

Leaching Behavior of a Salinized Field in the Lower Reaches of the Syr-Darya River, Kazakhstan

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Abstract: In the lower reaches of the Syr-Darya River vast land areas have become wet deserts because of salinity problem as a consequence of rice-based cropping system. To investigate the reclamation strategy for such areas, one field was leached twice and cultivation trials, using furrow irrigation, were conducted after the leaching. The salinity (EC_e) of 0 to 20 cm surface soil was decreased by leaching from 71.2 to 7.9 $dS\ m^{-1}$. The groundwater level during trial was at 1 to 2 m depth. The EC_{gw} values in the studied area varied from 3.2 to 87.9 $dS\ m^{-1}$, and were almost constant regardless of the irrigation for cultivation. The mean EC_e value at 20 to 25 cm depth in the trial field after cultivation was 6.0 $dS\ m^{-1}$, while values in non-leached arable and abandoned fields were 12.7 and 50.0 $dS\ m^{-1}$, respectively. The values increased with decreasing soil depth. In the trial field, correlation coefficients between the clay content and EC_e values were high at the same depth at 0.77* at 20 to 25 cm and at 0.87* at 60 to 65 cm. In the non-leached fields, correlation coefficients between the clay content at 90 to 95 cm depth and EC_e values at each depth studied (20-25, 60-65 and 90-95 cm) were high. These results showed that (1) leaching was effective in reclaiming fields in this area, (2) upland crop-based furrow irrigated agriculture can replace rice-based rotation, and (3) installing subsurface drainage systems at approximately 100 cm depth is required.

Key words: Electrical conductivity, clay content, groundwater, leaching, saline soil.

Large-scale rice paddy fields have been developed in the lower reaches of the Syr-Darya and Amu-Darya Rivers since the early 1960s. However, deterioration of the environment due to excessive water use from these rivers and desertification caused by soil salinization in this region is in progress since the late 1980s (USSR-UNEP, 1990). The large volume of water used for irrigating paddy fields also served as subsurface irrigation for upland crops adjacent to paddy fields and contributed to the leaching of salts accumulated during the cultivation of upland crops (Tsutsui

and Ogino, 1995). Shallow groundwater tables hustled in salt accumulation around the paddy fields that eventually led to abandonment of fields (USSR-UNEP, 1990). According to Khakimov (1989), 60 to 70% of the soil in the irrigated area is classified as moderate to severely affected by salinity in Kazakhstan. Desertification caused by salinity not only decreases agricultural production, but also deteriorates the health of local people and destroys the ecosystems in the Aral Sea basin (USSR-UNEP, 1990; Mainguet, 1991; Tsutsui, 1993).

Many studies have reported that reclamation of salt-affected soil requires leaching of the salts accumulated on the surface soil to below the root zone (Ayers and Westcot, 1985; Hoffman, 1986; Rao and Leeds-Harrison, 1991). Such reclamation relies on subsurface drainage, which allows the removal of salts with leaching water (Ayers and Westcot, 1985; Faltas and Willardson, 1992; Hoffman and Durnford, 1999; Letey, 1999; Oster *et al.*, 1999; Kelleners *et al.*, 2000). Effects of subsurface drainage in reclamation are established (Hachicha *et al.*, 2000; Sharma *et al.*, 2000; Mathew *et al.*, 2001). Rao and Leeds-Harrison (1991) stated that influence of the reclamation method on the quantity and quality of the drainage water must be understood, and these authors and Kelleners *et al.* (2000) reported the results obtained from simulation studies. In arid and semi-arid areas the groundwater salinity and level of water table during cultivation after leaching are also important. Tsutsui and Ogino (1995) suggested that to solve the agricultural problem in the lower reaches of the Syr-Darya River the efficiency of applied water, i.e., proper surface irrigation for non-rice crops, would be necessary to avoid dependence on subsurface irrigation.

The major objective of the present study was to find a strategy to reclaim the fields abandoned because of salt accumulation, and to test the possibility of cropping using furrow irrigation to replace the current paddy-based crop rotation system. This paper also shows the effect of the leaching of salts to reclaim the field and its influence on groundwater table and salinity levels at the Shamenov Kolkhoz on the lower reaches of the Syr-Darya River.

