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Studies on Appropriate and an Empirical Model for Salt Leaching of Saline-Sodic Soils of Shoaybiyeh Central Plains of Khuzestan Province

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ABSTRACT

Soil salinity and sodicity are serious challenges related to soil management and sustainable production in arid and semi-arid regions. To overcome this challenge, leaching of accumulated salts from such soil is necessary. The most important task in leaching practices is assessment of water quantity required for leaching of saline and saline-sodic soils. Therefore, reliable estimation of the required leaching water quantity is vital for reducing soil salinity to a desirable level. The objectives of this study were to introduce an empirical model to account for reclamation water and to compare the obtained results with some available models. Consequently, a large area of 6205 ha with S4A2 salinity/sodicity class in Khuzestan, Iran, was selected to obtain the required data. This experiment was conducted with two treatments and tree replicates. In the first treatment, the experiment was conducted by applying just 100 cm water depth in four-25 cm intervals. In the second treatment, 5000 kg/ha Sulfuric Acid was applied prior to salt leaching together with leaching water. The intermittent ponding method was conducted with double rings in a rectangular array. Soil samples were taken from 0-25, 25-50, 50-75, 75-100, 100-125, 125-150 cm soil depths before, during and after each leaching water application interval. The required physical and chemical analyses were performed on the collected data. The leaching water was supplied from Karun river. Four mathematical models were applied to the collected experimental data to derive a suitable empirical model. The results indicated that the logarithmic models can estimate the capital leaching requirement much than other models. Also the empirical relation given by Hoffman can not resemble the field conditions. However, the empirical relationships introduced by Rajabzadeh, Verma and Gupta, Pazira and Keshavarz, Mohamadzadeh, Pazira and Kawachi, Leffelar and Sharma, Revee, Dieleman overestimate the depth of reclamation water. The empirical model of Asadi underestimated the depth of required reclamation water compares to the newly proposed model.

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INTRODUCTION

Salt concentration and accumulation in a soil profile affects soil physical and chemical properties such as osmotic pressure, infiltrability, and hydraulic conductivity and leaves behind such effects as to disrupt or completely stop growth and development of most crop and horticultural plants. The consequence of extreme solubility of sodium (Na) salts and precipitation of calcium carbonate (CaCo3) at high pH values (that happens usually and naturally) increases salt concentration or salinity (the process of salinization) and raises the pH value of soil solution (the alkalinization process) leading to accelerated soil sodication (the alkalization or sodication process). Therefore, in agricultural plans for areas under irrigation, soil salinity and sodication must be reduced to desirable levels in order to achieve economic efficiency in agricultural and horticultural production. From the practical and empirical points of view, the only definitive and long-term solution for amending saline and sodic soils is to remove soluble salts from soil profile through leaching with water of

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suitable quality. Field tests are recommended to determine the quantity of water needed for leaching salts from salt-affected soil profiles. Results of such tests make it possible to prepare and present curves of leaching salts from soil profiles and to use these curves for determining the quantity of water needed to reduce salinity to the desirable level. Conducting such research and field tests requires substantial time and funds to take many soil samples and perform physical and chemical analyses. However, theoretic models and leaching equations, which have been developed based on empirical and mathematical relationships, use the technology of computer simulation models to analyze the leaching process of salts from soil profiles (after various quantities of water have been applied) with acceptable approximation and accuracy. Empirical models are the product of observational data and empirical measurements fitted to mathematical relations (and, therefore, no physical and mathematical preconditions are involved in their derivation). Although used in a specific location or for a specific problem, empirical models of this type can be an important part of a complex numerical model, and their application for making preliminary and approximate estimates can prove useful in achieving information needed for soil improvement.

Empirical relationships and leaching curves can be used for a specific soil depth with respect to the soil type, degree of salinity, or exchangeable sodium percentage. Researchers have developed many empirical models including those introduced by Reeve [27], Dieleman [9], Hoffman [13], Kawachi, and Gupta and Verma [12]. In Iran, leaching experiments have been carried out in most provinces facing salinity problems [22]. Based on numerous research and experiments conducted in the central part of the Khuzestan Province during the course of many years, an empirical relation has been introduced in the form of a hyperbola. Moreover, Pazira and Keshavarz [22] introduced an exponential model for estimating the quantity of water required in leaching saline and sodic areas in the southeastern part of Khuzestan Province. Rajabzadeh *et al*. [26] conducted a study in the central part of Khuzestan Province and found that the logarithmic model with the one meter depth of leaching water application in four 0.25 m intervals was the most efficient among the common methods used [1,2]. In another study in the Jufeir region of the southwestern part of Khuzestan Province, an exponential empirical model was introduced for determining the depth of water required for leaching to desalinize saline and sodic soils [16].

The purpose of this research was to conduct field tests in a part of the lands located in the central plain of Shoaybiyeh in Khuzestan Province to desalinize soil profiles, and to find a suitable model for estimating the depth of leaching water needed for improving soils in the region. To do this, various mathematical models were fitted to field data and results were compared with those of available empirical models.

Table 1: Some experimental models of soil leaching.

