Saline-Seep Reclamation in the Northern Great Plains

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ABSTRACT

SALINE seeps affect extensive dry cropland areas in the northern Great Plains. Methods have been devised to reduce the subsurface flow of water to saline-seep areas. Little information is available on what methods and procedures should be used to reduce soil salinity in arrested (hydrologically controlled) saline seeps. Study objectives were (a) to determine changes in soil salinity with time; (b) to evaluate the effectiveness of soil ridges, straw mulch (20 t/ha), gypsum (11 t/ha), fallow, and check (natural revegetation with grasses and weeds) in accelerating the reclamation process; and (c) to determine potential crop yields in arrested saline-seep areas.

Soil salinity of the 0- to 30-cm soil depth was reduced sufficiently 2 years after the seep was arrested to allow many crops to be successfully grown. Crop yields in the arrested saline-seep areas generally equalled average county yields after 3 to 4 years of hydrologic control. The straw mulch treatment was the most effective in reducing soil salinity in the 0- to 90-cm soil depth. The check (revegetated) treatment was the least effective in reducing soil salinity in the 0- to 90-cm soil depth. Gypsum application did not accelerate the reclamation process, probably because sufficient naturally occurring gypsum had been precipitated in the soil profile during saline-seep formation. No deterioration in soil permeability or structure was observed during the reclamation process.

Seven years after hydrologic control was obtained, soil salinity was still higher in the arrested saline-seep areas than in that of adjacent nonseep areas. Rate of salt removal from arrested dryland saline-seep areas depends on distribution and amount of precipitation received. Hydrologic control in the recharge area must be maintained to prevent reactivation of an arrested saline seep.

INTRODUCTION

Dryland soil salinity (saline-seep) problems resulting from the crop-fallow system of farming became very apparent during the 1960's and 1970's in the northern Great Plains (references 1, 2, 6, 7, 9, 10, 17). Saline seeps develop when percolating soil water from upslope recharge areas accumulates above nearly impermeable geologic strata and seeps to the soil suface at a downslope position. Saline seeps reduce productivity of agricultural land and disrupt normal farming operations due to their random size and distribution, wetness, and associated soil salinity.

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Research during the 1970's indicated that many saline seeps can be controlled by implementing more intensive cropping systems in the recharge area (references 3, 11, 12, 17, 19). Deep-rooted crops, such as alfalfa (*Medicago sativa* L.), have been shown to be very effective in reducing the subsurface flow of water (hydrologic control) to existing saline-seep areas (references 3, 5, 12). Drainage of the saline subsurface water presents disposal and other socioeconomic problems (references 6, 8, 20) and is generally not considered a viable solution for saline seeps in the northern Great Plains.

Calcium, Na, and Mg sulfates are the predominant salts associated with dryland saline seeps in the northern Great Plains (references 1, 2, 4, 8, 10, 17). Analyses of soil water compositions associated with saline seeps indicate that soil solutions are in equilibrium with gypsum and lime (reference 18).

The objectives of this study were (a) to determine changes in soil salinity with time in arrested saline-seep areas; (b) to evaluate the effectiveness of several soil management procedures in reducing soil salinity in arrested saline-seep areas; and (c) to determine potential crop yields in arrested saline-seep areas.

METHODS AND MATERIALS

Two previously described (references 10, 12, 13) saline-seep sites that had been arrested (hydrologically controlled) by growing alfalfa in the recharge area were used to determine the effectiveness of five soil management treatments on reducing root zone soil salinity. The geology of seep A, located near Sidney, Montana, is characterized by Wisconsin clay loam glacial till soil *(Typic Argiborolls)* deposited over weakly consolidated sandstone, siltstone, lignite, and/or dense clay of the Tongue River formation of the Fort Union Group. Geologic characteristics of seep B, located near Froid, Montana, are similar to those of seep A except that the glacial till is capped with 30 to 60 cm of sandy loam soil *(Typic Argiborolls)*. The approximate sizes of the salt-affected (discharge) area for seeps A and B were 0.7 and 0.6 ha, respectively. Alfalfa was established in the recharge area of seep A in May 1973 and of seep B in May 1972.

