Establishment of Blue Grama and Fourwing Saltbush on Coal Mine Spoils Using Saline Ground Water

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Abstract

This study was conducted in the greenhouse to determine the effect of limited irrigation of topsoiled sodic shaley spoil with water of various salinities on the emergence and growth of 2 native plant species and on the infiltration rate and salinity buildup of the topsoil. Columns containing 20 cm of sandy loam soil over sodic shaley spoil were seeded to blue grama *(Bouteloua gracilis)* or fourwing saltbush *(Atriplex canescens)*. The columns were irrigated with water having 4 levels of salinity ranging from 750 to 12,890 µmhos/cm and sodium adsorption ratios ranging from 2 to 68. The emergence and growth of blue grama was reduced as the salinity of the water increased; no plants survived the most saline treatment. The most saline water reduced the emergence of fourwing saltbush, but the saltbush grew well after the seedling stage. The infiltration rate was lowered as the sodicity of the irrigation water increased, and the electrical conductivity of the soil increased as the amount and salinity of the water increased. The study indicates that moderately saline water (EC≤4230 µmhos) will probably be suitable for revegetating mine spoils using blue grama and fourwing saltbush.

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The largest reserves of coal in New Mexico at depths that are economically feasible for surface mining are found in the Fruitland Formation in the San Juan Basin in the northwestern part of the state (Shomaker et al. 1971). The climate of the San Juan Basin is semiarid continental with high diurnal temperatures and infrequent precipitation. The average annual precipitation along the western and southern exposures of the Fruitland Formation varies from about 13 to 25 cm. The evaporation during the growing season (May–September) is about 125 cm; so a water deficit occurs most of the time (USDC 1972). Water from the San Juan River has been used for irrigation by 2 mines located near the river to establish vegetation. Mines that are farther from the river may need to utilize groundwater for irrigation to revegetate strip-mined lands. Groundwater from many aquifers in the area is saline, the soluble salt content ranging from 3,200 to over 10,000 ppm. This study was conducted to determine the effect of saline water on the germination and growth of fourwing saltbush [*Atriplex canescens* (Pursh) Nutt.] and blue grama [*Bouteloua gracilis* (H.B.K.) Lag.] when applied in amounts normally used by mines in the San Juan Basin.

Information on the establishment of native range species with saline water is limited. Stewart (1967) reported good to excellent growth of 2 shrub and 6 grass species in the Tularosa Basin of southern New Mexico, using water containing up to 16,000 ppm salt. Fourwing saltbush made good growth in well-drained soils when sufficient water was applied to provide leaching of soluble salts. To successfully establish plant using saline water, leaching of soluble salts was necessary. The saline water did not reduce plant growth in species with high salt tolerance once the plants had grown past the seedling stage.

Jensen et al. (1965) demonstrated that establishment of tall fescue (*Festuca arundinacae* Schreb) and tall wheatgrass [*Agropyron elongatum* (Host) Beav.] was possible on saline-sodic soils of Nevada using waters with low salt content. (The salinity of the irrigation water used was not given). Applications on alternate dates was better for plant survival than irrigations at 4- or 8-day intervals. Their results were similar to findings by Stewart. The most critical stage of growth proved to be establishment.

Blue grama and fourwing saltbush are 2 native range species of wide distribution throughout southwestern rangelands and are valuable forage species for livestock and wildlife (Lamb 1971, Gould 1973, Bell 1973). Bernstein (1958) listed blue grama as having the ability to survive in soils having an electrical conductivity (EC) of up to 6,000 μmhos/cm. Knipe (1968) simulated moisture tension levels of 0 to 16 atmospheres, using aqueous mannitol solutions, and found the germination percentage of blue grama was not significantly reduced until moisture tensions of 10 atmospheres (EC = 27,800 μmhos/cm) were reached. The germination percentage at 16 atmospheres (EC = 44,400 μmhos/cm) was significantly lower than at 13 atmospheres (EC = 36,100 μmhos/cm), being 42.2 and 72.7%, respectively. Vigor of blue grama seedlings was noticeably reduced when moisture tensions exceeded 1 atmosphere (EC = 2770 μmhos/cm).