No. of equation	Name of empirical model	Type of mathematical model	Mathematical model relationship
1	Reeve (1957)	Hyperbolic function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = \frac{1}{5[\frac{Dlw}{Ds} - 0.15]}$
2	Dieleman (1963)	Exponential function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = e^{-[\frac{Dlw}{Ds}]}$
3	Leffelaar & Sharma (1977)	Hyperbolic function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = \frac{0.062}{[\frac{Dlw}{Ds}]} + 0.034$
4	Hoffman (1980)	Hyperbolic function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = \frac{K}{[\frac{Dw}{Ds}]}$
5	Pazira & Kawachi (1998)	Hyperbolic function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = \frac{0.076}{[\frac{Dlw}{Ds}]} + 0.023$
6	Verma and Gupta (1989)	Power function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = 0.099\ \frac{Dw}{Ds}^{-1.27}$
7		Power function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = 0.09\ \frac{Dw}{Ds}^{-1.63}$
8	Pazira & Keshavarz (1998)	Power function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = 0.0764\ \frac{Dlw}{Ds}^{-0.864}$
9	Rajabzadeh (2009)	Exponential function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = 0.8653 e^{-0.4498\frac{Dlw}{Ds}}$
10	Asadi (2011)	Logarithmic function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = -0.035 - 0.22\, Ln \frac{Dlw}{Ds}$
11	Asadi (2012)	Logarithmic function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = 0.07 - 0.16\, Ln \frac{Dlw}{Ds}$
12	Mohammadzadeh (2013)	Power function	$\frac{(ECf - ECeq)}{(ECi - ECeq)} = 0.059\ \frac{Dlw}{Ds}^{-1.181}$

In the above table, D_w is the gross depth of water (for leaching) in cm, D_s the depth of the soil layer (from ground surface) in cm, and EC_i electrical conductivity of soil saturation extract before applying a specific depth of water in dS/m, and D_{lw} the net depth of water for leaching (that, after deducting the water needed to offset the water deficit in the related soil layer, moves out of the soil layer column by gravity and deep percolation) in cm.

Moreover, EC_{eq} is the electrical conductivity of soil saturation extract that reaches chemical equilibrium by the water applied (for leaching) in dS/m, and K the empirical coefficient with no dimensions.

MATERIALS AND METHODS

The studied region is a part of Shoaybiyeh plains located in Khuzestan Province with an area of 15800 ha. It locates 40 Km far from south of Shushtar city and lies inside 48^o, 37’, 48”E to 48^o, 50’ longitudinal and 31^o, 37’ to 32^o latitudinal. It is limited to Shoaybiyeh fells from north, to Shatit River from east and to Dez River from west and south. In terms of climate categories it is an arid and semi arid region with hot, dry and long summers and short, soft and no freezing winters. Its annual precipitation is 237mm with an average temperature of 23.7^{oc} and annual evaporation rate of 3339.8 mm.

Since about 13295 ha of all studied area have saline-sodic soil, from low to extreme, it can be argued that salinity and sodicity is the main qualitative limitation of more than 84% of the region’s soils. Thus, this study was carried out on saline-sodic lands and in the process of land selection and definition of repetition time, it was tried to select an extreme saline-sodic land because according to investigations, if reclamation of these lands (extreme saline-sodic) is practicable, it will be justifiable and practicable to generalize the obtained results to other classes with different degrees of salinity and sodicity in the studied region.

In order to perform required experiments, salinity and sodicity maps were studied and Deylam soil in Typic Calciorthids group and Aridisals order with S_4A_2 salinity-sodicity class (extreme salinity and relative extreme sodicity) before leaching tests was selected as the target soil. In the study zone, the area of Deylam soil series is 6205 ha (more than 39% of the region’s soil). Tables 2 and 3 present the situation, series, and salinity-sodicity classes of the soils in the study area, and some physical characteristics of the various layers in the soil profiles before leaching.

To desalinize soils, leaching of soluble salts from soil profiles was carried out. The experiment had two treatments and was conducted with three replications. Leaching was performed using the intermittent ponding method and the required water was taken from the Shatit River. Table 4 lists results obtained from the chemical analysis of the water used in both treatments. In the first treatment, no amendment material was used and the 1 meter depth of water was applied in four 0.25-meter intervals. However, in the second treatment, five tons of 95% sulfuric acid was applied and leaching was then carried out by using irrigation water.

The six double cylinders used in the experiment were arranged 5 meters apart on the perimeter of a circle with a radius of 5 meters. Soil samples were taken from depths of 0-25, 25-50, 50-75, 75-100, 100-125, and 125-150 centimeters of the soil profiles before leaching and after application of 25, 50, 75, and 100 centimeters of water. The samples were sent to the laboratory for analysis. In each experiment, the electrical conductivity, pH, cation exchange capacity, sodium adsorption ratio, exchangeable sodium percentage, saturation percentage, lime, gypsum, and cations and anions (Na, Ca, Mg, Cl, sulfate, carbonate, and bicarbonate) in the soil extract solution were measured. The chemical characteristics of the various soil layers before and after applying 100 cm of water in the related treatments are presented in Table 5 respectively. The salinity values (electrical conductivity of the soil saturation extract) before, during, and after each water application were determined for the desired horizons in the soil profiles (that is, at the depths of 0-25, 0-50, 0-75, 0-100, 0-125, and 0-150 centimeters) relative to the mean weight calculations for different depths of water applied. The results for both treatments are listed in table 6.

