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A Practical Desalinization Model for Large Scale Application

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ABSTRACT

Salinity of soil and water is the most important agricultural hazard in arid and semi-arid regions. In saline soils, yield production directly influences by soluble salts in the root zone as well as by shallow water table depth. The first step for reclamation of such soils is reducing salinity to optimum level by leaching. The objective of this study was to develop a practical model to estimate water requirement for reclamation of saline-sodic soils at large scale based on some obtainable soil physical characteristics. Consequently, a large area of 3,216 ha with S_4A_3 salinity/sodicity class (extreme salinity and sodicity) was selected to obtain the required data. Several mathematical models were applied to the collected data to verify their estimation capability. The results indicated that at large scale, the proposed logarithmic model can provide much better estimates for leaching process than the previously proposed models.

Keywords: Desalinization; Reclamation requirement; Saline-sodic soils; Salt leaching

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INTRODUCTION

Large areas in arid and semi-arid regions are imposed to salinity or both salinity and sodicity. From water consuming point of view, the saline or saline-sodic soil needs more irrigation water to produce reasonable agricultural products. Unfortunately, enough water is not always available in such areas. Considering the poor quality and improper use of water for agriculture, salinity has caused gradual reduction in soil quality of these regions.

It is obvious that soil and water salinities are the main limiting factors affecting crop production in arid and semi-arid regions. This may lead to an extra yield reduction when coupled with water scarcity (Homaee & Schmidhaiter, 2008; Homaee *et al*., 2002). In arid and semi-arid areas of Iran, the main reason for salt accumulation in soils is water scarcity (Pazira & Homaee, 2010). Low annual precipitation in these regions is far less than what is needed to leach out the excess salts from soil profile. Consequently, most soils in these areas have the potential to tend to salinity or to both salinity and sodicity. However, salinization may also result from presence of high amount of salts contained in the parent materials from which the soils are formed (Pazira & Homaee, 2010). A reasonable crop production in these soils can only be obtained after desalinization practices. The most practical method for soil desalinization is salt leaching by application of water either with or without soil amendments. This can be achieved by applying enough water on soil surface to infiltrate into subsurface drains or to deeper soil layers (Pazira & Homaee, 2010).

Although numerous research have been conducted to investigate different aspects of soil salinity (Corwin *et al*., 2007; Ben-Gal *et al*., 2008; Cote *et al*., 2000; Konukcu *et al*., 2006; Homaee & Schmidhalter, 2008; Homaee *et al*., 2002 a. b. c. d), most of them are related to plant responses to salinity rather than desalinization process (Pazira & Homaee, 2010; Hendrikus Barnard *et al*., 2010).

Although the inevitable way of soil desalinization is salt leaching from the root zone, practically considerable amount of water is required to leach out excess salts from the root zone. If the natural soil drainage condition is not suitable, applying such amount of water will build up more salinity, unless a subsurface drainage system is established. To assess soil desalinization, one may conduct a set of experiments in laboratory by using some physical models, but the application of results obtained from such experiments in field scale is difficult. Consequently, conducting field desalinization experiments are still needed to fulfill the natural requirements (jurinak, 1981).

In saline soils, plant response to salinity directly influences by salt contents within the root zone as well as by water table depth. Soil desalinization not only depends on quantity of applied leaching water, but also strongly related to its quality as well as to internal soil drainage conditions. Even after initial/capital leaching and when the soil is under cultivation, some more extra water than the plant consumptive use is needed to leach out the remained salts in the soil, as well as the salts entered by irrigation practice.

Reclamation of saline-sodic soils may require some amendment materials such as gypsum, sulfuric acid, elemental sulfur or calcium compounds to replace sodium ions.

From mathematical point of view, the experimental leaching models can be categorized either as Hyperbolic (Leffelaar & Sharma, 1977; Hoffman, 1980; Pazira & Kawachi, 1981; Mohsenifar *et al*., 2006), Power form (Verma & Gupta, 1989; Pazira & Keshavarz, 1998) or Exponential functions (Dieleman, 1963; Rajabzadeh *et al*., 2009).

Previously, several experimental and theoretical models have been developed and verified to estimate the quantity of water required for soil reclamation (RR) in Khuzestan province, Iran. But all these models due to their limited range of applications could not provide reasonable recommendations for large scale soil reclamation in that area. Considering the weakness of previously suggested models, this area was selected to take necessary measures to conduct comprehensive experiments and to propose a practical model in which the main contributing factors are taken into account. Such a model should be able to predict the optimal reclamation water by means of some collectable soil and environmental parameters. The objectives of this study were to investigate the accuracy and validity of the previously proposed models and to propose a new model for estimating water requirements for capital leaching to desalinize these soils.

MATERIAL AND METHODS

To collect the required data, intensive sets of large scale experiments were conducted in Amishiyeh soil series of Khuzestan plains, Iran. The study area is located in the south Khuzestan province which covers an area of 22,500 ha. This area is located between 48°, 20' and 48°, 38' East longitude, and 31°, 51' and 31°, 55° North latitude. Average long term annual temperature and rainfall are 24.9°C and 252.1 mm, respectively. The soil temperature regime is Hypertermic and the soil moisture regime is Aridic (Torric). The soil order was categorized as Entisols, with the texture varied from Silty-Clay to Silty-Clay-Loam, having massive structure. According to soil survey and land classification studies, the salinity (S) and sodicity (A) of this area was classified as S_4A_3 (extreme salinity and sodicity). Over 96 percent of the study area has salinity and sodicity limitations. To conduct the experiments, a large saline-sodic area of 3,216 ha (14.35% of the total area) was selected by primary investigation of soil salinity maps. Some physical properties of experimental soil layers before applying any leaching water is presented in Tables 1 and 2.