Fourwing saltbush has been noted for its good salt tolerance (Jones 1969, U.S. Forest Serv. 1937). Welch (1978) reported healthy fourwing plants growing in soil having an electrical conductivity of 7,800 μmhos/cm or greater. Springfield (1966) induced moisture stress in fourwing saltbush using various concentrations of mannitol. As moisture stress increased, total germination was delayed and decreased. In recent years, fourwing saltbush has shown potential for use in the revegetation of western rangelands strip-mined for coal (Aldon 1978; Alson and Springfield 1973, Gould et al. 1975, McKell 1978, Thornburg and Fuchs 1978).

Table 1. Characteristics of Doak topsoil and shaley spoil used in columns in the greenhouse.

	Doak soil	Spoil
Cations (meq/l)		
Calcium	5.0	13.4
Magnesium	1.7	4.3
Potassium	0.3	0.2
Sodium	0.3	152.0
Anions (meq/l)		
Bicarbonate	3.5	3.2
Chloride	2.8	34.7
Sulfate	1.1	132.2
Sodium adsorption ratio	0.2	51.0
Electrical conductivity (μmhos/cm)	700	10,400
ph	7.0	7.8
CEC (meq/100gm)	13.9	34.8
Saturation percentage	22	81
Particle size distribution (%)		
Sand	63	24
Silt	27	38
Clay	10	38

Methods and Materials

This study was conducted in the greenhouse at New Mexico State University. Columns were constructed of 45.7-cm (18-inch) long sections of 16.7-cm outside diameter polyvinyl chloride pipe having 0.5-cm wall thickness glued to a 20-cm square piece of 0.5 thick sheet plastic which served as a base for the columns. Four 0.5-cm diameter holes were drilled in the base of each column for drainage. The columns were filled by layers from the bottom with 7.6 cm of sandy soil, 15 cm of shaley spoil, and 20 cm of the A-horizon of Doak soil, a fine, loamy, mixed, mesic, Typic Haplargid. The columns were filled in this manner to simulate topsoiled surface mine spoils. The shaley spoil was obtained from the San Juan Mine located about 24 k west of Farmington, N. Mex. Doak soil is a major soil type found along the exposure of the having 0.5-cm wall thickness glued to a 20-cm square piece of 0.5 cm thick sheet plastic which served as a base for the columns. Four 0.5-cm diameter holes were drilled in the base of each column for drainage. The columns were filled by layers from the bottom with 7.6 cm of sandy soil, 15 cm of shaley spoil, and 20 cm of the

Table 2. Chemical analyses of groundwater from 2 strata in the San Juan Basin, 3 synthesized solutions, and tap water used in the greenhouse.

	Strata		Synthetic Water No.			
	Westwater Canyon	Entrada	1	2	3	Tap water
pH	7.9	7.9	7.9	8.1	9.2	7.5
Ec (μmhos/cm)	4255	12500	4230	8700	12890	730
SAR*	12	74	10	30	68	2.5
Cations (meq/l)						
Sodium	34.8	137.0	30.2	89.7	144.7	3.8
Potassium	0	6.1	2.1	4.5	7.1	0.7
Calcium	16.6	6.0	17.4	13.0	3.4	3.3
Magnesium	0.7	0.9	0.1	5.4	5.6	1.3
Anions (meq/l)						
Chloride	0.4	14.2	1.3	7.9	4.4	2.8
Sulfate	50.6	137.4	46.8	92.6	145.7	2.6
Bicarbonate	1.0	2.2	1.4	2.1	1.7	3.2
Carbonate	0.0	0.0	0.0	0.0	0.0	0.0

*Sodium adsorption ratio

Fruitland Formation in San Juan County, and the Doak soil used in this study was obtained approximately 30 km southeast of Farmington. The sandy soil used as a filler material was obtained about 25 km northeast of Las Cruces. The analyses of the Doak soil and spoil are presented in Table 1.