Since all the water applied may not be used for leaching soluble salts out of soil profiles and some if it may be used to offset the soil moisture deficit, even applying large volumes of water will not result in a chemical equilibrium of the soil with the water used in leaching. To overcome this problem, desalinization values were determined based on the averages of salinity by weight as follows:

$$X = [D_{lw}/D_s] \qquad Y = \left[\left(EC_f - EC_{eq}\right)/\left(EC_i - EC_{eq}\right)\right] \tag{13}$$

EC_i, EC_f are electrical conductivity of soil saturation extract before and after leaching (dS/m), D_{lw} the net depth of water for leaching, and D_s the depth of the soil layer (m). Actually, D_{lw} represents the depth of water that, after offsetting the moisture deficit in the related layer, leaves it by gravity. Deducting EC_{eq} from the numerator and denominator of the mentioned fraction will cause the results obtained from the effects of external factors such as the amount of evaporation, the condition of the internal drainage in the soil, the quality of water used for leaching, and the conditions under which the experiment is conducted, to become independent. In fact, this will convert the function from the explicit to the implicit state. After obtaining all the values of the leaching experiments, the required analysis was performed using SPSS, Curve Expert, and Excel. The four mathematical models including the power, exponential, inverse, and logarithmic models were fitted to the desalinization values, were analyzed using statistical criteria such as coefficient of determination and standard deviation at the one percent level of significance, and the most suitable desalinization model for the tested soils was determined. The ME, RMSE, CD, EF, and CRM statistics were used to evaluate the accuracy, validity, and efficiency of the proposed model.

Table 2: Series, salinity and sodicity class and some physical characteristics of the studied soil.

series name	salinity and sodicity class (before test)	depth of water table (m)	hydraulic conductivity (m/day)	depth of impervious layer (m)
Deylam	S_4A_2	1.90	1.74	More than 5.3m

Table 3: Some physical characteristics of different layers of soil profile before leaching process in Deylam soil series.

Row	Sampling depth (m)	Soil Particles (%)			Soil texture	Soil density (gr/cm3)		Total porosity (%)	Permeability (mm/hr)		Humidity (mass percentage)			Soil moisture deficit (cm)	Cumulative Soil moisture deficit (cm)
		sand	silt	clay							Before leaching	Filed capacity	Wilting point		
1	0-25	27.2	53.8	19.0	SiCL	1.64	2.66	38.0	2.00	S	10.12	24.50	14.25	5.90	5.90
2	25-50	10.0	57.8	38.6	SiCL	1.54	2.65	42.0	1.38	S	9.91	23.35	14.50	5.17	11.07
3	50-75	8.8	58.6	32.6	SiCL	1.65	2.70	39.0	0.88	V.S	20.65	21.50	14.00	0.35	11.42
4	75-100	11.2	57.0	31.8	SiC	1.60	2.68	40.0	0.50	V.S	11.11	20.25	13.25	3.66	15.08
5	100-125	14.2	53.4	32.4	SiC	1.70	2.66	36.0	0.63	V.S	10.39	21.50	13.00	4.72	19.80
6	125-150	16.2	51.0	32.8	SiC	1.70	2.68	37.0	0.63	V.S	12.63	23.00	15.00	4.41	24.21

Table 4: Chemical decomposition of the water used to leach out soluble salts from soil profile.

Water source	EC_w (ds/m)	pH	T.D.S (mg/lit)	Na^+	Mg^{2+}	Ca^{2+}	K^+	Sum of cations	Cl^-	So_4^{2-}	Hco_3^{2-}	Sum of anions	SAR	Wilcox category
				(meq/lit)					(meq/lit)					
Shatit river	1.12	8.3	720	5.55	3.20	2.80	0.03	11.58	5.85	2.60	3.30	11.75	3.20	C3-S1

Table 5: Some chemical characteristics of soil layers before and after leaching.

Sampling time	Soil depth (cm)	ECe (dS/m)	pH	T.N.V (%)	Gypsum	C.E.C	Ex.Na$^+$	SAR	ESP*
					(meq/100gr)				
Before leaching	0-25	94.46	7.5	36.50	5.63	15.02	3.97	29.53	26.43
	25-50	39.30	7.8	40.75	1.34	12.84	2.62	25.69	20.40
	50-75	35.91	7.9	41.13	1.56	13.75	2.68	26.86	19.49
	75-100	35.55	8.0	41.13	1.60	11.56	3.52	27.60	30.45
	100-125	36.70	8.0	40.87	2.63	14.29	3.86	31.83	27.01
	125-150	37.15	8.1	41.88	4.44	15.30	2.48	26.22	16.30
After leaching	0-25	2.30	8.2	37.50	0.29	19.02	0.70	2.84	3.68
		4.39	8.0	37.00	0.29	18.26	0.72	2.78	3.94
	25-50	2.63	8.2	40.50	0.29	19.02	0.76	2.73	3.99
		8.24	8.2	39.50	0.29	18.26	0.23	6.61	1.26
	50-75	3.46	8.4	41.00	0.29	17.12	1.85	4.62	10.81
		9.45	8.4	40.00	0.29	17.50	0.51	5.97	2.91
	75-100	4.28	8.4	42.00	0.34	15.22	3.28	6.73	21.55
		14.29	8.3	40.00	0.29	15.22	3.19	12.15	20.96
	100-125	10.33	8.4	42.00	0.39	14.08	3.93	8.19	27.91
		18.91	8.2	40.00	1.30	20.92	2.99	16.60	14.29
	125-150	15.72	8.2	42.00	5.45	18.26	3.97	11.03	21.74
		10.88	8.1	39.50	11.10	15.22	9.88	9.92	64.91
Avarage	Before leaching	46.51	7.9	40.38	2.87	13.79	3.19	27.96	23.33
	After leaching	6.45	8.3	40.83	1.18	17.12	2.42	6.02	14.95
		11.03	8.2	39.33	2.26	17.56	2.92	9.01	18.05

$$*ESP = \frac{100\ (Ex.Na^+)}{C.E.C}$$

Table 6: Calculated values (weight average) for Initial salinity (EC_i) and Final salinity (EC_f) of saturated soil extract before and after applying different amounts of leaching water (gross) in different soil layers of Deylam soil series (with and without reclamation substances).