Table1: Some major properties of experimental site

Soil series	Salinity and Sodicity Class	Depth of Water Table (m)	Hydraulic Conductivity (m/day)	Depth of Impervious Layer (m)	Basic Infiltration Rate Before Leaching (cm/hr)			Descriptive Notation
					First rep.	Second rep.	average	
Amishiye	S_4A_3	2.80	0.60	> 6.00	0.37	0.59	0.48	Slow

Table2: Some physical characteristics of the soil layers before leaching

depth (cm)	Soil texture	Soil moisture (%)			Bulk density	Real density	Total Porosity (%)	Permeability		Moisture deficit (cm)	
		PWP	M	FC	gr/cm^3			Rate (mm/hr)	Descriptive Notation	Layers	Cumulative
0-25	SiCL	14.49	5.7	21.94	1.46	2.71	46.13	0.59	M.S	5.93	5.93
25-50	SiCL	14.96	12.9	21.3	1.6	2.7	40.75	0.87	V.S	3.36	9.29
50-75	SiC	15.36	13.1	20.67	1.65	2.7	38.89	0.20	V.S	3.12	12.41
75-100	SiC	15.36	15	20.67	1.65	2.7	38.89	0.20	V.S	2.34	14.75
100-125	SiCL	15.51	17.8	20.74	1.61	2.7	40.37	0.20	V.S	1.18	15.93
125-150	SiC	15.48	21.9	24.32	1.61	2.69	40.15	0.40	V.S	0.97	16.91

M: initial soil water content

According to Table2, the soil profile is heavy to very heavy textured and the cumulative soil moisture deficit was between 5.93 cm in the first and 16.91 cm in the soil profile. Ranges of soil permeability were between 0.59 to 0.40 mm/hr and the total porosity varied from 46.13% in first layer to 40.15% in the last one.

All experiments were conducted with two replicates. In the first replicate, the experiment was conducted just by applying 100 cm water depth in four-25cm intervals. In the second replicate, 5,000 kg/ha Sulfuric Acid (95%) was applied prior to salt leaching together with leaching water. The required water for leaching was supplied from Karun River. The intermittent ponding method (Loáiciga & Allison, 2007) was conducted with six double rings infilterometer in a circular array with 10 m in diameter. The total applied water depth was 100 cm (four-25cm depths).

Soil samples were taken from 0-25, 25-50, 50-75, 75-100, 100-125 and 125-150 cm soil depths, each in three replicates. These replicates reflect the samples that were taken before, during and after each leaching water application interval. The collected soil samples were then analyzed in the laboratory and their ECe, pH, CEC, $ExNa^+$, $CaSO_4$, $CaCO_3$, total Anions and total Cations were measured. The mean chemical properties of different soil layers for the first and second experimental replicates are respectively given in Tables 3 and 4. The equilibrated salinity was also measured after fourth leaching water interval application from 0-5 cm soil depths in three replicates.

Table3: Some chemical characteristics of different soil layers before and after applying leaching for first replicate

Sampling time	Soil depth (cm)	EC_e (dS/m)	pH	T.N.V (%)	Gypsum (%)	C.E.C (Cmol+/kg)	$Ex.Na^+$ (Cmol+/kg)	Mg^{2+} (meq/lit)	Ca^{2+} (meq/lit)	Na^+ (meq/lit)	SAR	ESP⋆
Before leaching	0-25	66.50	7.9	45.3	0.38	13.0	4.85	148.0	64.0	757.0	73.53	37.31
	25-50	35.90	8.1	48.2	0.35	15.4	1.05	72.5	65.5	380.0	45.75	6.82
	50-75	32.00	8.2	47.0	0.37	10.8	1.35	71.5	64.0	343.7	41.76	12.50
	75-100	34.40	8.1	46.0	0.39	9.1	1.50	105	72.5	354.8	37.66	16.48
	100-125	27.20	8.1	47.2	0.17	11.9	0.75	68.5	63.0	303.8	37.47	6.30
	125-150	30.20	8.1	48.5	0.19	12.8	2.30	68.0	66.0	282.0	34.45	17.97
After applying 100 cm leaching	0-25	4.80	8.1	47.0	0.17	14.0	0.78	11.0	26.0	10.7	2.49	5.57
	25-50	4.80	8.2	48.0	0.04	15.4	2.08	13.0	22.0	13.4	3.20	13.51
	50-75	5.20	8.2	45.0	1.12	11.0	0.90	12.0	25.0	31.0	7.21	8.18
	75-100	7.40	8.3	44.0	1.12	8.94	2.10	15.0	24.0	58.4	13.22	23.49
	100-125	15.20	8.2	47.0	1.22	12.0	1.20	24.0	34.0	124.0	23.03	10.00
	125-150	19.10	8.2	47.0	1.22	13.14	1.20	33.0	25.0	168.0	31.20	9.13
Mean	Before	37.70	8.08	47.03	0.31	12.17	1.97	88.92	65.83	403.55	45.1	16.23
	After	9.42	8.2	46.33	0.82	12.41	1.38	18.0	26.0	67.58	13.39	11.65
Deference	Decrease	28.28	-	0.7	-	-	0.59	70.92	39.83	335.97	31.71	4.58
	Increase	-	0.12	-	0.51	0.24	-	-	-	-	-	-