Eighty-eight columns were used in the study. Salinity sensors manufactured by Soil Moisture Incorporated were buried at a depth of 15 cm in 16 of the columns to monitor the salinity level of the topsoil 24 hours after each irrigation. A salinity bridge was attached to the sensors to determine EC of the soil solution. Half of the columns were seeded to blue grama (var. Lovington) and the remainder to fourwing saltbush at a rate of 40 seeds per column. The columns without salinity sensors were arranged in the greenhouse in 3 blocks with each block containing 12 columns seeded to blue grama and 12 seeded to fourwing saltbush. Eight of the columns with salinity sensors were placed randomly among the columns in block one, and the other 8 columns were randomly placed in block two. Within a block the same number of columns were seeded to blue grama or fourwing saltbush. These species are common on the exposure of the Fruitland Formation and show medium and high tolerance, respectively, to salinity.

The columns were irrigated with tap water from the greenhouse, which had an EC of 730 μmhos/cm, or 1 of 3 synthesized saline waters with ECs of 4,230, 8,700 or 12,890 μmhos/cm. The latter 3 solutions were mixed in the laboratory using distilled water and reagent grade chemicals, to simulate water from 2 aquifers underlying the coal exposure of the Fruitland Formation and a mixture of waters from these aquifers. The analyses of the various waters are presented in Table 2. Irrigations began with an initial application of 5.1 cm of water followed by 1.27-cm applications every fourth day or when the topsoil in 75% of the columns was dry to a depth of 0.5 cm. After 15 cm of water had been applied, the quantity of water per application was changed to 2.54 cm weekly. In each block, a total of 25, 32.5, or 37.5 cm of the various waters were applied to each of 8 columns with no sensors. These rates were chosen to represent the amount of water applied under different dates of seeding if irrigated throughout the growing season. The columns with sensors received 37.5 cm of water. The rate and frequency of irrigations in this study were intended to simulate actual practice at mines in the San Juan Basin, which allows sufficient water for plant establishment and good growth but is not intended for deep percolation and leaching of salts.

Infiltration time for each column was recorded at each irrigation as the number of minutes between application and disappearance of water from the soil surface. To reduce the effects of soil cracks on the apparent infiltration rate, the soil surface along the edge of the columns was tapped gently and other surface cracks were closed. Infiltration time was converted to infiltration rate in centimeters per hour.

The columns were arranged in blocks in the greenhouse with all combinations of plant species, salinity levels, and irrigation levels randomized in each block.

Plant counts were made daily from the initiation of emergence (6th day after seeding) for 15 days and emergence percentage was calculated on the basis of the number of seeds planted. The number of plants in each column receiving the same quality of water was used to evaluate emergence from the salinity treatment. Thus, average emergence percentage of each species in a particular salinity treatment was based on the emergence percentage from 9 columns. One month after seeding, plants were thinned to 6 blue grama or 4 saltbush per column. Plant height measurements were recorded weekly thereafter. Six days after final irrigations, plants were clipped at the soil surface. Top growth was oven dried for 48 hours at 110°C and dry weight was recorded.

The data were initially analyzed as a complete factorial using analysis of variance procedures. Because of significant differences between species and significant interactions in comparisons with species, the data for each species was analyzed separately for ease of interpretation. The data for emergence were analyzed as a simple randomized complete block because all columns had received the same amount of water at each date of data collection and each column was seeded to a single species. The data for plant size and water and infiltration were analyzed as a split block with irrigation levels as blocks.

Results and Discussion

To facilitate discussion of results, the irrigation waters will be identified as follows:

Tap water — EC = 730 mhos/cm, SAR = 2.5
Water #1 — EC = 4230 mhos/cm, SAR = 10
Water #2 — EC = 8700 mhos/cm, SAR = 30
Water #3 — EC = 12890 mhos/cm, SAR = 68

Plant Emergence

Data for accumulative emergence of fourwing saltbush and blue grama from the sixth through the twentieth day after initiation of irrigation are presented in Figure 1. Seedlings of both species were first observed on the sixth day after the first irrigation. Emergence of fourwing saltbush was nearly complete by 8 days after irrigation began in columns irrigated with tap water and waters #1 and #2, with averages of 24, 21, and 21%, respectively. Twenty days after the first irrigation, emergence percentages with these waters were not significantly different (25, 21, and 24%, respectively). Emergence in columns irrigated with water #3 was significantly lower