Reclamation treatments were established in May 1976. The most saline area of each seep was used for the study. Treatments included (a) soil ridging to reduce runoff (ridges 15 cm high and 30 cm apart); (b) straw mulch (20 t/ha) to reduce evaporation from the soil surface; (c) 11 t/ha of gypsum, broadcast and incorporated; (d) fallow; and (e) check (i.e., no treatment — foxtail barley *(Hordeum jubatum* L.) and kochia *(Kochia scoparia* (L.) Schrad) were allowed to grow). By 1977, foxtail barley provided about 75% ground cover with little kochia present. Treatments were laid out in a randomized complete block design with 3 × 3 m plots and three replications. All treatments were tilled periodically to control weeds except for the straw mulch and check treatments. The soil ridges were reestablished by hand after each cultivation. Vegetation on the straw mulch treatment was chemically controlled. The study was terminated in October 1979.

An area adjacent to the above plots with a similar soil salinity was cropped annually from 1976 to 1979 to determine the yield potential of crops grown on the arrested saline-seep areas. Because of limited area available, forage or grain yields were determined from single-row, nonreplicated plots 0.3 m wide × 21 m long in 1977 and two-row plots 0.6 m wide × 21 m long in 1978 and 1979. Alfalfa, sweet clover *(Melilotus officinalis* L.), barley *(Hordeum vulgare* L.), spring wheat *(Triticum aestivum* L.), and oats *(Avena sativa* L.) were grown on this area in 1976; however, yields were not determined. Flax *(Linum usitatissimum* L.), sunflower *(Helianthus annuus* L.), safflower *(Carthamus tinctorius* L.), and corn *(Zea mays* L.), in addition to the aforementioned crops, were grown in 1977, 1978, and 1979. Because of limited space, guard or border crop rows were not used. Nitrogen, 45 kg N/ha, was applied to the cropped area each year.

Soil samples were collected to a depth of 120 cm in October 1975 from two sites within the area to be used for the reclamation treatments. The soil samples were composited by depth and prepared for analyses. Electrical conductivities (EC), decisiemen/m (dS/m), of saturated soil extracts were determined (reference 21). Soil samples were collected from each reclamation plot of both seeps in May 1977 to a 60-cm soil depth and in October 1979 to 180-cm soil depth and saturation extracts of the samples analyzed for EC and soluble Ca, Mg, and Na (reference 21). Cation concentrations were determined using an atomic absorption spectrophotometer. In November 1982, duplicate soil samples were collected to a depth of 300 cm from approximately the same area occupied by the reclamation treatments from 1976 to 1979, composited and analyzed for EC and soluble Na, Ca, and Mg. Sodium-Adsorption-Ratios (SAR) were calculated from the Na, Ca, and Mg data (reference 21). Analyses of soil samples collected in 1971 (seep A) or 1972 (seep B) and nonseep area (one sample site each) were used to show changes in soil salinity with time.

Effects of soil management treatments on changes in soil salinity after 4 years were evaluated using a split-block analysis with soil management as the main treatment and soil depth as subplot. Differences discussed as significant were evaluated at the 90% confidence level.

RESULTS AND DISCUSSION

Soil Salinity Changes with Time

Annual precipitation in the area of seep A was below normal in 1976, 1977, 1979, 1980, and 1981 (Table 1). Consequently, the rate of salt removal from the soil profile may have been slower than it would have been with average precipitation. Except for 1976, precipitation trends were similar at seep B.

Soil salinity in October 1975 is shown in Fig. 1 for seep A and in Fig. 2 for seep B. Profile distributions and levels of soil salinity in the seeps in 1975 were nearly identical to those measured in 1971 or 1972 for both sites (data not shown). Also shown in Figs. 1 and 2 are average soil salinity data from the reclamation plot area in 1979 and 1982 and from adjacent nonseep areas (1971 or 1972 data). Soil salinity was highest at the soil surface at both seep sites in 1975. As hydrologic control was attained by growing alfalfa on the recharge area, the water-table level in the seep area began declining by 1975 (reference 12). As the water-table level dropped below 120-cm depth, surface soil salinity in the seep area began to decline. By October 1979, when the study was terminated, surface-soil (0 to 15 cm) EC had declined to 3.6 dS/m at seep A and 5.6 dS/m at seep B.

