DESALINIZATION OF AN IRRIGATED, MOLE-DRAINED, SALINE CLAY LOAM SOIL

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Desalinization of an irrigated, saline, clay loam soil that had been drained with unlined and lined mole drains, at 0.7 m depth, was determined during a 10-yr reclamation period. Within 5 yr the mean electrical conductivity (EC) of the surface 60 cm of soil, for about one-half of the plot area, had been reduced from greater than 8 to less than 4 dS m^{-1}. The mean EC for the plot area at the 0- to 60-cm and 0- to 180-cm depths declined in a logarithmic order with time. Desalinization of the surface 30 cm of soil was greater under the unlined drain regime than under the lined, but at 30- to 120-cm depths, desalinization was greater under the lined. The salts were mostly sodium, calcium and magnesium sulfates. Although the unlined mole drains had an average discharge of 24% of that from the lined, the average salt discharged through the unlined drains was 80% of that from the lined ones. The lined drains removed more salts over a greater range of depths.

Key words: Desalinization, reclamation, mole drainage, soil salinity

[Désalinisation d'un loam argileux salin, irrigué et drainé par charrue-taupe.]
Titre abrégé: Désalinisation du sol.
La désalinisation d'un loam argileux salin et irrigué, drainé à l'aide de drains en coulée de taupe alignés et non alignés, à une profondeur de 0,7 m, a été déterminée pendant une période de mise en valeur de 10 ans. En moins de cinq ans, la conductivité électrique moyenne (CE) des 60 premiers centimètres du sol, pour environ la moitié de la superficie parcellaire, a été réduite d'un peu plus de 8 à moins de 4 dS m^{-1}. La CE moyenne pour la superficie parcellaire aux profondeurs de 0 à 60 et de 0 à 180 cm a été réduite de façon logarithmique avec le temps. La désalinisation des 30 premiers centimètres du sol est plus prononcée pour les drains alignés que non alignés, mais aux profondeurs de 30 à 120 cm, elle est plus forte pour les drains alignés. Les sels sont, pour la plupart, des sulfates de sodium, de calcium et de magnésium. Bien que les drains non alignés ont un taux d'évacuation moyen de 24% par rapport aux drains alignés, le taux moyen d'évacuation des sels par les drains non alignés est de 80% par rapport à celui des grains alignés. Ceux-ci extraient plus de sels sur un plus grand éventail de profondeur.

Mots clés: Désalinisation, mise en valeur, drainage par charrue-taupe, salinité du sol

Unlined and lined mole drains were used in a drainage reclamation project in southern Alberta. The soil was a saline clay loam (Brown Regosolic fluvial) under irrigation. The effectiveness of the drains in removing excess water after flooding events has been reported (Sommerfeldt 1984), and desalinization of the soil with the two types of drains is reported here.

The leaching efficiency of a soil can be affected by the percolation rate of the water. Solution concentration may increase with a slower percolation rate, and more salts can be leached from the soil per unit of water. According to Talsma (1967) soil desalinization is faster when the soil is subjected to continuous flooding, as compared to alternate flooding. However, with alternate flooding complete desalinization is achieved with considerably less water because of greater leaching efficiency during the falling water table stage than during the flooding stage. Miller et al. (1965) also report greater efficiency of water use with intermittent ponding in desalinizing a soil, although it takes more time. Sommerfeldt (1984) reported that the average discharge per unit area from the unlined mole drains was 24% of that from the lined drains. If the percolation rate was a factor in the leaching efficiency in that soil, that is, the slower the percolation rate the more concentrated the drain water, then one may anticipate that the rate of desalinization of the land drained with unlined mole drains would be greater than the drain discharge rates indicate. The study reported here was carried out to determine the rate and relative effectiveness of the unlined and lined mole drains in the desalinization of the soil in that study.