⋆(ESP=$Ex.Na^+$×100/CEC)

Table4: Some chemical characteristics of different soil layers before and after applying leaching for second replicate

Sampling time	Soil depth (cm)	EC_e (dS/m)	pH	T.N.V (%)	Gypsum (%)	C.E.C (Cmol+/kg)	$Ex.Na^+$ (Cmol+/kg)	Mg^{2+} (meq/lit)	Ca^{2+} (meq/lit)	Na^+ (meq/lit)	SAR	ESP⋆
Before leaching	0-25	66.50	7.9	45.3	0.38	13.0	4.85	148.0	64.0	757.0	73.53	37.31
	25-50	35.90	8.1	48.2	0.35	15.4	1.05	72.5	65.5	380.0	45.75	6.82
	50-75	32.00	8.2	47.0	0.37	10.8	1.35	71.5	64.0	343.7	41.76	12.50
	75-100	34.40	8.1	46.0	0.39	9.1	1.50	105.0	72.5	354.8	37.66	16.48
	100-125	27.21	8.1	47.2	0.17	11.9	0.75	68.5	63.0	303.8	37.47	6.30
	125-150	30.20	8.1	48.5	0.19	12.8	2.30	68.0	66.0	282.0	34.45	17.97
After applying 100 cm leaching	0-25	5.50	8.0	47.0	0.57	14.0	0.46	20.5	28.0	11.3	2.29	3.29
	25-50	5.50	8.2	48.0	0.13	17.4	0.84	21.0	22.0	16.2	3.49	4.83
	50-75	6.50	8.2	46.0	0.04	12.9	1.26	22.0	18.0	55.0	12.30	9.77
	75-100	13.30	8.3	44.0	1.03	10.3	3.50	19.0	22.0	123.0	27.17	33.98
	100-125	40.8	8.2	45.0	1.29	9.8	2.1	75.0	53.0	371.0	46.44	21.43
	125-150	35	8.1	46.0	0.40	12.7	2.2	67.0	52.0	294.0	38.11	17.32
Mean	Before	37.7	8.08	47.03	0.31	12.17	1.97	88.92	65.8	403.55	45.1	16.23
	After	17.77	8.17	46.00	0.58	12.85	1.73	37.42	32.5	145.08	21.63	15.10
deference	Decrease	19.93	-	1.03	-	-	0.24	51.50	33.3	258.47	23.47	1.13
	Increase	-	0.09	-	0.27	0.68	-	-	-	-	-	-

⋆(ESP=$Ex.Na^+$×100/CEC)

The data presented in Tables 3 and 4 indicate that soil pH was betwee 7.9 to 8.2 before leaching. Soil salinity has decreasing trend in respect to soil depth. However, it was slightly increased in 75-100 and 125-150 cm layers. The ESP value varied between 6.3 to 37.31. The gypsum content was varied between 0.38% and 0.17%. The lime content (T.N.V) varied between 45.3 and 48.5 % in the soil profile.

Using the data presented in Tables 2, 3 and 4, the desalinization values were obtained from

$$X = \frac{D_{lw}}{D_s} \quad (1)$$

$$Y = \frac{(EC_f - EC_{eq})}{(EC_i - EC_{eq})} \quad (2)$$

where, D_{lw} is depth of applied water for leaching, D_s is depth of soil, EC_i and EC_f are Electrical Conductivity (dS/m) of saturated extract before and after leaching, respectively; and EC_{eq} is Electrical Conductivity of soil water at equilibrium.

The value of EC_{eq} is considered as EC_e of the soil upper layer after leaching was stopped and D_{lw}/D_s is the ratio of net depth of leaching water (D_{lw}) to unit depth of soil (D_s). The quality of water used in this study is given in Table 5. This is classified as C_4-S_2 based on the Willcox diagram (Richards, 1954).

Table5: Chemical properties of the used water for soil desalinization

ECw	T.D.S	pH	Na^+	Ca^{2+}	Mg^{2+}	K^+	Sum of Cations	Cl^-	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Sum of anions	SAR	$adjR_{Na}$
(dS/m)	(mg/lit)		(meq/lit)					(meq/lit)					$(meq/lit)^{0.5}$	
2.362	1512.0	8.2	15.0	2.0	10.0	-	27.0	13.0	11.0	3.0	-	27.0	6.10	6.19