The alfalfa was removed from the recharge area of both seeps in the fall of 1978. At seep A, the recharge area has been annually cropped since alfalfa removal. At seep B, most of the recharge area has been in the crop-fallow rotation since 1979. Consequently, salts in the upper 90 cm of the soil profile in seep B appear to be

TABLE 1. MONTHLY AND TOTAL YEARLY PRECIPITATION AT SEEPS A AND B AND A LONG-TERM AVERAGE.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
	cm												
						Seep A							
1976	1.60	0.23	0.86	5.56	5.13	10.31	1.32	2.13	0.56	0.36	0.56	1.07	29.69
1977	1.52	0.84	0.08	0.51	3.56	2.79	4.06	3.30	7.37	1.27	1.27	2.01	28.58
1978	0.36	0.89	0.89	0.99	15.60	7.87	4.04	1.22	9.17	0.15	2.92	1.70	45.80
1979	0.30	2.26	1.85	4.52	3.73	3.23	6.86	0.61	2.57	0.81	0.79	0.20	27.73
1980	1.93	0.71	0.30	0.94	0.69	4.88	1.88	7.39	3.71	4.93	1.24	1.60	30.20
1981	0.10	0.51	0.30	2.77	1.45	8.10	6.45	6.53	1.55	1.93	1.02	1.40	32.11
1982	2.18	0.84	4.52	1.68	5.92	6.07	5.44	4.47	4.62	8.10	0.38	2.67	46.89
Average 1949-1982	1.02	0.97	1.24	3.02	5.21	7.29	4.52	4.32	3.30	2.19	1.10	1.09	35.01
						Seep B							
1976	0.74	0.05	0.43	5.33	3.96	23.95	1.22	9.91	1.09	0.36	0.56	1.07	47.95
1977	1.07	0.66	0.36	0.51	3.35	2.26	4.47	3.23	5.69	1.42	1.42	1.17	25.61
1978	0.25	0.48	0.66	0.76	15.72	7.92	8.66	0.18	11.25	0.41	1.93	1.47	49.69
1979	0.23	1.52	0.89	3.38	3.89	4.85	6.32	0.48	1.45	0.69	0.43	0.00	24.13
1980	1.35	0.28	0.25	0.51	0.25	4.62	0.71	8.00	6.65	4.01	0.71	1.40	28.74
1981	0.15	0.15	0.84	0.99	2.62	7.77	1.52	2.69	2.24	2.49	1.47	0.97	23.90
1982	2.62	0.58	2.16	1.07	8.05	6.30	1.96	4.85	4.45	3.89	0.10	2.08	38.11
Average 1941-1982	1.11	0.81	1.18	3.08	5.25	8.32	4.91	4.24	3.44	2.05	1.10	1.01	36.50

Precipitation data from U.S. Weather Bureau for Sidney, Montana (reference 22)
Precipitation data from U.S. Weather Bureau for Culbertson, Montana (reference 22)

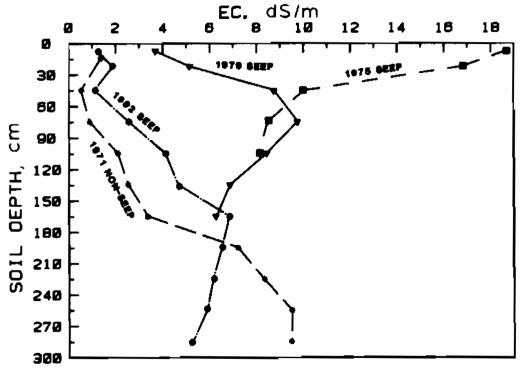

Fig. 1—Electrical conductivity (EC) of saturated soil extracts as a function of soil depth at site A for the seep area in 1975, 1979, and 1982 and for an adjacent 1971 nonseep affected soil.