Row	Sampling depth (m)	salinity of saturated soil extract before leaching (dS/m)	salinity of saturated soil extract after different frequencies of leaching water (dS/m)									
			EC_f (25)		EC_f (50)		EC_f (75)		EC_f (100)		EC_f (avarage)	
1	0-25	94.46	5.94	9.14	4.42	6.71	2.99	6.28	2.30	4.39	3.91	6.63
2	0-50	66.88	10.26	15.29	6.07	5.79	2.74	5.57	2.47	6.32	5.38	8.24
3	0-75	56.56	17.21	20.75	14.96	9.57	3.07	8.71	2.80	7.36	9.51	11.60
4	0-100	51.31	19.73	21.64	19.35	13.26	5.52	11.75	3.17	9.09	11.94	13.93
5	0-125	48.38	21.25	22.17	21.48	15.18	8.99	13.86	4.60	11.06	14.08	15.57
6	0-150	46.51	22.53	22.52	22.90	16.70	12.31	15.36	6.45	11.03	16.05	16.40

RESULTS AND DISCUSSION

This study's results show that the salinity of saturated soil extract in both treatments decreased after leaching process. In both treatments, this decrease had a sharp trend in surface layers especially within 0-25 cm of soil surface. Unlike salt distribution before leaching, this distribution's direction is from surface to depth because salts are leached out from soil so that as the depth of leaching water increases accumulation of salts in bottom layers increases. In general, after applying leaching process on Deylam soil series, soil extract salinity was decreased to 40.06 and 35.49 in treatments 1 and 2, respectively.

According to analyses as well as fitting four mathematical models i.e. logarithmic, power, exponential and inverse models to the values extracted from X and Y variables, derived from field desalination experiments in Deylam soil series, exponential model with a determination coefficient of 0.727 and standard error of 0.089 in a significance level of 1% is the best model for treatment 1 which is shown as follows:

$$Y = 0.071 - 0.112\,\mathrm{Ln}\,X \tag{14}$$

Replacement of related variables results in:

$$\frac{EC_f - EC_{eq}}{EC_i - EC_{eq}} = 0.071 - 0.112\,\mathrm{Ln}\frac{D_{lw}}{D_s} \tag{15}$$

Having relation 2, required depth for removing soluble salts from soil profile with a given thickness and a given final salinity of saturated soil extract is computed as follows:

$$D_{lw} = D_s.\exp\left[\langle(\frac{EC_f - EC_{eq}}{EC_i - EC_{eq}}) - 0.071\rangle/(-0.112)\right] \tag{16}$$

$$EC_f = \left[(EC_i - EC_{eq}).(0.071 - 0.112\,\mathrm{Ln}\frac{D_{lw}}{D_s}) + EC_{eq}\right] \tag{17}$$

In this study EC_f in 0-100cm layer of soil profile per 100cm of depth of leaching water (D_w), water deficit in 0-100cm layer of soil profile before leaching and salinity of leaching water were estimated as3.17 dS/m, 15.08 cm and 1.12 dS/m, respectively. Therefore, leaching efficiency coefficient can be derived from the following empirical relations:

$$r = \frac{D_w}{D_p} \tag{18}$$

$$f = \frac{r.EC_w}{EC_{eq}} \tag{19}$$

Where:
r is gross depth of leaching water to net depth of leaching water or deep permeation ratio (D_p=D_{lw}); EC_W is salinity of leaching water in dS/m and EC_{eq} is final salinity of the studied layer after applying a given amount of leaching water in dS/m.
Therefore, we have:

Dw=100 cm

$$r = \frac{D_w}{D_p} = \frac{100}{84.92} = 1.177$$

Dp=100-15.08=84.92

$$f = \frac{r.EC_w}{EC_{eq}} = \frac{(1.177).(1.12)}{(3.17)} = 0.416$$

The calculated leaching efficiency coefficient of soluble salts (f=0.416) agrees with the studied region's soil texture reported in valid literatures and this implies that the obtained results are logic. The numerical value of this coefficient represents the efficiency of applied leaching water for removing soluble salts from soil profile which can be substituted with the water content of soil during leaching process.

According to analyses as well as fitting different empirical models, logarithmic model with a definition coefficient of 0.804 and standard error of 0.053 in a significance level of 1% is the best model for treatment 2 which is shown as following:

$$Y = 0.087 - 0.094\,\mathrm{Ln}\,X \tag{20}$$

By replacing related variables the above relation is written as:

$$\frac{EC_f - EC_{eq}}{EC_i - EC_{eq}} = 0.087 - 0.094\,\mathrm{Ln}\frac{D_{lw}}{D_s} \tag{21}$$

Having the above relation, required depth for removing soluble salts from soil profile with a given thickness and given EC_f of saturated soil extract can be derived from the following relation:

$$D_{lw} = D_s.\exp\left[\langle\left(\frac{EC_f - EC_{eq}}{EC_i - EC_{eq}}\right) - 0.087\rangle/(-0.094)\right] \tag{22}$$

$$EC_f = \left[\left(EC_i - EC_{eq}\right).\,(0.087 - 0.094\ \mathrm{Ln}\frac{D_{1w}}{D_s}) + EC_{eq}\right] \quad (23)$$

Having relations 1 and 7, desalination curves of Deylam soil series were obtained. Figure 1 shows the results.