Four mathematical models including Exponential, Power, Inverse and Logarithmic functions were fitted to the obtained experimental data using curve estimation technique. Then, regression coefficient, standard error at the significance level at 1% were obtained and the functions were compared based on these statistics. The best fitted model with the highest significancey was then selected. Similar procedure was conducted for the replication that received chemical amendment. The water needed for leaching to reduce soil salinity was determined, using the best fitted model. To evaluate model performance, analysis of residual errors, differences between measured and predicted values, were used (Homaee *et al.*, 2002a; Zarei *et al.*, 2010). These statistics were Maximum Error (ME), Root Mean Square Error (RMSE), Coefficient of Determination (CD), Modeling Efficiency (EF), and Coefficient of Residual Mass (CRM). The mathematical expressions of these statistics can be written as (Zarei *et al.*, 2010):

$$ME = max|Pi - Oi|_{i=1}^{n} \quad (3)$$

$$RMSE = \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}\right]^{\frac{1}{2}} \quad (4)$$

$$CD = \frac{\sum_{i=1}^{n}(O_i - \bar{O})^2}{\sum_{i=1}^{n}(P_i - \bar{O})^2} \quad (5)$$

$$EF = \frac{\sum_{i=1}^{n}(O_i - \bar{O})^2 - \sum_{i=1}^{n}(P_i - \bar{O})^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (6)$$

$$CRM = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i} \quad (7)$$

Where, P_i is the predicted values, O_i is the observed (measured) values, ō means of the observed data, and *n* is the number of samples.

The lower limit for ME, RMSE, and CD is zero. The maximum value for EF is one. Both EF and CRM can be negative. A large ME value represents the worst case performance of the model, while a large RMSE value shows how much the simulations overestimate or underestimate the measurements. The CD gives the ratio between the scatter of the simulated values and of the measurements. The EF value compares the simulated values to the averaged measured values. A negative EF value indicates that the averaged measured values give a better estimate than the simulated values. The CRM is a measure of the tendency of the model to overestimate or underestimate the measurements. A negative CRM shows a tendency to overestimation. If all simulated and measured data are the same, these statistics yield: ME = 0; RMSE = 0; CD = 1; EF = 0 and CRM = 0.

As the prerequisite of soil desalinization and land reclamation in large scale is

to equip the field with drainage systems (open or subsurface), for this reason based on available data obtained during the field studies, efforts were made to calculate the optimal depths and spacing of tile drains based on Glover-Dumm equation:

$$L = \pi \frac{\left[\frac{K(D + 0.5Y_0) * t}{S}\right]^{\frac{1}{2}}}{\left[ln 1.16 \frac{Y_0}{Y_t}\right]^{\frac{1}{2}}} \qquad (8)$$

Where, K is Saturated Hydraulics Conductivity (0.6 m/day), Hp is depth of soil barrier (6.0 m), d is depth of tile drain installation (2.0 m), C is maximum permissible water table height (1.2 m), S is drainable porosity (0.077), T is irrigation interval (5 day) and Ri is recharge or deep percolation due to irrigation (0.025 m/irrigation for sugar cane as most consuming perennial crop). Using these data, the spacing of 50 m was obtained which seems to be practically and economically acceptable.

RESULTS AND DISCUSSION

Based on the data presented in Table 2, from application of 100 cm water that was given to soil for both leaching and total deficit moisture for the entire 150 cm soil depth, the amount of 16.91cm belonged to water deficit. Thus, the net depth of applied leaching water was about 83.1 cm.

In order to develop a desalinization model, the data presented in Tables 6, 7, 8 and 9 were employed by making use of equations 1 and 2. The obtained results and the derived empirical models are also represented in Tables 10 and 11 respectively.

Table 6: Initial and final weighted mean EC_e before and after leaching for first replicate

Soil depth (cm)	ECe (dS/m) before leaching	ECe (dS/m) after leaching				
		D_w=25cm EC_f (25)	D_w=50cm EC_f (50)	D_w=75cm EC_f (75)	D_w=100cm EC_f (100)	Mean of EC_f
0-25	66.50	5.60	4.41	4.20	4.80	4.75
0-50	51.20	7.09	6.06	4.85	4.80	5.70
0-75	44.80	14.86	6.67	5.40	4.93	7.97
0-100	42.20	21.05	10.00	8.38	5.55	11.24
0-125	39.20	24.76	15.20	12.30	7.48	14.95
0-150	37.70	27.23	18.67	14.45	9.42	17.44

Based on data presented in table 3

Table 7: Initial and final weighted mean EC_e before and after leaching for second replicate

Soil depth (cm)	ECe (dS/m) before leaching	ECe (dS/m) after leaching				
		D_w=25cm EC_f (25)	D_w=50cm EC_f (50)	D_w=75cm EC_f (75)	D_w=100cm EC_f (100)	Mean of EC_f
0-25	66.50	4.80	6.00	5.00	5.50	5.33
0-50	51.20	6.75	6.50	5.20	5.50	5.99
0-75	44.80	11.17	7.23	5.80	5.83	7.51
0-100	42.20	18.13	11.23	8.00	7.70	11.26
0-125	39.20	-	15.44	13.80	14.32	14.52
0-150	37.70	-	-	16.33	17.77	14.76

Based on data presented in table 4 - Data were not reliable

Table 8:The obtained desalinization values for the experimental soils for first replicate