Materials and Methods

Description of the study areas

Trials were conducted at the Mechet irrigation block in Shamenov Kolkhoz, located in the lower reaches of the Syr-Darya River, Kzyl-Orda region, Kazakhstan, in 1997 and 1998. The Kolkhoz was composed of four main irrigation blocks: Hatos, Mechet, Sartaban, and Yeltai. The abandoned fields in the Kolkhoz were about 600 ha of the 1600 ha total area because of high salinity during 30 years of irrigated agriculture involving paddy-based crop rotation system (personal information from Director of Shamenov Kolkhoz, Shamenov U.). Rice paddy and pasture are rotated within each irrigation block, and pastures are usually not irrigated. The trial field was developed in 1976, but was abandoned in 1978 after two years of cultivation.

The area belongs to the inland climate type of the Eurasian continent. According to the data of the Kzyl-Orda branch office of Kazakhstan meteorological agency, the mean temperature in summer is 27°C with a maximum of around 42°C, while the mean temperature in winter is -5°C with a minimum of around -28°C. The average annual precipitation is around 200 mm.

Layout of the study fields

Figure 1 gives details of the experimental layout and surroundings of the trial field. The field (designated as A) was divided into three blocks, with each further sub-divided into sections, I, II, III and IV. The A block in the left side was continually irrigated for leaching and cultivation; the other two blocks in the right were not irrigated. In the arable land (B) alfalfa was

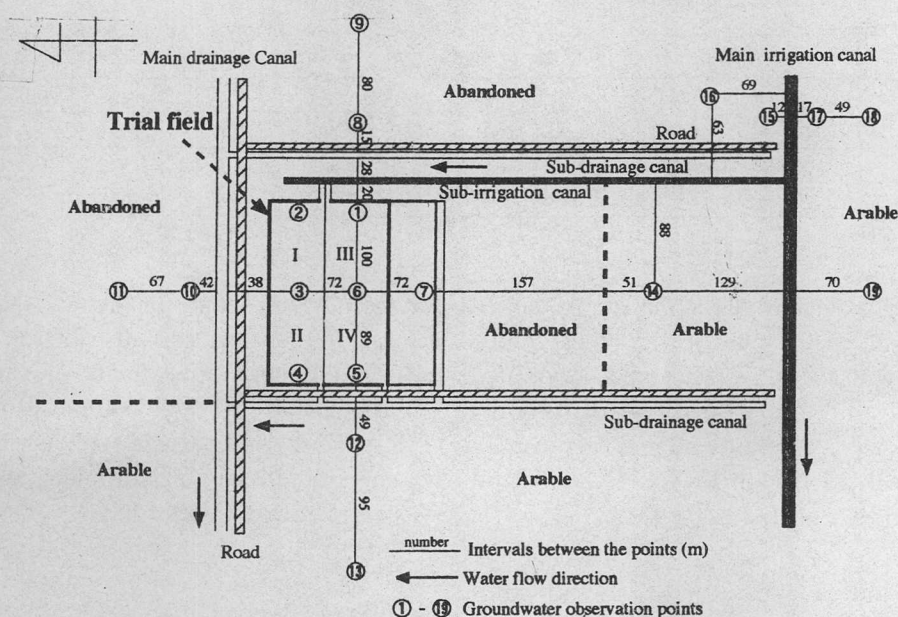


Fig. 1. Map of the study area showing the observation points for groundwater table and salinity levels, and intervals in meters between the points.

successively cultivated since 1996 under rotation. The abandoned lands around the trial field were designated as C. The trial field was approximately 2.5 ha (174 x 144 m²). A 2 m wide sub-irrigation canal was on the east side, and a 5 m wide sub-drainage canal was on the west side, which was connected to a main drainage channel (13 m wide and 1.8 m deep, laid from east to west on the north side). Irrigation water was taken from the Syr-Darya River at about 50 km upstream.