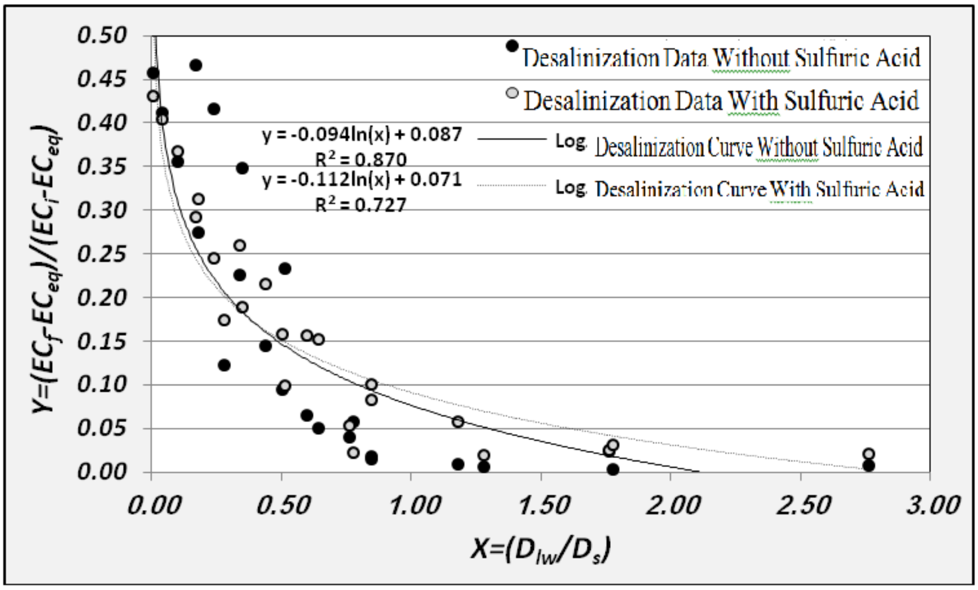

Fig. 1: Soil desalination curves under the influence of two leaching treatments in Deylam soil series.

According to figure 1, in the soil series removing salts is easier in treatment 1 compared with treatment 2. Comparison of the curves show that in the case of applying sulfuric acid as reclamation substance, more leaching water is required compared with the case of no use of sulfuric acid.

From the curves shown in Fig.1, final electrical conductivity of soil (EC_f) and required net depth of water for reclamation (D_{1w}) can be estimated. It should be noted that if one wish to estimate total required depth of leaching water, soil water deficit in the considered soil layer, surface evaporation and precipitation amount should be taken into account in the calculations and planning of leaching process. However, the curves are valid only for the region's soil and within initial electrical conductivity limits of 35.55 dS/m to 94.46 dS/m and exchangeable sodium percentage (ESP) of 26.81 to 31.36.

The statement of desalination in terms of pore porosity volume describes removing salts from soil layers better than D_{1w}/D_s ratio because it considers water to whole column soil ratio as total porosity while this assumption is not true in reality and porosity volume is the volume which leaching water crosses inside it. In this study the obtained determination coefficient based on volumetric porosity was higher than water to soil ratio but the obtained values are more realistic and they are suitable for evaluation of soil salinity. According to this method and statistical analyses and fitting different empirical models, power model with determination coefficient of 0.806 and standard error of 0.718 and reserve model with determination coefficient of 0.896 and standard error of 0.043 in a significance level of 1% are the best models for treatments 1 and 2, respectively which are shown as following:

$$Y = 0.210\ X^{-1.915} \quad (24)$$

$$\frac{EC_f - EC_{eq}}{EC_i - EC_{eq}} = 0.210\ (\frac{D_w}{n.D_s})^{-1.915} \quad (25)$$

$$Y = 0.010 + \frac{0.214}{X} \quad (26)$$

$$\frac{EC_f - EC_{eq}}{EC_i - EC_{eq}} = 0.010 + \frac{0.214}{(\frac{D_w}{n.D_s})} \quad (27)$$