MATERIALS AND METHODS

Site description and preparation (1967–1969) have been reported previously (Sommerfeldt 1984). In brief, unlined and lined mole drains were used to reclaim a saline (partially saline-sodic), poorly drained, clay loam soil (Brown Regosolic fluvial), with till at 0.6 m depth. The plot area, 100×200 m, was graded to a uniform 1% downslope gradient and 0% lateral gradient. Border dykes were constructed perpendicular to the contours at 7.6-m intervals across the site for gravity irrigation. A supply ditch across the top end of the site provided water for irrigation. Two drain ditches were installed across the lower end of the site, a shallow one to collect runoff water, and a deeper one into which the mole drains discharged. Parshall flumes were used to measure the quantities of water delivered and discharged as runoff. Drain discharge was measured at intervals, using a calibrated container and stop watch. Four sets each of unlined and lined mole drains and three check strips were installed, parallel to the slope. There were three drains to a set, installed at 0.7-m depth. Spacing between the unlined drains was 5.0 m and between the lined drains it was 7.6 m. (One set of adjacent unlined and lined drains failed, leaving a balanced design experiment of three replications of each drain type and three check strips.) The plot area was seeded to tall wheatgrass (*Agropyron elongatum* [Host] Beauv.) in 1969.

The desalinization process, which began in 1970, consisted of regular flooding of the area at 2- to 3-wk intervals, using border dyke irrigation, during the growing seasons of 1970–1979. The total amounts of water applied and runoff were measured. The system was designed to apply the water across the whole plot area in one setting and the runoff from the whole area was collected into one common drain. The average annual application of water applied during the growing season was 77 cm from irrigation (total water applied less total runoff) and 16.5 cm from precipitation.

Drain discharge was measured at the termination of flooding and at predetermined intervals thereafter until the drains ceased to flow. Intervals varied from 6 to 8 h immediately after flooding to every 24 h later in the drainout period (Sommerfeldt 1984). Water samples were collected for analyses each time the drain discharge was measured, to determine electrical conductivity (EC) (Bower and Wilcox 1965), Na and Ca + Mg (Chang and van Schaik 1965), SO_4 (Rasnick and Nakayama 1973), HCO_3 (Bower and Wilcox 1965) and Cl ions (Stout and Johnson 1965).

Each strip, 100 m long, was divided into four, from top to bottom. Soil samples were collected each fall for analyses, at the 0- to 15-cm, 15- to 30-cm, 30- to 60-cm, 60- to 90-cm, 90- to 120-cm, 120- to 150-cm, and 150- to 180-cm depths from the midsection of each quarter, near the central drain. The EC of the saturation extract and the Na, Ca + Mg, SO_4, HCO_3 and Cl ion concentrations in the saturation extract were determined by methods listed above. The data, which had a log normal distribution, were log-transformed and analyzed by analyses of variance.

RESULTS

Before the plot area was established in 1967, the mean EC of the surface 60 cm of soil throughout most of the area was greater than 8 dS m^{-1}; no soil had an EC less than 4 dS m^{-1} (Fig. 1). By 1974 about one-half of the area had an EC of less than 4 dS m^{-1} and about two-thirds of the area had an EC of less than 8 dS m^{-1}. By 1979 the area with