The trial field (A) was leached twice by ponding of 20 to 30 cm irrigation water on August 20, 1997 and on June 8, 1998. Ten upland crops were cultivated in the abandoned field after leaching from July 1 to October 11, 1998. The field was furrow-irrigated from June 29 to September 10, 1998. The furrow-irrigation was practiced at 3-day interval for the first two weeks

and then at 2-week interval during rest of period.

The electrical conductivity of the irrigation water (EC_{iw}) and of the drainage water (EC_{dw}) was measured during every irrigation. The mean EC_{iw} of the sub-irrigation canal water during the irrigation period was 1.8 dS m⁻¹ with a range from 1.5 to 1.9 dS m⁻¹. The accumulated salt was mostly sodium chloride and sodium sulphate (Table 1). Irrigation water was also sodium salt-dominant.

Nineteen observation points, designated with circled numbers, were chosen for measuring the levels of the groundwater table and the electrical conductivity of groundwater (EC_{gw}) within and outside the field (Fig. 1). Points 1 to 7 were in the trial field (A), points 8 to 11, 15 and 16 were in the abandoned land (C), and the

Table 1. Mean of the EC_e , pH and ion composition of the saturated soil extract at each groundwater observation point (shown in Fig. 1) and of the irrigation water

	EC_e ($dS\ m^{-1}$)	pH	Cation ($mmol_c\ L^{-1}$)					Anion ($mmol_c\ L^{-1}$)		
			Na^+	K^+	Mg^{2+}	Ca^{2+}	TSC*	Cl^-	SO_4^{2-}	TSA**
Soil	38.4	7.8	501.2	3.5	124.0	28.8	657.5	226.5	425.0	651.5
Irrigation water	1.8	7.7	15.6	0.7	11.6	7.7	35.6	11.6	22.2	33.8

*total concentration of soluble cations; **total concentration of soluble anions.

remaining points were in the arable land (B). Plastic pipes with drilled holes and covered with cloth, were installed 3 to 3.5 m deep to record observations on groundwater. Groundwater levels were measured daily while the EC_{gw} was measured on alternate days.

Five soil samples at 0 to 20 cm depth from each of I to IV sections were drawn before and after leaching treatment. The samples of each section were mixed before analysis of salinity. Other soil samples from A, B and C were taken from different soil profiles at harvesting time on October 9, 1998. Fourteen soil samples were taken at 20 to 25 and 60 to 65 cm depth from points 1 to 7 in the trial field. Thirty-three soil samples from the other 11 points at 20 to 25 cm, 60 to 65 cm and 90 to 95 cm depth were also taken. These samples were air-dried and ground to pass through a 2-mm sieve. Soil salinity (EC_e , electrical

conductivity of saturation extract of soil), pH and the particle size distribution were measured. Saturation extracts of samples were obtained using the method of Rhoades (1982) and the soil particle size distribution was measured using a hydrometer method (Gee and Bauder, 1986).

Results

Table 2 shows the effect of leaching on the EC_e values at 0 to 20 cm depth in each of sections I to IV of the leached field during 1997 and 1998. Leaching was especially effective in 1997. The EC_e values were reduced from preceding leaching value of 71.2 to 6.0 $dS\ m^{-1}$. The values for 1998 were 16.8 and 7.9 $dS\ m^{-1}$, respectively. The pH values of the soil in the leached field before and after leaching were 8.1 and 8.5, respectively, in 1997 and were 8.1 and 8.0, respectively, in 1998.

Table 2. EC_e values ($dS\ m^{-1}$) at 0-20 cm depth of each section before and after leaching in 1997 and 1998

Section	1997		1998	
	8/18*	9/14**	6/6*	6/20**
I	71.5	5.0	13.6	7.8
II	81.1	6.1	19.6	10.1
III	80.6	7.2	24.1	7.2
IV	51.5	5.8	10.0	6.4
Mean	71.2	6.0	16.8	7.9

*before leaching; **after leaching.