Advances in Environmental Biology, 8(12) July 2014, Pages: 824-834

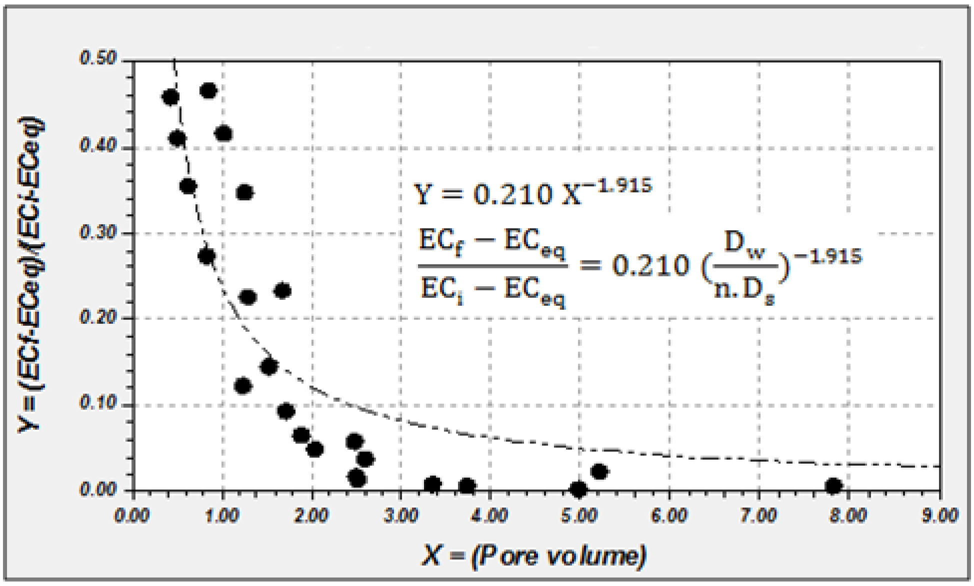

Fig. 2: Soil desalination curves versus different amounts of pore water in Deylam soil series (without reclamation substance).

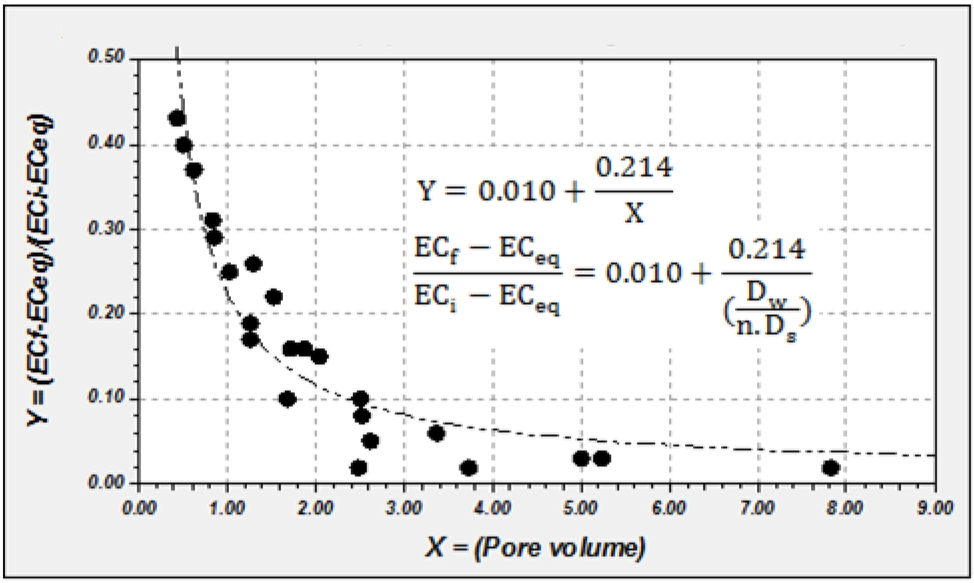

Fig. 3: Soil desalination curves versus different amounts of pore water in Deylam soil series (with reclamation substance).

Having average weight of the salinity of saturated soil extract, derived from tests, and using the following relations, initial removed and remained salts percentages were calculated.

$$Y = \frac{EC_f}{EC_i} \times 100 \tag{28}$$

$$Y' = 100 - (\frac{EC_f}{EC_i} \times 100) \tag{29}$$

$$X = \text{Pore Volume} = \frac{D_w}{(n.D_s)} \tag{30}$$

Where D_w is depth of leaching water in cm, Y is removed salt percentage, Y' is remained salt percentage, P.V is pore water volume and n is soil porosity. Figures 4 and 5 indicate the relationship between initial removed salts with pore water volume and initial remained salt.

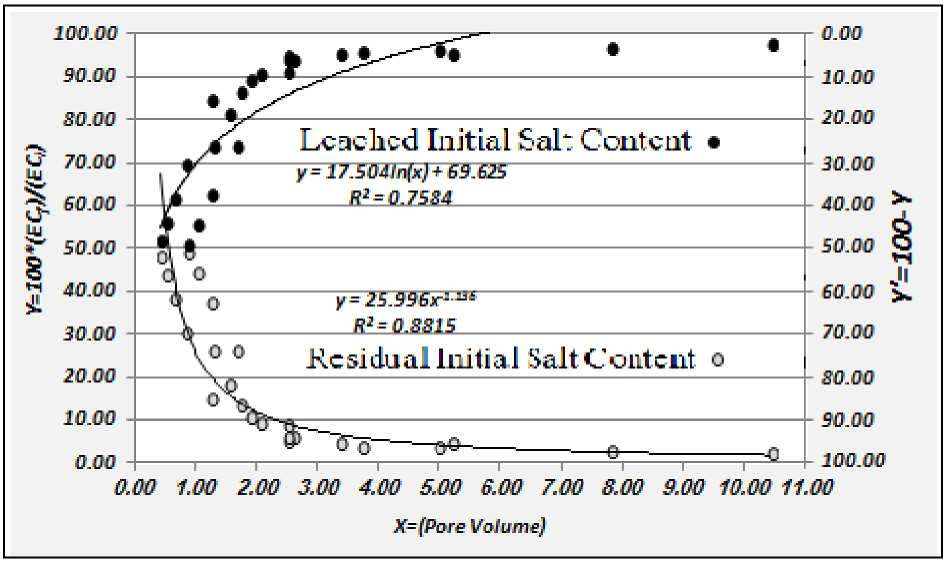

Fig. 4: Variation of initial removed and remained salts to pore porosity after leaching process in Deylam soil series (without reclamation substance).