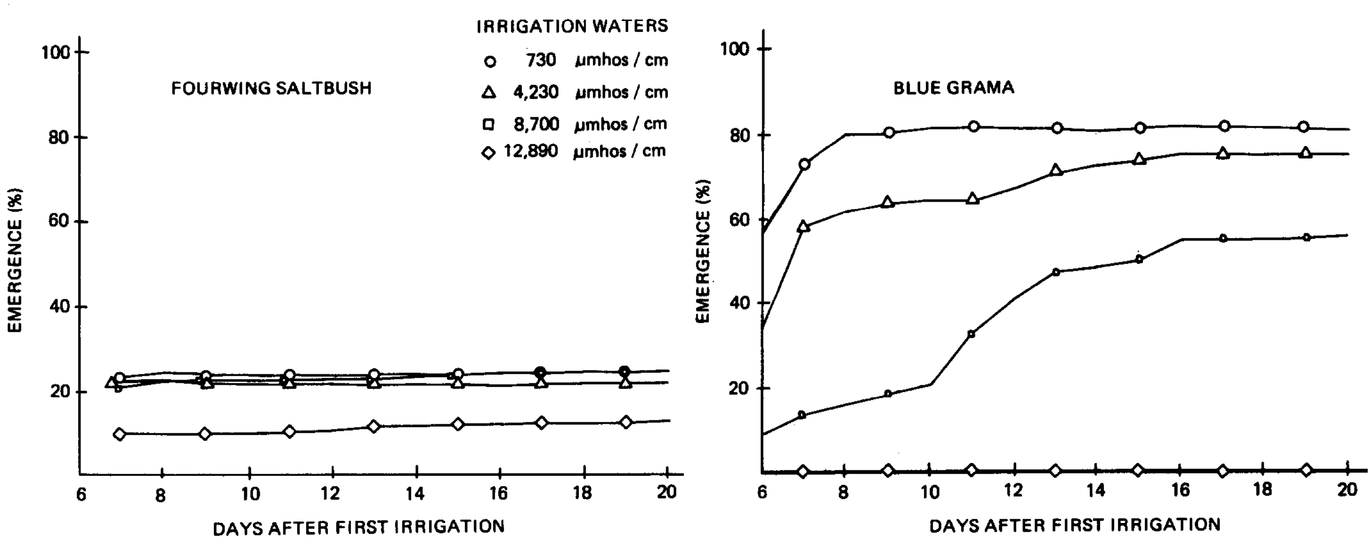

Fig. 1. *Accumulative emergence of fourwing saltbush and blue grama irrigated with four waters of different salinity*

Table 3. Average dry weight (g) of fourwing saltbush and blue grama top growth at 3 levels of irrigation using water with 4 salinity levels.

EC of the irrigation water µmhos/cm)	Level of irrigation					
	Fourwing saltbush			Blue grama		
	25 cm	32.5 cm	37.5 cm	25 cm	32.5 cm	37.5 cm
	c	b	a	b	a	a
730	5.60A	8.71A	11.01A	5.34A	8.08A	8.82A
	c	b	a	b	a	a
4,230	4.23B	8.13A	9.35B	4.12AB	7.19A	6.57B
	c	b	a	b	a	a
8,700	4.60AB	7.55A	9.57B	1.89BC	6.00A	6.80AB
	b	a	a	a	a	a
12,890	2.52C	8.25A	8.47B	0 C	0 B	0 C

Note: For each species and salinity level of water, numbers with the same lower case letter above them are not significantly different at the 5% level of probability using Duncan's multiple range test. Similarly, numbers in a column followed by the same upper case letter are not significantly different.

than with tap water, being 9 and 12% at 8 and 20 days, respectively, after the first irrigation.

The germination percentage of blue grama was much greater than for fourwing saltbush, but blue grama showed greater sensitivity to saline treatments. On the sixth day after the first irrigation the emergence in columns receiving waters #1 and #2 was 61% and 16%, respectively, of the emergence in columns receiving tap water. The emergence with tap water was virtually complete 8 days after irrigation began, while emergence continued until the sixteenth day with waters #1 and #2. At the 5% level of probability, the total emergence of blue grama in columns irrigated with tap water and water #1 did not differ, but emergence with water #2 was significantly less than for tap water or water #1. Only one seedling emerged in columns irrigated with water #3, and that seedling died after 15 cm of water had been applied.