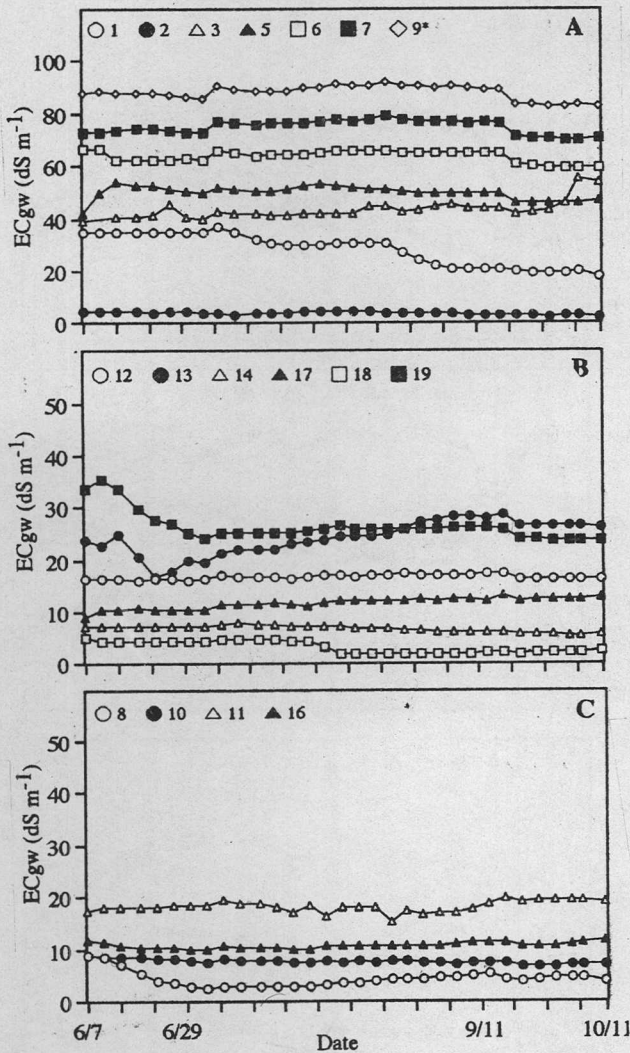


Fig. 2. EC_{gw} at 17 points related to time: (A) leached field except for point No.9; (B) non-leached arable land; (C) non-leached abandoned land (6/7) at the beginning of leaching; (6/29) the beginning of furrow irrigation; (9/11) the end of furrow irrigation; point No. 9 belongs to group C.

Figure 2 shows the periodic values of EC_{gw} at 17 of 19 observation points during the trial in 1998 (No. 4 and 15 were discarded because of accidents). The 17 points were

grouped according to whether they were in A trial field (except No. 9 with the highest value), in B arable land, or in C abandoned land.