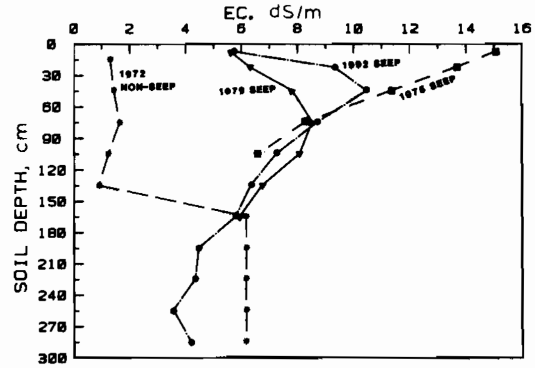

Fig. 2—Electrical conductivity (EC) of saturated soil extracts as a function of soil depth at site B for the seep area in 1975, 1979, and 1982 and for an adjacent 1972 nonseep affected soil.

reaccumulating as indicated by the 1982 soil EC data (Fig. 2). At seep A, the 1982 soil EC data for the 0- to 150-cm soil depth indicate that soil salinity has continued to decrease with time (Fig. 1). The soil EC data presented in Figs. 1 and 2 indicate that a more intensive cropping system than has been used in the recharge area of seep B will be needed to reverse the trend of salt accumulation in the upper profile; whereas, the annual cropping system employed in the recharge area of seep A has been very effective in maintaining hydrologic control of the discharge (seep) area.

Soluble Na and Mg concentrations in the upper 60-cm soil profile were reduced considerably at seep A by 1982, as compared with those in 1971, and were approaching those of the nonseep soil profile (Fig. 3). Similar trends were observed for the 0- to 60-cm depth in the profile at seep B when comparing the 1972 data with that of 1979. However, increases in Na and Mg concentrations were observed in 1982 compared with 1979 at seep B because of the return to a crop-fallow culture on the recharge area (Fig. 3).

Reclamation Treatments

The 1979 soil salinity profiles (EC data) for reclamation treatments established in 1976 at seeps A and B are shown in Figs. 4 and 5. Statistical analysis of the 1979 EC data by treatment and soil depth (0 to 180 cm) indicated a significant ($P = 0.05$) treatment by soil

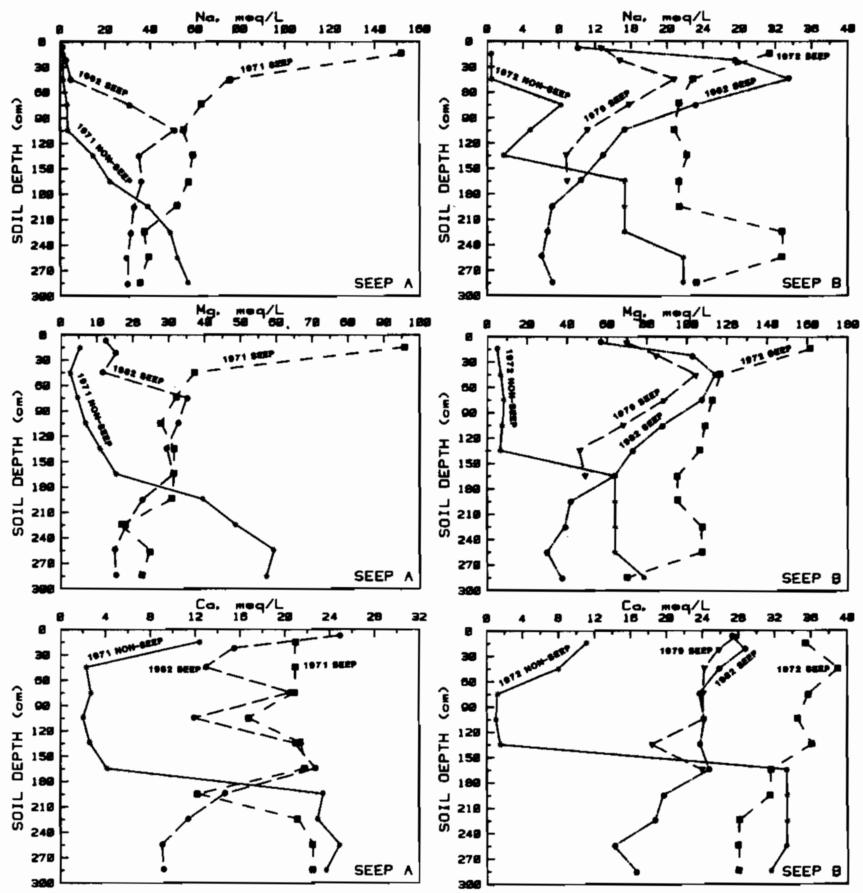

Fig. 3—Sodium, Mg, and Ca concentration in saturated soil extracts as a function of soil depth at sites A and B for seep and nonseep affected soil profiles.