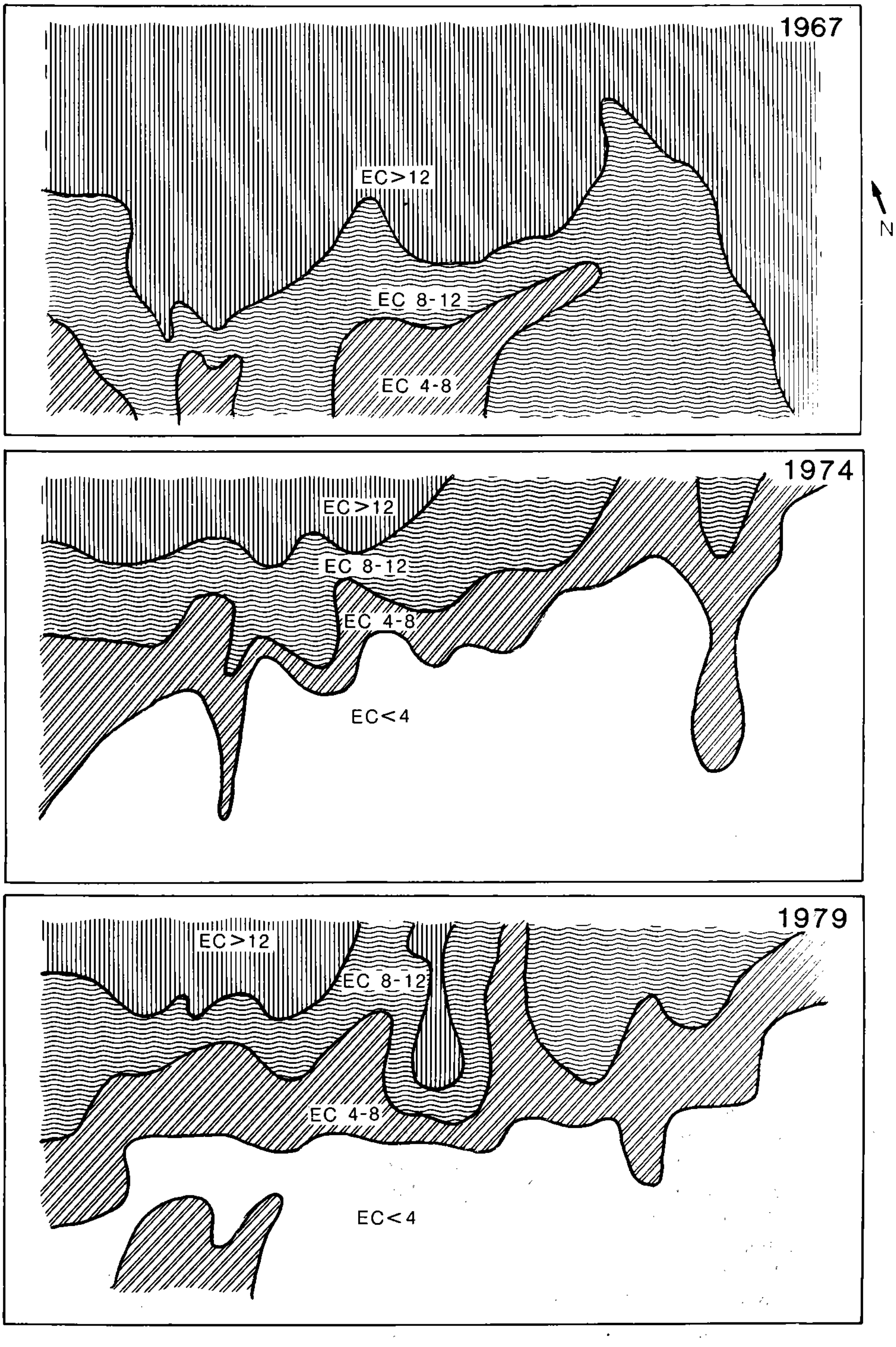

Fig. 1. Salinity of the plot area, as indicated by EC (dS m^{-1}, 0- to 60-cm depth) in 1967, 1974 and 1979. Irrigation was by gravity, flowing from south to north.

an EC of less than 8 dS m^{-1} had decreased slightly, but the level of salinity in that area where the EC exceeded 8 dS m^{-1} had decreased. Desalinization of the surface 60 cm of soil occurred at the upslope side of the plot, the area of lowest EC initially and closest to the irrigation ditch.

This order of reclamation was also indicated by the way in which the vegetation became established. Two years after the reclamation process was begun, fescue grass (*Festuca elatior*) carried in by the irrigation water, dandelion (*Taraxacum officinale* Weber), and Canada thistle (*Cirsium arvense* [L.] Scop.) began to invade the upper areas of the plot and to spread downslope with time. The tall wheatgrass was slow in becoming established in the lower end of the plot area, especially in the northwest corner (Fig. 1, upper left), where salinity was most extreme. At termination of the experiment, vegetation had become established throughout the plot area, but remained sparse in a small area in the northwest corner.

The type of drain as such did not have a significant effect on the leaching of salts from the soil, as indicated by the EC results (Table 1), on the amounts of Na and Ca + Mg leached from the soil, or on the sodium adsorption ratio (SAR). However, there were significant ($P<0.01$) drain-by-depth interactions. Unlined drains were more effective than lined ones in reducing the EC in the surface 30 cm of soil, whereas lined drains were more effective at the 30- to 120-cm depth. Similar responses to the drains were obtained for Na, Ca + Mg and SAR.