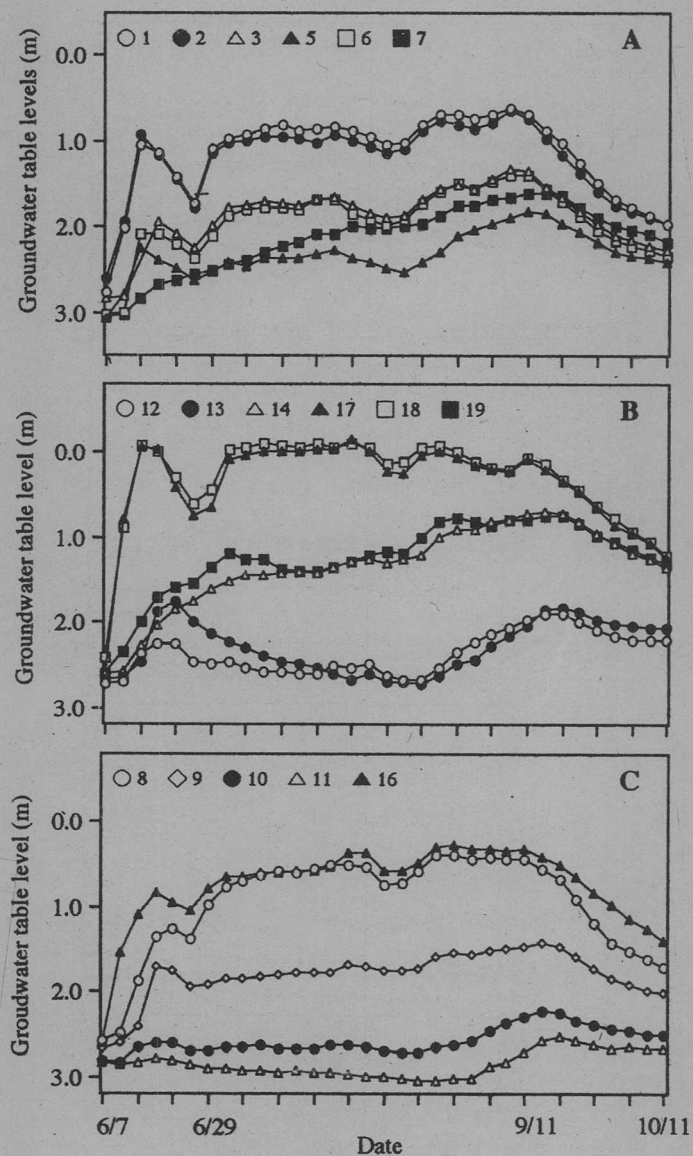


Fig. 3. Groundwater table levels at 17 points related to time: (A) leached field; (B) non-leached arable land; (C) non-leached abandoned land.

The EC_{gw} values varied widely from point to point, and were almost constant throughout the trial, although irrigation for the cultivation experiment was applied. The

pH values at the 17 points were 7.5 to 8.0. The EC_{dw} values of water in the main drainage canal varied between 4 and 8 $dS m^{-1}$ throughout the trial.

Table 3. EC_e values and clay and sand contents for the given depths at 17 observation points on October 9 after harvest

Group ^a	No. ^b	EC_e (dS m ⁻¹)			Particle size distribution (%)					
		Depth (cm)			Clay			Sand		
		20-25	60-65	90-95	20-25	60-65	90-95	20-25	60-65	90-95
A	1	8.8	10.5	-	35.7	16.5	-	38.3	49.5	-
	2	6.9	4.3	-	19.5	15.7	-	56.7	77.8	-
	3	8.3	4.7	-	29.1	25.5	-	41.3	20.1	-
	4	3.8	4.7	-	17.7	15.3	-	76.9	59.2	-
	5	6.2	23.2	-	22.2	47.7	-	69.0	10.7	-
	6	3.4	4.2	-	22.4	20.9	-	72.4	48.7	-
	7	4.9	11.4	-	19.5	29.1	-	70.1	31.9	-
	Mean	6.0	9.0	-	23.7	24.4	-	60.7	42.5	-
B	12	18.8	12.2	7.2	40.1	33.3	16.8	34.3	11.0	64.4
	13	8.2	2.4	2.8	35.7	14.1	14.6	24.0	83.9	83.8
	14	9.7	6.8	7.2	33.4	53.9	9.3	44.1	3.1	87.9
	18	4.6	3.1	3.5	31.4	33.2	6.9	26.9	7.2	88.8
	19	22.4	18.0	16.3	39.6	40.3	13.6	25.9	7.3	67.3
	Mean	12.7	8.5	7.4	36.0	35.0	12.2	31.0	22.5	78.5
C	8	56.0	57.0	23.7	31.8	25.2	18.2	44.7	43.6	56.5
	9	58.8	43.7	52.4	35.9	53.2	38.3	35.2	3.5	10.7
	10	41.3	54.6	22.1	28.8	19.8	23.6	50.2	40.6	42.9
	11	51.4	41.3	30.6	38.2	33.6	23.7	27.2	25.9	44.1
	16	42.7	28.4	27.3	37.0	55.1	25.4	35.7	11.1	44.2
	Mean	50.0	45.0	31.2	34.3	37.4	25.8	38.6	24.9	39.7

-: no data; a: (A) trial field; (B) non-leached arable fields; (C) non-leached abandoned fields;
b: same as shown in Fig. 2.

Figure 3 shows the fluctuations in the levels of groundwater table with time at the 17 points during the trial. About one week after leaching began, the groundwater table near irrigation canals (Nos. 1 and 2 in A, Nos. 17 and 18 in B, and Nos. 8 and 16 in C) reached levels of less than 1.0 m from the soil surface and maintained these levels until the irrigation was stopped. At other points the groundwater levels responded with distinctive patterns, depending on distance from the canal. But

the levels of EC_{gw} and the groundwater table showed no relationship.