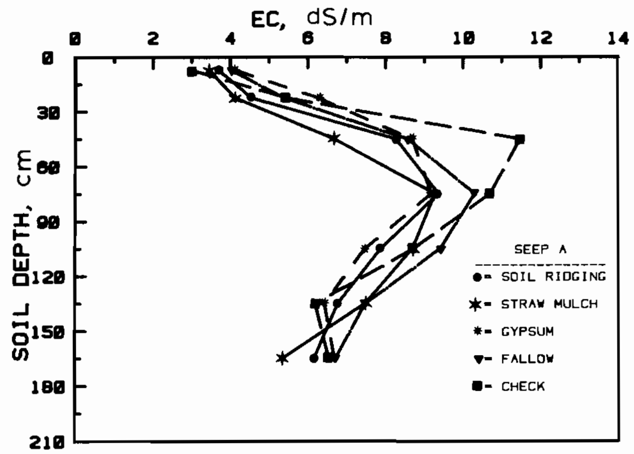

Fig. 4—Electrical conductivity (EC) of saturated soil extracts as a function of soil depth for the soil ridging, straw mulch, gypsum, fallow, and check (natural revegetation) treatments at seep site A after 4 years.

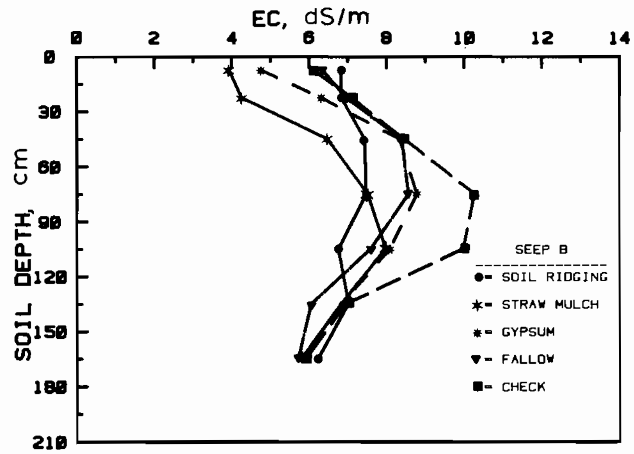

Fig. 5—Electrical conductivity (EC) of saturated soil extracts as a function of soil depth for the soil ridging, straw mulch, gypsum, fallow, and check (natural revegetation) treatments at seep site B after 4 years.

depth interaction at both seep sites. The general trends were for the straw mulch treatments to be the most effective in reducing soil salinity and the check (natural revegetation) treatment the least effective at both seep sites.

Electrical conductivity of the 0- to 30-cm soil depth was reduced by all reclamation treatments between May 1977 (Table 2) and October 1979 (Table 3) at both seep sites. At seep A, the average soil EC level of the 0- to 30-cm soil depth was reduced from 8.4 dS/m in 1977 to 4.4 dS/m in 1979 with a similar reduction in EC for the 0- to 60-cm depth. At seep B, the average soil EC level of the 0- to 30-cm soil depth was reduced from 9.6 dS/m in 1977 to 5.9 dS/m in 1979. A similar reduction in soil EC was noted for the 0- to 60-cm soil depth.