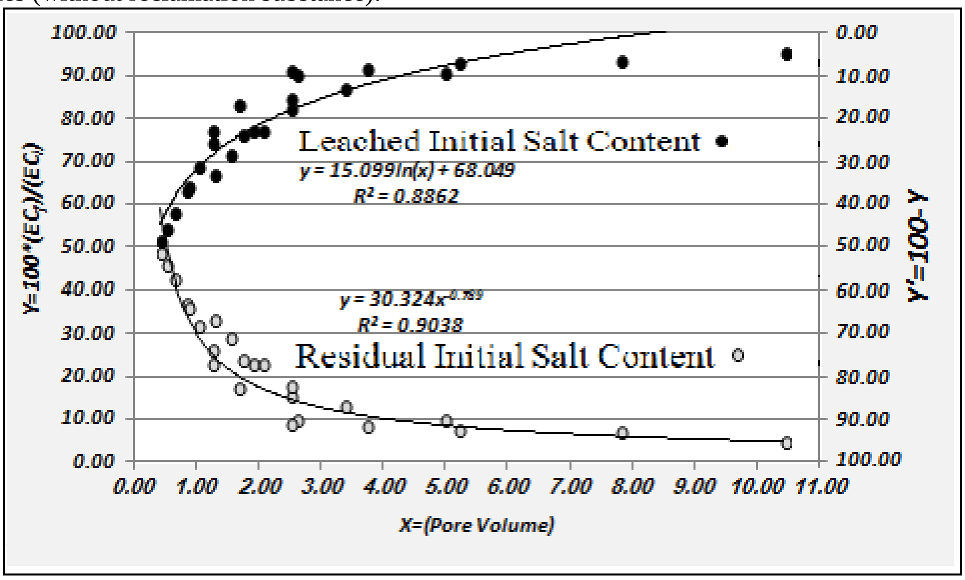

Fig. 5: Variation of initial removed and remained salts to pore porosity after leaching process in Deylam soil series (with reclamation substance).

In treatment 1, 100cm depth of leaching water removed 95.86%, 91.95%, 83.19%, 76.73%, 70.90% and 65.49% (average) of initial salts in the related depths while in treatment 2 the same amount of water removed 92.98%, 87.68%, 79.49%, 72.84%, 67.83% and 67.73% (average) of initial salts in the related depths. The amount of applied water was 10.43, 4.99, 3.36, 2.51, 2.05 and 1.72 units of pore water in the related depths.

According to the results shown in figures 4 and 5, it can be concluded that in Deylam soil series and in treatment 1, applying one and two pore volumes removed about 68% and 78% of salts, respectively. The same trend is true in treatment 2 so that about 70% and 82% of salts were removed by applying one and two pore volumes, respectively.

According to results, removing soluble salts from soil profiles of the studied region is better done by frequent submergence method, especially in the surface layers of soil profiles, due to frequent changes of soil humidity so that applying a 100cm depth of leaching water, corresponding to 84.9cm deep seepage, reduced initial salinity by 91.95%, 76.73% and 65.49% in treatment 1 and by 87.68%, 72.84% and 64.73% in treatment 2 in 0.5, 1.0 and 1.5 m of soil profiles, respectively where permeated water amount was equal to 4.43, 2.13 and 1.31 units of pore water, respectively.

Our results agree with findings of some scholars. According to Nielsen and Biggar (1961) theory, for each pore volume, 50% and for two pore volumes 80% of salts should be removed from soil profile. According to scholars' reports, 75% of salts in a load san soil are transferred from one pore volume [Khosla and Abrol, 1979].

Van der Molen [31] showed in his study that 50% of soluble chloride salts are removed from soil profile by applying one pore volume. Also, a 120cm depth of leaching water is required to remove 98% of chlorides from deeps of soils which corresponds to 3.5 volumetric porosity units [30]. Asadi *et al* [1] reported in their study that in Amishiie soil series in southern regions of Khuzestan Province if no reclamation substance is used about 84% of initial salts will be leached out from soil while if 5 tones of the reclamation substance of sulfuric acid (concentration=9%) is used, about 78% of initial salts will be removed. In another study Mohammadzadeh *et al* [16] reported that in three soil series i.e. Sable, Karkhe and Salman in Jofeir region located in south west of Khuzestan, applying one and two pore volumes leached out about 50%, 75% and 65% of salts and about 75%, 83% and 78% of salts, respectively.

Table 7 shows five calculated mathematical statistics for observed and fitted date for two treatments of the studied soils.

Table 7: Calculated statistics for evaluation of models fitted to the studied soils.

Row	Model	treatment	CRM	RMSE	ME	CD	EF
1	Logarithmic	1	0.00	0.09	0.20	1.38	0.86
		2	-0.01	0.09	0.21	1.94	0.86
2	Inverse	1	0.00	0.14	0.31	3.74	0.27
		2	-0.01	0.14	0.30	4.71	0.26
3	Power	1	-0.41	0.56	2.59	0.07	-10.68
		2	-0.08	0.21	0.87	0.38	-0.63
4	Exponential	1	0.28	0.10	0.25	2.67	0.61
		2	0.13	0.10	0.24	4.01	0.61

The value of RMSE reported in this table indicates that logarithmic model has a better performance for treatment 1 than other models. Overestimation or underestimation tendency is almost the same in two logarithmic and reserve models and they have no significant difference in this regard. However, CRM value of both models indicates that the tendency is not so strong. Two logarithmic and reserve models and two exponential and power models have a significant difference. The minimum ME belongs to logarithmic model. The investigation of the five mentioned statistics in treatment 1 implies that with a negligible difference the fitted model follow a predicted trend but logarithmic model is better than other models for desalination of the studied region's soils. The RSME value of all four models in treatment 2 shows, again, that in this treatment logarithmic model has a better performance than other models. Also, the four mentioned models have the same overestimation or underestimation tendency but in all models CRM approaches to zero indicating that the tendency is not strong. The minimum ME belongs to logarithmic model. Again in this treatment the investigation of five statistics reveals that with a negligible difference, the fitted models follow the same trend but logarithmic model is better for desalination than other models.