Table 3 shows the EC_e values and clay and sand content at different soil depths at the 17 observation points. In A trial field, the EC_e values at 20 to 25 cm depth were almost the same as at lower levels of less than 8.8 dS m⁻¹. The EC_e values at 60 to 65 cm depth were higher for both the mean values and the variation than the upper EC_e values. In B the mean

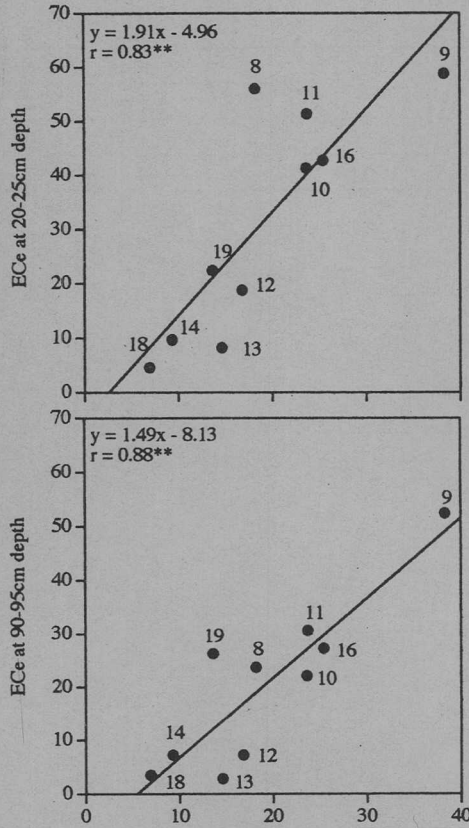


Fig. 4. Relationships between clay content at 90-95cm depth and EC_e values at different depths in non-leached fields (B and C).

EC_e values at 20 to 25 cm depth was twice as high as in A and in C it was 8.5 times as high as in A. The EC_e values generally increased with decreasing soil depth: the EC_e values at 20 to 25 cm depth were approximately 70% higher than at 90 to 95 cm depth. Details of the pH data were omitted here, but were almost the same (pH 7 to 8) throughout the area. The particle size distribution at different soil depths differed markedly between the 17 points. The distribution at 20 to 25 cm and 60 to 65 cm depths in the leached

field (A) showed a lower clay and a higher sand content than at the same depth in the non-leached fields (B and C). Also interesting is that at 90 to 95 cm depth the clay content in B was almost half of that in C and vice versa for the sand content, but no differences were found in the clay and sand contents at the two upper depths.

The relations between the variables of Table 3 were completely different in the leached experimental field (A) and in the non-leached fields B and C. In the

experimental field A, significant relationships were between the EC_e and clay content at the same depth, with correlation coefficients of 0.77* at 20 to 25 cm depth and 0.87* at 60 to 65 cm depth. B and C fields had highly significant relationships between the EC_e values at the three depths studied and clay content at 90 to 95 cm depth. Fig. 4 shows the EC_e related to the clay contents at 90 to 95 cm depth (at 60 to 65 cm the coefficient was 0.68*). The EC_e values at 20-25 cm depth were highly correlated with the EC_e values at the other two depths, 0.92** at 60 to 65 cm and 0.83** at 90 to 95 cm depth. The levels of groundwater salinity or water table showed no relationship with EC_e values.

Discussion

A saline field in the lower reaches of the Syr-Darya River was reclaimed. It was first of its kind in Kazakhstan. We report here effect of the leaching when crops are raised under furrow-irrigation to reclaim the abandoned field, to improve water application efficiency or to reduce environmental deterioration due to excessive irrigation water. Data were collected from the experimental field A (leached and cultivated) and neighboring field B (alfalfa cultivated in a rotation system) and abandoned field C.