Soil depth (cm)	Net depth of leaching water applied and related ratios of applied water to unit depth of soil (X,Y)				
	Dlw (cm)	19.07	44.07	69.07	94.07
0-25	X=dlw/Ds	0.76	1.76	2.76	3.76
	Y=ECf-ECeq/ECi-ECeq	0.01	-	-	-
	Dlw (cm)	15.71	40.71	65.71	90.71
0-50	X=dlw/Ds	0.31	0.81	1.31	1.81
	Y=ECf-ECeq/ECi-ECeq	0.04	0.02	-	-
	Dlw (cm)	12.59	37.59	62.59	87.59
0-75	X=dlw/Ds	0.17	0.50	0.83	1.17
	Y=ECf-ECeq/ECi-ECeq	0.34	0.04	0.00	-
	Dlw (cm)	10.25	35.25	60.25	85.25
0-100	X=dlw/Ds	0.10	0.35	0.60	0.85
	Y=ECf-ECeq/ECi-ECeq	0.43	0.13	0.09	0.01
	Dlw (cm)	9.07	34.07	59.07	84.07
0-125	X=dlw/Ds	0.07	0.27	0.47	0.67
	Y=ECf-ECeq/ECi-ECeq	0.57	0.29	0.21	0.07
	Dlw (cm)	8.09	33.09	58.09	83.09
0-150	X=dlw/Ds	0.05	0.22	0.39	0.55
	Y=ECf-ECeq/ECi-ECeq	0.68	0.41	0.28	0.13

EC_{eq}=5.23 dS/m

Table 9:The obtained desalinization values for the experimental soils for second replicate

Soil depth (cm)	Net depth of leaching water applied and related ratios of applied water to unit depth of soil (X,Y)				
	Dlw (cm)	19.07	44.07	69.07	94.07
0-25	X=dlw/Ds	0.76	1.76	2.76	3.76
	Y=ECf-ECeq/ECi-ECeq	0.03	0.05	0.03	0.04
	Dlw (cm)	15.71	40.71	65.71	90.71
0-50	X=dlw/Ds	0.31	0.81	1.31	1.81
	Y=ECf-ECeq/ECi-ECeq	0.08	0.08	0.05	0.06
	Dlw (cm)	12.59	37.59	62.59	87.59
0-75	X=dlw/Ds	0.17	0.50	0.83	1.17
	Y=ECf-ECeq/ECi-ECeq	0.20	0.11	0.07	0.07
	Dlw (cm)	10.25	35.25	60.25	85.25
0-100	X=dlw/Ds	0.10	0.35	0.60	0.85
	Y=ECf-ECeq/ECi-ECeq	0.39	0.21	0.13	0.12
	Dlw (cm)	9.07	34.07	59.07	84.07
0-125	X=dlw/Ds	0.07	0.27	0.47	0.67
	Y=ECf-ECeq/ECi-ECeq	-	0.35	0.30	0.32
	Dlw (cm)	8.09	33.09	58.09	83.09
0-150	X=dlw/Ds	0.05	0.22	0.39	0.55
	Y=ECf-ECeq/ECi-ECeq	-	-	0.39	0.43

EC_{eq}=2.79dS/m

Table10: The calculated model parameters and related statistics for evaluating different desalinization models performance for first replicate

Mathematical expression	Related coefficients		statistics parameters		
	A	B	R	SE	Sig F
$Y=a.e^{b.x}$	0.742	-4.073	0.917	0.084	0.001
$Y=a.x^{b}$	0.074	-0.755	0.913	0.086	0.001
Y=a+blnx	-0.035	-0.220	0.925	0.079	0.001
Y=a+b/x	0.050	-0.034	0.898	0.092	0.001

Table 11: The calculated model parameters and related statistics for evaluating different desalinization models performance for second replicate

Mathematical expression	Related coefficients		statistics parameters		
	A	B	R	SE	Sig F
$Y=a.e^{b.x}$	0.22	-0.67	0.68	0.67	0.001
$Y=a.x^{b}$	0.09	-0.75	0.65	0.60	0.001
Y=a+blnx	0.12	-0.10	0.66	0.10	0.001
Y=a+b/x	0.09	0.03	0.56	0.11	0.001

For the first replicate, the Logarithmic model with maximum correlation coefficient (R) of 0.93 and minimum standard error (SE) of 0.079 was selected. This was significant at 1% of significancey level. The best fitted empirical model obtained to be:

$$Y = -0.035 - 0.22 lnX \quad (9)$$

For the second replicate, the Logarithmic model was also provided the best results, having maximum R value of 0.75 and minimum SE of 0.1 at 1% significantly level. The obtained relation can be written as:

$$Y = 0.125 - 0.103 lnX \quad (10)$$

By substituting Eqs.1 and 2 into Eq.9, the latter can be written as:

$$\left[\frac{(EC_f - EC_{eq})}{(EC_i - EC_{eq})}\right] = -0.035 - 0.22 \ln\left(\frac{D_{lw}}{D_s}\right) \quad (11)$$

By making use of Eq.11, the net water depth (D_{lw}) needed for reducing soil salinity after applying leaching water and final soil salinity can be determined by:

$$\frac{D_{lw}}{D_s} = \frac{exp(Y-a)}{b} \quad (12)$$

$$D_{lw} = D_s . exp\left[\frac{Y+0.035}{-0.22}\right] \quad (13)$$

$$EC_f = \left[\left(-0.035 - 0.22 ln\left(\frac{D_{lw}}{D_s}\right) \times EC_i - EC_{eq}\right) + EC_{eq}\right] \quad (14)$$

By substituting Eqs.1 and 2 into Eq.10, the latter can be re-written as:

$$\left[\frac{(EC_f - EC_{eq})}{(EC_i - EC_{eq})}\right] = 0.125 - 0.103 ln\left(\frac{D_{lw}}{D_s}\right) \quad (15)$$