Plant Height and Dry Weight of Plant Top Growth

Accumulative heights of fourwing saltbush and bluegrama with each increment of irrigation water shown in Figure 2 are averages of data from 9 columns for the 10- to 25-cm levels of irrigation, 6 columns for the 25- to 32.5-cm levels, and 3 columns for the 32.5- to 37.5-cm levels. The average height of fourwing saltbush at a given level of irrigation, as indicated by analysis of data at the 25-, 32.5-, and 37.5-cm levels of irrigation, did not differ for the 4 irrigation waters. Generally, plants irrigated with tap water tended to be taller than plants in columns receiving saline water. The increase of soil salinity associated with the application of additional amounts of the various saline waters had little, if any effect on the growth rate of fourwing saltbush. The dry weight of fourwing saltbush top growth increased significantly with time in all irrigation treatments (Table 3) except with water #3. In contrast to the weights of plants harvested after 25 or 37.5 cm of water #3 were applied, the weight of plants after application of 32.5 cm was unexplainably high.

Fourwing saltbush plants in columns irrigated with tap water were not significantly taller than plants in columns receiving more saline water, but they were heavier at the final irrigation.

The tendency toward smaller plants as the salinity of the water

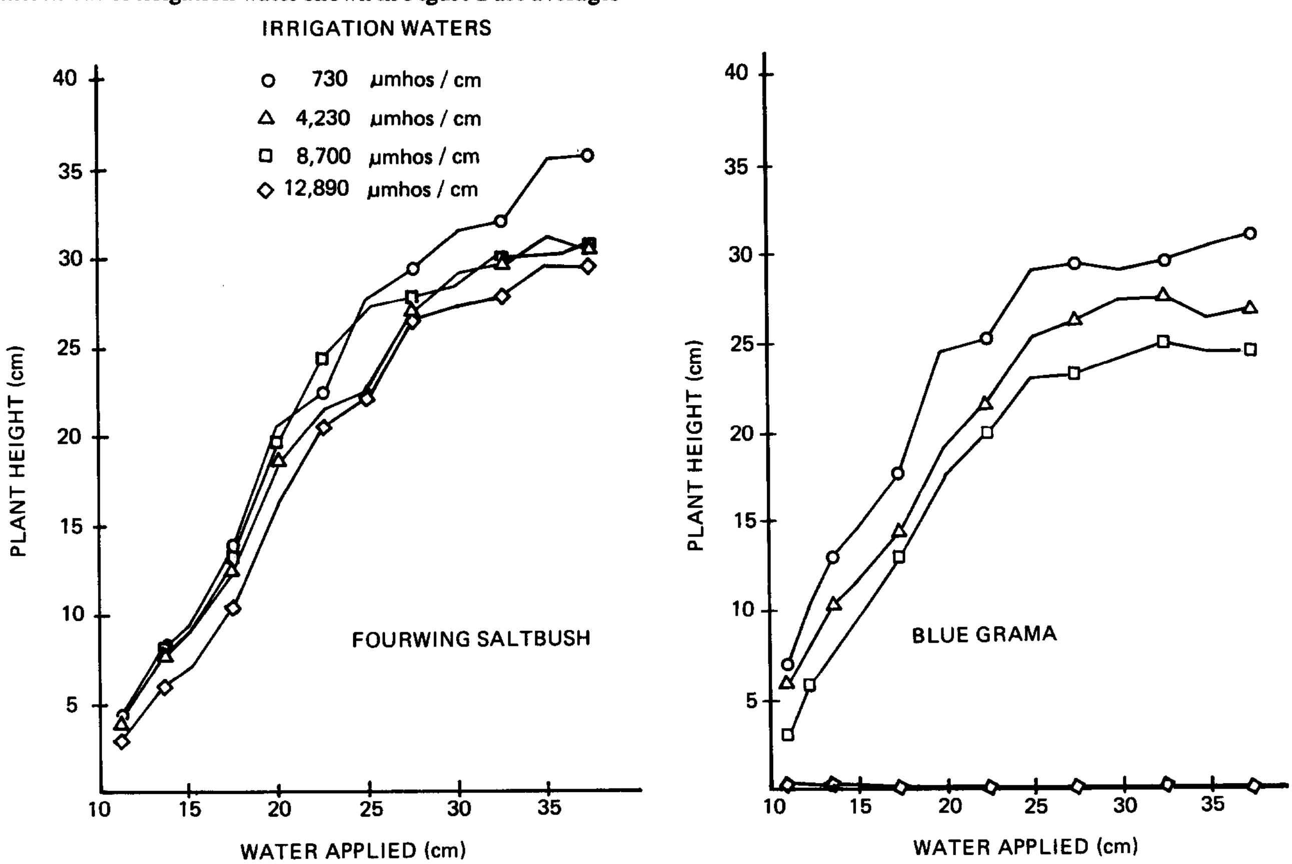

Fig. 2. *Accumulative growth of fourwing saltbush and blue grama after application of various quantities of saline water ranging EC from 730 to 12,890 µmhos/cm.*

increased may be partly attributable to the slower germination and initial growth of fourwing saltbush. The height and weight of plants irrigated with the various saline waters were quite similar after the final irrigation, which indicates a high salt tolerance for this species.

The delay in germination of blue grama (Figure 1) caused by increases in salinity of the irrigation water resulted in differences in plant height at the time of the first height measurements (Figure 2). The rate of growth thereafter appeared to be similar with tap water and waters #1 and #2. Analyses after application of 25 cm of water showed the height of plants irrigated with tap water was significantly greater than plants irrigated with waters #1 and #2, which did not differ. After the last irrigation the plants receiving tap water were taller than those receiving water #2 but were not taller than plants in columns irrigated with water #1.

The weight of blue grama plants was quite variable and a significant increase in weight did not occur during the period between the last 2 harvests (Table 3). There was a tendency for plants irrigated with tap water to be heavier than plants in columns irrigated with more saline water. No plants survived in columns irrigated with highly saline water (EC = 12,890 μmhos/cm). Apparently, blue grama is only moderately tolerant to salinity, which is in agreement with Bernstein's report (1958).