Salt removal, derived from EC and drain discharge data, through the unlined drains varied between 68 and 115% of that of the lined drains (Table 2), even though the discharge from the unlined drains was only 24% of that of the lined drains (Sommerfeldt 1984). (The amount of salt removed was that discharged through the drains less the amount applied through the irrigation water.) On two occasions, 1974 and 1977, more salt was discharged from the unlined than from the lined drains.

Table 1. Electrical conductivity of the saturation extract from the soil at different depths (means 1967–1979)

Depth (cm)	Check	Unlined drain	Lined drain	Mean
	(dS m^{-1})			
0–15	4.6	3.3	4.4	4.1*a*
15–30	6.4	5.9	6.1	6.1*b*
30–60	9.3	9.6	8.6	9.2*c*
60–90	9.3	9.6	8.7	9.2*c*
90–120	9.8	9.2	9.0	9.3*c*
120–150	10.4	9.3	9.6	9.8*c*
150–180	10.7	9.3	9.9	10.0*c*

Depth and depth × drain significant at the 0.01% level of probability.
a–c Means with the same letter are not significantly different ($P<0.05$) according to Duncan's multiple range test.

Table 2. Salt leached from the soil each year, derived from EC of the drain water and drain discharge data

Year	Number of floodings	Drain Unlined	Drain Lined	Unlined/ lined
		(t ha^{-1})		(%)
1970	6	5.6	6.6	84
1971	7	2.7	4.0	68
1972	6	4.2	5.5	75
1973	7	6.6	7.5	88
1974	7	7.7	6.7	115
1975	5	3.6	5.2	69
1976	6	5.4	5.7	95
1977	6	3.1	2.8	111
1978	4	1.2	1.6	77
1979	5	0.4	2.8	14

Drain water quality was poorest in the beginning years of the reclamation process and improved with time to termination of the study, of which data for 2 yr, 1970 and 1979, are reported (Table 3). In 1970, the water quality from the lined drains at peak and at cease flow was better than that from the unlined drains. In 1979, the water quality from the lined drains at peak flow was better than that from the unlined drains, but at cease flow it was worse. Relatively more Na was leached from the soil than Ca and Mg, such that the SAR was reduced with time, the greatest reduction being with unlined drains. Also, the drain water quality was best immediately after the flooding stopped and

Table 3. Summary of mean drain water quality in 1970 and 1979 at peak and cease flow, after flooding events, illustrating changes with time

	Drain			
	Unlined		Lined	
Component	1970	1979	1970	1979
EC (dS m^{-1})				
At peak flow	26.6	4.6	5.9	1.4
At cease flow	32.9	4.9	21.0	10.1
Na (mmol L^{-1})				
At peak flow	330.0	33.6	53.4	6.9
At cease flow	444.3	35.0	224.8	91.9
Ca + Mg (mmol L^{-1})				
At peak flow	61.6	11.4	13.0	7.6
At cease flow	121.5	13.5	68.9	27.6
SAR				
At peak flow	35.9	10.0	11.7	3.5
At cease flow	40.2	9.3	28.4	16.0

deteriorated with time until drainage ceased. However, the differences in quality between peak and cease flow were least with unlined drains.

The mean initial (1967) salt distribution in the soil for the plot area was fairly evenly distributed throughout the profile, except in the 0- to 15-cm depth (Table 4, 1967). Salts were leached from the 180-cm profile in the first year of flooding, but the greatest effect was in the surface depths.

By 1973 the EC of the surface 0–15 cm of soil was reduced to less than 4 dS m^{-1} (Table 4), and remained below that level throughout the remainder of the experiment, except in 1979. Below this depth the EC decreased slowly. By 1977 it was less than 8 dS m^{-1} to 180 cm, two and one-half times deeper than the depth of the drains, because of radial flow of the leaching water to the drains.