By using Eq.15, the net water depth (D_{lw}) needed for reducing soil salinity after applying leaching water and final soil salinity can be determined by:

$$\frac{D_{lw}}{D_s} = exp\left[\frac{(Y-a)}{b}\right] \tag{16}$$

$$D_{lw} = D_s . exp\left[\frac{(Y-0.125)}{-0.103}\right] \tag{17}$$

$$EC_f = \left[\left(0.125 - 0.103ln\left(\frac{D_{lw}}{D_s}\right)\right) \times EC_i - EC_{eq}\right] + EC_{eq} \tag{18}$$

Based on the data given in Tables 6 and 7, the remaining initial salts as well as removed initial salts percentage can be calculated as presented in Tables 12 and 13.

The data given in Table 12 indicate that by applying 100 cm leaching water, 92.85, 88.87, 82.22 and 73.35 percents of the initial salts were leached out from corresponding depths, respectively. The used leaching water for these depths corresponds to 8.67, 4.9, 3.42 and 2.57 pore volumes, respectively.

Table 12: The relation between depth of applied leaching water and remaining initial salts and initial removed salts in soil for first replicate

D_w (cm)	Initial salinity (%)	D_s (cm)				Means EC_e
		0-25	*0-50*	*0-75*	*0-100*	
25	Remained	8.42	13.85	33.17	49.88	26.33
	Removed	91.58	86.15	66.83	50.12	73.68
50	Remained	6.63	11.82	14.89	23.70	14.26
	Removed	93.37	88.18	85.11	76.30	85.74
75	Remained	6.32	9.47	12.05	19.86	11.92
	Removed	93.68	90.53	87.95	80.14	88.08
100	Remained	7.22	9.38	11.00	13.15	10.19
	Removed	92.78	90.62	89.00	86.85	89.81
Average	Remained	7.15	11.13	17.78	26.65	15.68
	Removed	92.85	88.87	82.22	73.35	84.32

The data given in Table 13 indicate that by applying 100 cm leaching water, 91.98, 88.30, 83.24 and 73.32 percents of the initial salts were leached out from the corresponding depths. The applied leaching water for these depths corresponds to 8.67, 4.9, 3.42 and 2.57 pore volumes, respectively.

Table 13: The relation between depth of applied leaching water and remaining initial salts and initial removed salts in soil for second replicate

D_w (cm)	Initial salinity (%)	D_s (cm)				Means EC_e
		0-25	0-50	0-75	0-100	
25	Remained	7.22	13.18	24.93	42.96	22.07
	Removed	92.78	86.82	75.07	57.04	77.93
50	Remained	9.02	12.70	16.14	26.61	16.12
	Removed	90.98	87.30	83.86	73.39	83.88
75	Remained	7.52	10.16	12.95	18.96	12.39
	Removed	92.48	89.84	87.05	81.04	87.61
100	Remained	8.27	10.74	13.01	18.25	12.57
	Removed	91.73	89.26	86.99	81.75	87.43
Average	Remained	8.01	11.69	16.76	26.69	15.79
	Removed	91.98	88.30	83.24	73.32	84.21

By using Eqs. 9 and 10, that were proven to be the best empirical relations for the entire study area, the leaching curves were obtained. These results are presented in Figures 1 and 2, respectively.

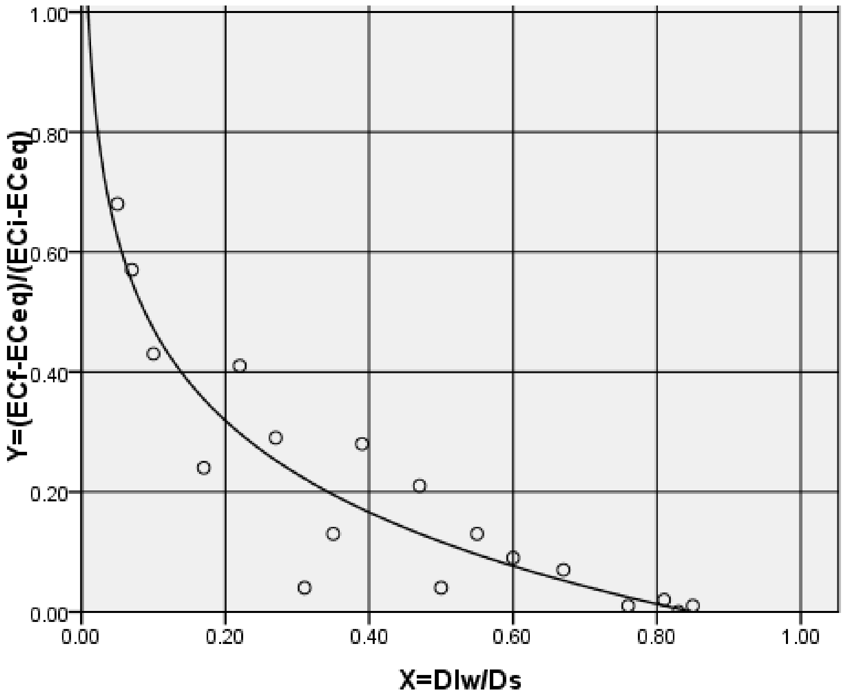

Fig. 1: Soil desalinization curve in the study area for the first replicate (leaching water without amendment)