Water Infiltration Rate

The average infiltration rate for the various irrigation waters, at each irrigation after the initial application, are presented for the 2 species in Figure 3. The infiltration rates for 9 columns in each block are averaged at the 5- to 25-cm levels of irrigation, 6 columns are averaged for the 27.5- to 32.5-cm applications, and 3 columns are averaged for the 35- and 37.5-cm applications.

Infiltration rates for all waters declined rapidly from the 5- to 12-cm level of application, and at a slower rate until 22.5 cm had been applied. A reduction in the rate of infiltration with repeated applications of water is to be expected (Musgrave 1955). The rapid decline in infiltration rates after 5 cm of water were applied is because initially dry pores were partially filled with water before additional applications were made (Taylor and Ashcroft 1972). Except for water #4 in blue grama columns, infiltration rates increased with all waters after 22.5 cm were applied. These increases may be attributed to more rapid use of water by the increasing volume of plant foliage and higher evapotranspiration associated with higher temperatures in the greenhouse. Infiltration rates were calculated from the time the water was applied until it had disappeared from the soil surface. Because of greater evaporation and transpiration, the soil became dry and more water was needed to saturate the upper few centimeters of soil. Infiltration rates probably would have been lower if the upper centimeter of soil had been wetted before the regular application of water.

In columns with fourwing saltbush, the infiltration rates were highly variable within water treatments, resulting in nonsignificant differences between treatments after applying 25, 32.5, or 37.5 cm of water. The infiltration in columns with blue grama was somewhat different than in the saltbush columns. There was a greater increase in the infiltration rate for tap water in the blue grama columns than in the saltbush columns, but only a slight increase occurred with water #1. The infiltration rate for water #2 was similar for both species. The infiltration rate with water #3 dropped to a lower level in the columns with blue grama, and the rate continued to decline as more applications of water were applied. No blue grama plants grew in columns receiving water #3, so the only loss of water was from evaporation or deep drainage. Consequently, a saturated-flow condition probably occurred more quickly with treatment, and the infiltration rate was less variable. At the 25-, 32.5-, and 37.5-cm levels of irrigation the infiltration rate with tap water was significantly greater than with water #3, while rates with waters #1 and #2 did not differ significantly from rates with tap water or water #3.

