional salts were released during the long period of moist exposure. Unlike the topsoil case, however, spoil SAR's (Figure 2, 2.0 and 2.8 rate) were not elevated and in two cases were actually reduced. One possible conclusion is that Na, in larger proportion than Ca and Mg, was migrating upward.

Plant Response

If the above increases in salts, especially Na in the topsoil, are of practical significance under current conditions, then native plant growth should be considered. Most plants of high and medium salt tolerance would not be affected by the increases in salts shown (Salinity Laboratory Staff 1954). Most low tolerance plants would not be adapted in the surrounding areas, and would likely not be selected for revegetation. Two prominent native plants used extensively in revegetation, blue grama(Bouteloua gracilis) and fourwing saltbush (Atriplex canescens), are tolerant to the salinities shown in this study (Weiler and Gould 1983). The blue grama tolerance may be limited to less than 6.0 mmhos/cm (EC) while fourwing saltbush can exceed 8.0 mmhos/cm.

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Table 1. Topsoil and spoil properties prior to irrigation.

Properties	Topsoil	Spoil
Clay (%)	23.2	46.5
Silt (%)	14.3	27.1
Sand (%)	62.5	26.4
Texture	Sandy Clay Loam (course)	Clay
Saturated hydraulic conductivity (cm/hr.)	7.0	<0.1
Water repellency (seconds)	0	10
Water content at 1/3 Bar (%)	11.6	42.7
EC (mmhos/cm)	2.45	10.3
SAR	8.46	37.9
Organic matter (%)	-	0.57
pH	8.0	8.4
Soluble (meq/l)		
Na	16.1	57.6
Ca	6.3	3.1
Mg	1.2	1.5

Table 2. Depth of water penetration into spoil, two days after irrigation.

Topsoil depth (cm)	Irrigation rate (cm/week)			
	0.25	1.3	2.0	2.8
10	0	0	10.0	17.2
20	0	0	11.3	12.1
30	0	0	2.2	13.2
40	0	0	4.0	13.3

Table 3. Electrical conductivity (mmhos/cm) of topsoil in contact with spoil (10 cm layer above spoil).

Topsoil depth cm	Control	Irrigation rate (cm/week)			
		0.25	1.3	2.0	2.8
10	2.5^{a}	4.3^{b3*}	5.1^{c3}	3.9^{b1}	4.1^{b2}
20	2.5^{a}	3.1^{b2}	3.1^{b2}	4.6^{c2}	2.5^{a1}
30	2.5^{a}	2.5^{a1}	2.5^{a1}	3.9^{b1}	2.8^{a1}
40	2.5^{a}	2.7^{a1}	3.4^{b2}	3.9^{b1}	3.9^{b2}

[*] Values in rows with same letter and columns with same number are not significantly different (p=.05).