Significant reductions in soluble salts (Na, Mg, and Ca) of the 0- to 30-cm soil depths are shown in Fig. 3 for seeps A and B. From 1976 to 1979, no visual signs of poor soil permeability, sodic soil problems, or soil and organic matter dispersion were observed. These observations are supported by the relatively low SAR values (<15) measured in 1977 (Table 2) and 1979 (Table 4). The types of salts that formed the seeps, mainly Mg and Ca sulfates, are credited with preventing any severe sodic soil problems from developing during the leaching process. The SAR values of the 0- to 30-cm and 0- to 60-cm soil depth were greatly reduced from May 1977 to October 1979 (Tables 2 and 4). The reason

TABLE 2. AVERAGE SOIL EC AND SAR OF THE 0— TO 30—CM AND 0— TO 60—CM SOIL DEPTH IN MAY, 1977 AT SEEP A AND B.

		Soil Depth, cm							
		0 To 30		0 To 60		0 To 30		0 To 60	
Treatment	Seep:	A	B	A	B	A	B	A	B
		EC, dS/m				SAR			
Soil ridging		7.99	9.19	8.41	9.84	9.40	4.30	11.00	4.60
Straw mulch		6.76	7.87	7.30	8.35	8.30	3.60	9.70	4.00
Gypsum		8.47	10.64	8.60	11.44	10.20	5.30	10.60	5.40
Fallow		8.85	9.01	9.28	10.04	11.10	5.20	12.10	5.50
Check		9.92	11.51	10.55	11.18	12.00	4.70	12.90	4.60
Mean		8.40	9.64	8.83	10.17	10.20	4.60	11.30	4.80
Significance level of F-Value	P=	0.248	0.612	0.173	0.751	0.533	0.587	0.587	0.560

TABLE 3. AVERAGE SOIL EC IN SEVERAL DEPTHS IN OCTOBER, 1979 AT SEEP A AND B.

		Soil Depth, cm							
		0 To 30		0 To 60		0 To 90		0 To 120	
Treatment	Seep:	A	B	A	B	A	B	A	B
		EC, dS/m							
Soil ridging		4.12	6.83	5.50	7.03	6.46	7.14	6.74	7.06
Straw mulch		3.79	4.09	4.75	4.88	5.88	5.54	6.44	6.03
Gypsum		5.21	5.54	6.37	6.47	7.07	7.05	7.15	7.25
Fallow		4.70	6.64	5.99	7.23	7.06	7.56	7.53	7.56
Check		4.24	6.60	6.65	7.22	7.66	7.98	7.87	8.38
Mean		4.41	5.94	5.85	6.57	6.83	7.05	7.15	7.26
Significant level of F-Value	P=	0.072	0.312	0.002	0.418	0.009	0.393	0.045	0.375

TABLE 4. AVERAGE SAR IN SEVERAL SOIL DEPTHS IN OCTOBER, 1979 AT SEEP A AND B.

		Soil Depth, cm							
		0 To 30		0 To 60		0 To 90		0 To 120	
Treatment	Seep:	A	B	A	B	A	B	A	B
		SAR							
Soil ridging		3.6	2.8	5.8	2.9	7.2	2.9	7.9	2.8
Straw mulch		1.5	1.4	3.5	1.9	5.7	2.1	6.9	2.3
Gypsum		3.6	2.2	5.9	2.8	7.2	3.1	7.7	3.1
Fallow		3.9	3.4	6.3	3.7	8.0	3.7	9.2	3.5
Check		4.2	3.2	7.6	3.4	9.1	3.5	8.9	3.5
Mean		3.4	2.6	5.8	2.9	7.4	3.1	8.1	3.0
Significant level of F-Value	P=	0.164	0.272	0.086	0.355	0.121	0.281	0.274	0.265

that the gypsum treatment was no more effective in reducing the salt content than any of the other reclamation treatments may be because Ca sulfate was already present in large quantities in the soil prior to the reclamation process.