Experimental field A was leached once in 1997 and in 1998. The first leaching was so effective that the salinity was reduced to a mean 6.0 from 71.2 $dS\ m^{-1}$. In fine textured soils, about 70% initial salt can be removed by continuous ponding if the depth of water leaching through the profile equals the depth of soil reclaimed (Hoffman,

1986). In our leaching trial in 1997, more than 90% of the initial salt was removed by ponding at 1.5 times the depth of the water (30 cm) leaching through the soil profile of 0 to 20 cm depth. But the second leaching was not as effective: from 16.8 to 7.9 $dS\ m^{-1}$ (Table 2). The leaching effectiveness was reduced possibly because the subsurface drainage rate, depending on the soil permeability, might have been worsened because of clay deposition in the deeper soil layer, resulting from the first leaching.

The EC_{iw} of less than 2 $dS\ m^{-1}$ in the irrigation canal water was within the normal salinity level. However, the EC_{gw} in the experimental area was markedly different among the points and changed little throughout the trial. The groundwater salinity levels were classified according to the classification of saline waters by Rhoades *et al.* (1992). The highest class of brine or seawater was at the three worst points (Nos. 6, 7 and 9) having more than 45 $dS\ m^{-1}$. But most groundwaters in the experimental area were in the moderately saline class (2-10 $dS\ m^{-1}$) to highly saline class (10-25 $dS\ m^{-1}$) that are usually found in drainage water and groundwater. The reasons for variations in groundwater salinity could be many. In the lower reaches of the alluvial plain of the Purna Basin of India high amount of clay might have acted as a deterrent to flushing, resulting in high salinity levels of aquifers (Muthuraman *et al.*, 1992). The salinity of groundwater in a farm area in western Rajasthan, India, was found to vary because of differing contributions of canal water (Sundara Sarma *et al.*, 1993). In our area,

as shown in Table 3, extremely heterogeneous soil texture perhaps resulted in varying EC_{gw} values.

Data from experimental areas B and C provided information on the natural processes of salt accumulation. Data from experimental field A showed the leaching effects on salinity when furrow irrigation was started in the abandoned fields. Increased EC_e values with decreasing soil depth in B and C might have resulted from upward movement of saline water from the deeper soil or groundwater. Decreasing EC with increasing depth suggested that upward movement of water, including salt from shallow groundwater, was dominant (Chang *et al.*, 1988). However, in this study no relationships were found between EC_e values at 20 to 25 cm deep soil, levels of the groundwater salinity and the groundwater table.

Comparing the data of fields B and C (Table 3) also revealed that a low clay or high sand content at 90 to 95 cm depth might prevent salinization in the upper layers in this area. The obvious differences between them were a half clay content and a double sand content at 90 to 95 cm depth in the arable land (B) compared with those in the abandoned land (C) that had a high EC_e at 20 to 25 cm depth of more than 40 dS m^{-1} . In the leached A field, the EC_e values were related with clay content at the same soil depth. Thus, upper soils of more than 65 cm depth with a higher clay content generally had higher EC_e values. In the Taber Irrigation District, southern Alberta, a high soil salinity level was associated with a higher groundwater table and high clay content, suggesting that the relative permeability of the soil is important in affecting soil salinity because of the higher

clay content and lesser permeability of the soil (Chang *et al.*, 1985).

As a high clay content in lower soil layers can be considered to be important in soil salinization in our study area, installing effective subsurface drainage systems should be planned to counter salinization. Drainage is necessary because a salinity problem caused by poor drainage can not be adequately controlled until the water table is stabilized and is maintained at a safe depth – usually at least two meters (Ayers and Westcot, 1985). From an analysis of the causes of successful reclamation of 3000 ha salt-affected land caused by shallow groundwater in Kalaat Landelous of the northern Tunisia, Hachicha *et al.* (2000) concluded that installed subsurface drainage systems are effective in desalinizing land and that maintaining an efficient drainage system is necessary to keep the salinity levels low in the soil.

As shown in Table 3, furrow-irrigated agriculture is a good method to prevent soil salinization during cultivation after leaching. Therefore, our recommendations to sustain agriculture in the lower reaches of the Syr-Darya River are to replace the current paddy-based rotation system with upland crop-based furrow irrigation agriculture, and to minimize the use of irrigation water supplied from the Syr-Darya River. Furthermore, installing a subsurface drainage system below 100 cm depth helps to prevent salt from rising by capillarity.

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