The rates of desalinization in the surface 60 cm and in the 0- to 180-cm depths of soil followed logarithmic functions for all components (Table 5). Desalinization, which was most rapid in the beginning and decreased with time, was more rapid in the surface 60 cm than in the 0- to 180-cm depth. The relative amounts of Na and Ca + Mg leached

Table 4. Mean electrical conductivity of the saturation extracts from the soil at different depths in 1967, before reclamation began, and annually in the fall, after the season of leaching (Mean of plot area — 44 samples)

Depth (cm)	Year										
	1967	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
	(dS m^{-1})										
0–15	6.8	4.7	5.5	4.1	2.8	3.9	3.6	3.7	2.7	3.5	4.2
15–30	13.6	6.5	8.0	6.5	4.5	5.0	4.5	5.3	4.1	4.5	5.2
30–60	17.2	14.0	12.9	11.3	7.6	6.7	6.8	6.6	5.6	5.5	6.7
60–90	15.4	12.2	13.0	11.3	8.1	8.1	7.7	7.4	6.1	5.6	6.5
90–120	13.8	12.2	12.8	11.1	8.7	8.1	8.0	8.0	6.2	5.9	7.7
120–150	13.2	12.4	12.4	11.7	9.1	9.1	8.8	8.5	7.0	6.8	8.6
150–180	12.5	11.9	12.4	11.0	9.6	9.9	9.2	9.2	8.0	7.4	8.6
Mean	13.2	10.6	11.0	9.6	7.2	7.3	6.9	7.0	5.7	5.6	7.1
	a	*ab*	*ab*	*abc*	*bc*	*bc*	*bc*	*bc*	*c*	*c*	*bc*

Depth, year, depth × year, significant at the 0.01% level of probability.
a–c Means with the same letters are not significantly different ($P < 0.05$) according to Duncan's multiple range test.

Table 5. Regression equations for changes in EC, Na, Ca+Mg and SAR at the 0- to 60- and 0- to 180-cm depths, during reclamation

Depth (cm)	Equation†	Coefficient of correlation (r)
0- 60	Ln EC = 2.48 − 0.105t	−0.9442
0-180	Ln EC = 2.55 − 0.086t	−0.9611
0- 60	Ln Na = 4.68 − 0.120t	−0.9145
0-180	Ln Na = 4.73 − 0.097t	−0.9480
0- 60	Ln (Ca + Mg) = 3.44 − 0.106t	−0.8671
0-180	Ln (Ca + Mg) = 3.47 − 0.085t	−0.8943
0- 60	Ln SAR = 2.82 − 0.069t	−0.8709
0-180	Ln SAR = 2.93 − 0.054t	−0.9430

† Where t gives the number of years: 1 (1970) to 10 (1979) and 0 is 1969, before reclamation began (assumed to be 1967).

from the soil were such that the SAR also was reduced with time.

The soil salts, over years, were 95 ± 1% sulfate, 4.5 ± 1% bicarbonate and 0.5% chloride. The concentration of sulfate ions increased with depth, similar to the EC distribution. Most of the bicarbonate ions were concentrated near the surface of the soil and the chloride ions were fairly evenly distributed throughout all depths.

DISCUSSION

The order of desalinization, beginning at the upslope side of the plot area, is logical. The salinity in this area initially was less than that downslope and the intake rate and permeability (not measured) could have been greater than that downslope, because of better soil physical conditions, which allowed more leaching. Also, flooding always started at the upslope position and more water was applied there than downslope.

As indicated by drain discharge, more water apparently percolated through the soil with the lined drain regime than with the unlined drains. (Mean drain discharge, per unit area, from the unlined drains was 24% of that from the lined drains (Sommerfeldt 1984).) Water conduction in the unlined drains was less than in the lined, probably because the unlined drains were partially collapsed. This limited their drainage rate, resulting in slower water movement through the soil. Slower percolation of water in the soil with the unlined drains would favor solution of more salts than in the soil drained by lined drains, causing the differences in quality of water from the two drains. From this study one can conclude that the unlined drains were more effective in desalinizing the surface 30 cm of soil (Table 1), while the lined drains were more effective in desalinizing the soil in the 30- to 120-cm depth, because of greater depth of radial flow. But, averaged over the whole 180-cm depth, one drain was as effective as the other.

The relative effectiveness of the drains in removing salts varied with time. In 1970 the water quality from the lined drains was at all times better than that from the unlined drains. In 1979, the water quality from the lined drains was better than that from the unlined at peak flow, but at cease flow it was worse. This reversal is attributed to more salts being leached from the soil at the 60- to 120-cm depth with the lined drains than with the unlined drains because of greater depth of radial flow.

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