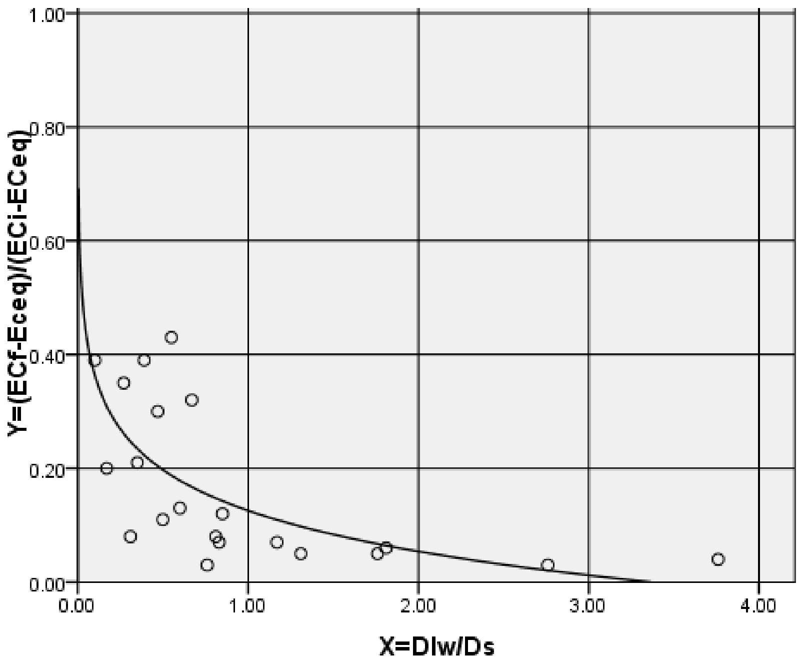

Fig. 2: Soil desalinization curve in the study area for the second replicate (leaching water + sulfuric acid)

Using these curves, the net required leaching water (D_{lw}) can be calculated for practical purposes. It is obvious that for calculating the total leaching water (D_w), the water deficit in soil profile, evaporation from soil and water surface, and the amount of precipitation should be considered. It should be noted that the calculations drawn from the desalinization leaching curves are valid for the study area conditions. Also it should be mentioned that salts that were removed until an equilibrium ECeq under specific soil-irrigation-water-drainage conditions is reached, were referred to as excess salts. Under the most ideal condition, this equilibrium will be 1.5 to 2.0 times of irrigation water salinity (in this study it was found to be 4.01 dS/m, that is the average of 5.23 and 2.79 dS/m which were obtained from replications 1and 2, respectively). Figures 3 and 4 shows the fraction of excess salts removed from both replications, expressed by Y= 1- ((ECf-ECeq)/(ECi-ECeq)) as a function of pore volumes.

It should be noted that in this case, the data that presents active salts removed were used (Hendrikus Branard *et al*., 2010). By subtracting ECeq from the actual and initial ECe values, leaching curves are obtained that are independent of the salinity of leaching water, existing drainage and evaporation conditions. Therefore the shape of leaching curves governed solely by soil characteristics.