Crop Yields

In 1977, a combination of a droughty growing season (Table 1) and a relatively high level of soil salinity resulted in low safflower yields and no yields for spring wheat, oats, and flax (Table 5). Ceral grain yields from both seep sites were equal to or better than the county averages (reference 14) for 1978 and 1979. Alfalfa forage yields at seep A were considerably higher than the county average, corn silage yields were much lower. Corn silage yields at seep B were near the county average in 1978 (high growing season precipitation) but below average in 1979. County averages for corn silage include irrigated corn; consequently the county averages tend to be higher than the dryland corn yields reported for this study. In 1977, safflower visually appeared to suffer from salt stress at both seep sites; whereas, sunflower appeared to be more tolerant to the relatively higher soil salinity level (Table 2). This observation is supported by data from Holm and Henry (reference 16) and Holm (reference 15). Sunflower yields at both seeps were higher than expected

TABLE 5. YIELDS OF SEVERAL CROPS GROWN IN FORMER ACTIVE SALINE SEEPS A AND B IN 1977, 1978, AND 1979 AND COUNTY YIELD AVERAGES IN 1978 AND 1979 FOR THOSE CROPS REPORTED.

	Seep sites				County average (reference 14)	
Crop	1977*	1978	1979	Average†	1978	1979
	kg/ha					
	Seep A				Richland County	
Spring wheat	—	2,462	1,586	2,024	2,184	1,398
Barley	1,430	4,547	2,135	2,704	2,382	1,333
Oats	—	3,385	1,577	2,481	1,971	1,247
Flax	—	578	477	528	—	—
Sunflower	4,736	708	1,133	2,192	—	—
Safflower	428	120	1,192	580	—	—
Corn (silage)	—	3,363	1,988	2,676	13,440	13,440
Alfalfa	6,297	5,708	9,834	7,280	4,346	3,360
Sweet clover	7,851	—	—	7,851	—	—
	Seep B				Roosevelt County	
Spring wheat	—	2,426	1,781	2,104	1,848	1,270
Barley	1,323	3,861	3,279	2,821	2,091	1,409
Oats	—	5,273	2,175	3,724	1,756	1,247
Flax	—	—	477	477	—	—
Sunflower	4,890	1,196	3,471	3,186	—	—
Safflower	414	1,598	1,170	1,061	—	—
Corn (silage)	—	16,948	3,474	10,211	17,920	11,200

*Drought resulted in crop failure for spring wheat, oats, and flax in 1977. Corn was not grown in 1977.
†Average of those years with yield data reported.

when compared with 1,232 kg/ha obtained on other nonsaline research sites in the area. The high sunflower yields may have resulted from lack of border competition from other sunflower plants. Safflower yields from both seeps in 1979 were near those obtained on nonsaline research sites in the area.

SUMMARY AND CONCLUSIONS

Results from the study suggest that once hydrologic control of saline-seep recharge and discharge areas is obtained, salts will leach from surface soils. At seep site A, where hydrologic control has been maintained since 1975 by annual cropping, the 1982 soil salinity (EC) in the 0- to 180-cm profile in the arrested seep area approached that of a 1971 nonsaline soil profile adjacent to the seep. However, at seep B where much of the recharge area was returned to a crop-fallow rotation in 1979, the 1982 soil profile EC levels increased slightly over the 1979 EC levels. This suggests that the formerly arrested seep B area is being reactivated and that action should be taken to crop the recharge area more intensively.

Time required to reduce soil salinity in arrested dryland seep areas to that of nonseep areas will depend largely on distribution and amount of precipitation. After 7 years, soil salinity in arrested seep areas is still higher than that in adjacent nonseep areas. Application of gypsum did not hasten the reclamation process because large amounts of Ca sulfate were already present in the seep area. During the leaching process, soil permeability and soil structure did not appear to deteriorate. Soluble Na and Mg concentrations declined more than Ca during the reclamation process. Using soil management practices that enhance water movement through the soil profile, such as fallow or fallow plus a surface mulch to reduce evaporation, will probably be more effective in reducing soil salinity than just letting the former seepage area become revegetated with grasses and/or weeds. General trends observed at both sites were for the check (natural revegetation) treatment to have the highest soil salinity in the 0- to 90-cm soil depth and the straw mulch treatment the lowest level of soil salinity.

Crop yield data from the arrested seep areas indicate that normal crop production is feasible in arrested seep areas given sufficient time to reduce the soil salinity level in the 0- to 60-cm soil depth. In this study, crop yields returned to normal in 2 to 4 years after the water-table level had dropped below 120 cm of the soil surface in the seep area.

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