Electrical Conductivity

The electrical conductivity measurements obtained with salinity sensors at the 15-cm depth in the columns are shown in Figure 4. The electrical conductivity began to rise after application of 7.5 cm of waters #1, #2, and #3. After application of 12.5 cm of water the electrical conductivity at the 15-cm level was greater than that of the applied water. The electrical conductivity increased as more water was applied except in the columns with fourwing saltbush that received tap water. With waters #2 and #3 the electrical conductivity was quite similar at each level of applied water in the columns containing blue grama or fourwing saltbush. Under irrigation with water #1 the electrical conductivity increased slightly faster in the columns with blue grama than with fourwing saltbush. After the 27.5-cm level of irrigation with water #1, there was an abrupt increase in salinity in columns with both species.

The growth rate of fourwing saltbush began to level off after application of 25 cm of waters #1, #2, and #3. The infiltration rate for water #1 increased sharply, which indicates the soil was becoming increasingly drier between irrigations, so moisture stress may have caused a reduction in growth rate, and the lower water content of the soil caused an increase in electrical conductivity. The infiltration rate for waters #2 and #3 in the saltbush columns increased only slightly and then declined. Possibly, the osmotic

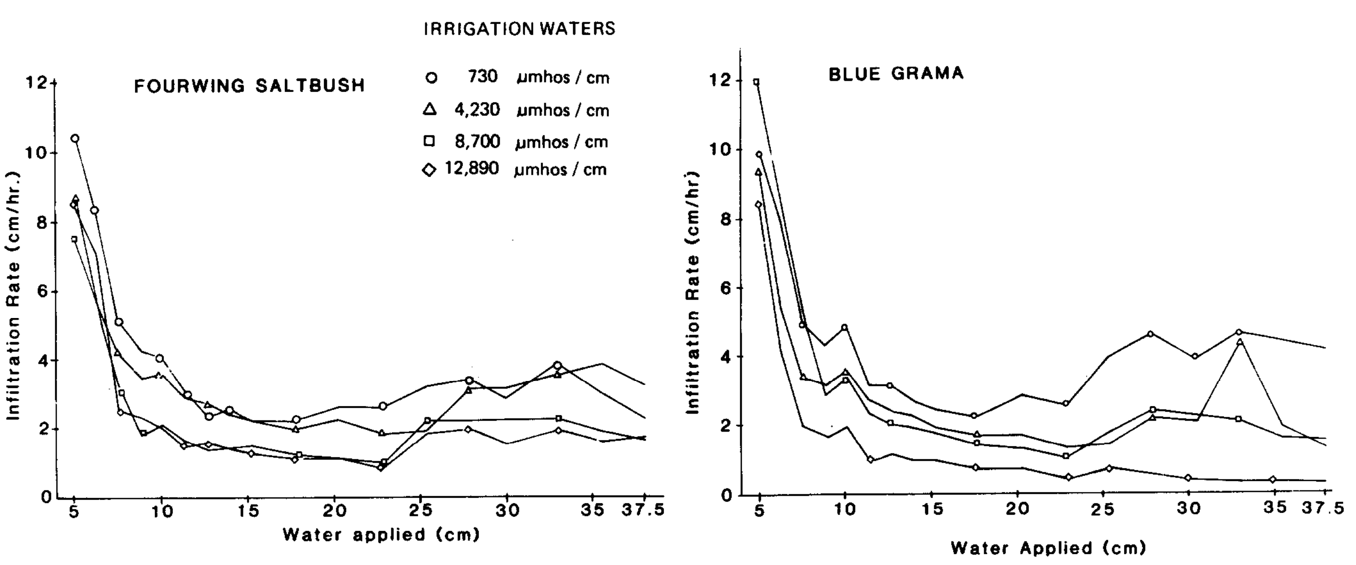

Fig. 3. *Water infiltration rate of columns seeded to fourwing saltbush and blue grama over 37.5 cm of applied irrigation with waters ranging in EC from 730 to 12,890* μmhos/cm.