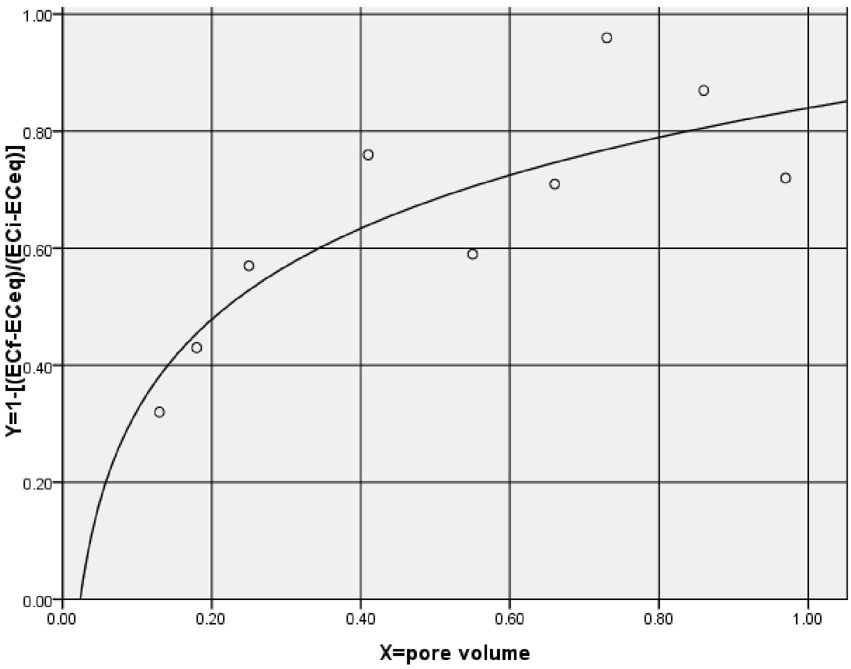

Fig.3: Fraction of excess salts removed from replication 1

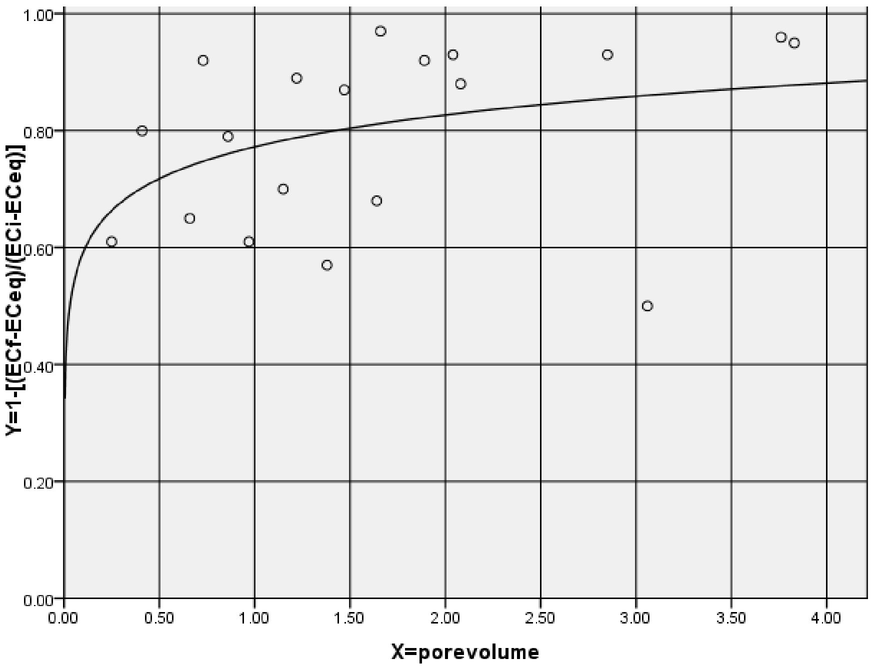

Fig.4: Fraction of excess salts removed from replication 2

Since the salt leaching follows the miscible displacement approach, based on the Biggar and Nielsen (1961) idea, for each pore volume, 50% and for two pore volumes about 80% of the initial salts should be removed from the soil profile. However, Figure 3 and 4 indicate the about 78% and 84% of the initial salts are leached out for one pore volume water application for the first and second replicates, respectively. This observation indicates that the Biggar and Nielsen approach underestimates the real condition as it was reported by some other researchers as well. Leaching of remained salts need more times and special treatments such as proper crop rotation, correct soil water management via deep percolation by which the residual salts can also be removed gradually and total soluble salts finally will leach out from soil profile.

To evaluate the obtained desalinization data these data were compared to some other previously proposed empirical models to assess the predictability of capital leaching water requirements. The related results are presented in Table 14. For this comparison the initial, final and equilibrated soil salinities were considered to be 45.0, 8.0 and 3.54(1.5 times of leaching water salinity) dS/m, respectively, in the depth of 150 cm.

Table 14: Comparison of required desalinization water for different available models and the newly proposed model

model	year	Required water for desalinization(m)				Weighted mean needed water (m)	Rank
		Soil depth incriment (D_s) (m)					
		0.25	0.50	0.75	1.00		
Reeve	1957	0.41	0.83	1.22	1.63	1.50	9
Dielman	1963	0.50	1.00	1.50	2.00	1.67	10
Leffelaar &Sharma	1977	0.15	0.30	0.46	0.61	0.54	5
Hoffman	1980	0.18	0.37	0.55	0.74	0.69	8
Pazira & Kawachi	1981	0.17	0.34	0.51	0.67	0.66	6
Verma & Gupta	1989	0.19	0.39	0.58	0.78	0.67	7
Pazira & Keshavarez	1998	0.13	0.26	0.39	0.51	0.50	3
Mohsenifar	2006	0.02	0.11	0.26	0.47	0.41	2
Rajabzadeh & Pazira	2008	0.13	0.27	0.40	0.54	0.51	4
Proposed model	2010	0.11	0.22	0.33	0.44	0.38	1

The results indicated that the models proposed by Mohsenifar (2006), Pazira & Keshawarz (1998), can provide second and third best perditions after the newly proposed model. Some other empirical models (e.g. Reeve, 1957; Dielman, 1962; Hoffman, 1980) did not provide a reasonable predictions. This can be related to different soil physical and chemical properties, and to desalinization experimental performances.

It should be mentioned that the soil desodification process (method of data generation, analysis, comparison and results) is rather the same as desalinization process and for this reason; it will not be presented in this article, but will be discussed in detail elsewhere.

CONCLUSION

The collected data from the extensive experiments indicates that by applying 100 cm leaching water, the soil salinity reduces to 88.87and 73.35 percents of initial salts in the first replicate. This was 88.30 and 73.32 percents of the initial salts for the second replicate at 0.5 and 1,0 m of soil profile, respectively. The soil water deep percolation itself can leach out about 84% of the initial salts when only 100 cm water applied. The results of correlation mathematical models indicate that Logarithmic model can well describe the collected experimental data at large scale. The newly proposed empirical model with minimum weighted mean of required leaching water (0.38), presents best performance from water saving point of view, compares to other models. Also from the data presented in tables 3 and 4, it is evidence that desalinization automatically takes care of desodification.Therefore, the important conclusion is that there is no need of any amendment of the form of Sulfuric Acid, etc., in the reclamation of the soils under consideration.

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