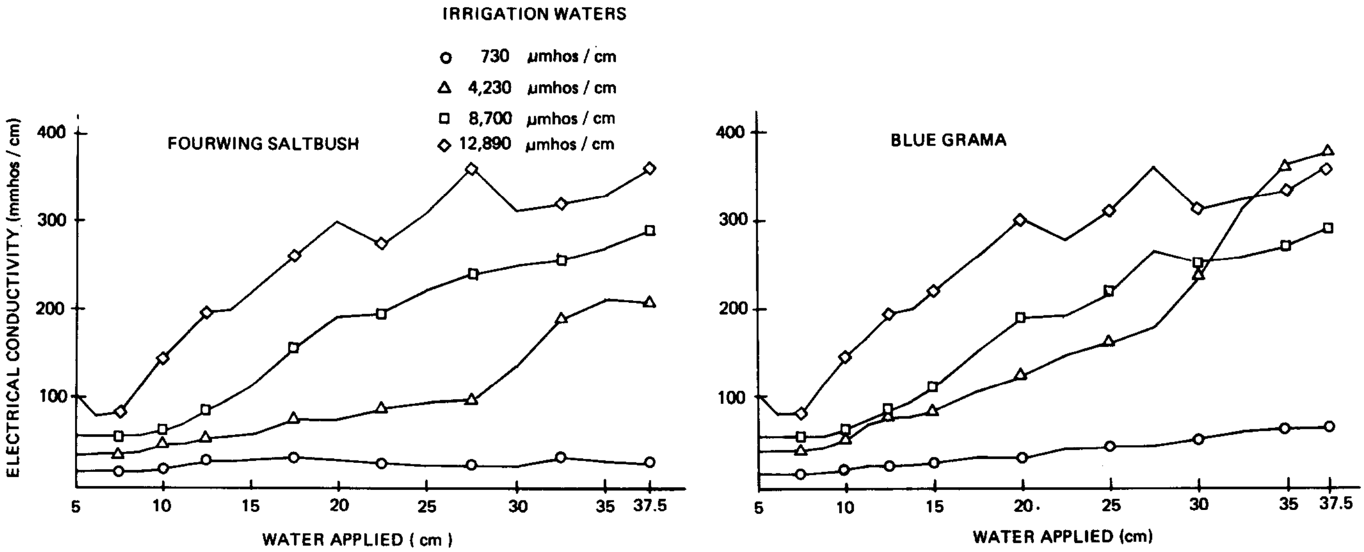

Fig. 4. *Changes in electrical conductivity with additions of saline waters as determined by salinity sensors buried at 15 cm in columns in the greenhouse.*

pressure created by the increasing salt level became inhibitory to plant growth, thus a reduced growth rate. At the same time, the plants were unable to remove as much water from the soil, so the electrical conductivity increased at a somewhat constant rate because the water level in the soil water was nearly constant at each reading.

The growth rate of blue grama tended to level off after application of 25 cm of tap water and waters #1 and #2 (Fig. 2). This reduction in leaf growth is partly attributable to stage of growth, as the plants started to produce flowering stalks. However, the increase of infiltration rate with tap water, and to a lower extent with waters #1 and #2 (Fig. 3), suggests a moisture stress may have developed between irrigations, and this also contributed to a reduction in growth. The electrical conductivity obtained with the salinity sensors was much higher than would be obtained by the saturation extract method, because the concentration of salt would be much lower in the latter method.

The data indicate that the quality of water from the Westwater Canyon Formation will probably be acceptable for use in revegetation on mine spoils but water from the Entrada Formation would be toxic to some species. The amount of water applied in this study did not permit leaching so all the salt applied remained in the soil. The electrical conductivity of the spoil material was greater than the EC of waters #1 and #2 so the salinity of the topsoil would increase with additional applications of saline water until a downward gradient of salinity from soil to spoil is achieved. The sodium level of waters #1, #2, and #3 caused a slight to significant reduction in the infiltration rate in the greenhouse. Further testing would be desirable under field conditions to determine whether the infiltration rate would be reduced sufficiently to increase runoff during a rainfall event.

To reduce the hazard for plant establishment and growth and for a reduction of the infiltration rate, field seeding should be made immediately prior to the period of maximum anticipated rainfall so that a minimal amount of ground water is used for plant establishment.

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