Although in both treatments logarithmic model had a better efficiency than other models according to the calculated mathematical statistics, however, in the same condition no use of reclamation substance during desalination process is preferred to the use of sulfuric acid, as the reclamation substance. Therefore, relation (14) is introduced as the superior relation. In order to analyze the introduced desalination model the obtained model was compared with other models in terms of estimating required leaching water for removing soluble salts. Table 8 shows the results. According to comparisons, initial electrical conductivity of soil until 120cm depth of soil, ECf (final electrical conductivity) and equilibrium extract electrical conductivity were 46 dS/m, 4 dS/m and 1.23 dS/m, respectively.

Table 8: Comparison of the results of different empirical models for leaching.

Row	Empirical model's name	Required water for reclamation of different soil layers (m)					Geometric mean of required water for soil reclamation (m)	Model fitness order	Mathematical shape of model
		0-25	0-50	0-75	0-100	0-150			
1	Reeve (1957)	0.61	1.23	1.84	2.45	3.68	1.65	9	Hyperbolic
2	Dileman (1963)	0.70	1.39	2.09	2.78	4.17	1.88	10	Exponential
3	Leffelaar&Sharma (1977)	0.56	1.11	1.67	2.22	3.34	1.50	8	Hyperbolic
4	Hoffman (1980)	0.81	1.62	2.42	3.23	4.85	2.18	11	Hyperbolic
5	Pazira&Kawachi (1981)	0.49	0.98	1.47	1.96	2.93	1.32	7	Hyperbolic
6	Verma&Gupta (1989)	0.31	0.63	0.94	1.26	1.88	0.85	4	Power
7	Pazira&Keshvarz (1998)	0.32	0.64	0.96	1.28	1.91	0.86	5	Power
8	Rajabzadeh *et al.* (2009)	0.31	0.61	0.92	1.22	1.83	0.82	3	Exponential
9	Asadi *et al.* (2013)	0.16	0.32	0.48	0.64	0.97	0.43	1	Logarithmic
10	Mohammadzadeh *et al.* (2013)	0.46	0.92	1.38	1.84	2.76	1.24	6	Power
11	Novin (2014)	0.27	0.54	0.81	1.08	1.63	0.73	2	Logarithmic

According to results, only Asadi *et al*. [3] model underestimates leaching water volume compared with Novin model. Rajabzadeh *et al*. [25], Verma and Gupta [32] and Pazira and Keshavarz [22] models estimate leaching water volume slightly more than Novin model. Mohammadzadeh *et al* [16], Pazira and Kawachi [21], Leffelaar and Sharma [15], Reeve [27] and Deilman [9] models estimate leaching water more than Novin model. Hoffman [13] model lacks a satisfied fitness for estimating required leaching water for reclamation of soils compared with Novin model. The reason can be traced in the difference between physical and chemical characteristics of the studied soils as well as leaching implementation methods. Similar results have been reported by other scholars [19,23].

Table 9 shows required net leaching water for desalination of the studied region's soil based on relation (16). The results shown in this table indicate that a sudden fall in the initial electrical conductivity of soil profile up to 6 dS/m demands a considerable amount of leaching water while less amounts of leaching water are required to gradually reduce soil salinity in the form of step by step leaching. If the initial electrical conductivity of soil profile is about 46 dS/m and we decide to reduce it to 4 dS/m in depth of 1.5m, the required leaching water will be about 16274 m3/ha. To reduce initial electrical conductivity from 46 to 32 ds/m, the required leaching water will be 61 m3/ha. Similarly, to reduce initial electrical conductivity from 32 dS/m to 16 dS/m, from 16 dS/m to 8 dS/m and from 8 dS/m to 4 dS/m, required leaching water will be 389 m3/ha, 472 m3/ha and 733 m3/ha, respectively indicating that desalination of soil in lower electrical conductivity requires more leaching water than extreme salinity condition.

Table 9: Required water for reducing initial salinity in different depths of soil profile up to final salinity (EC_f=4dS/m).

initial salinity (dS/m)	soil depth (cm)					initial salinity (dS/m)	soil depth (cm)				
	0-25	0-50	0-75	0-100	0-150		0-25	0-50	0-75	0-100	0-150
6	0.003	0.005	0.008	0.011	0.016	28	0.187	0.374	0.561	0.748	1.122
8	0.012	0.024	0.037	0.049	0.073	30	0.199	0.399	0.598	0.798	1.197
10	0.028	0.056	0.084	0.112	0.169	32	0.211	0.422	0.633	0.844	1.266
12	0.047	0.095	0.142	0.190	0.285	34	0.222	0.443	0.665	0.866	1.329
14	0.068	0.136	0.204	0.272	0.408	36	0.231	0.463	0.694	0.926	1.388
16	0.088	0.177	0.265	0.353	0.530	38	0.241	0.481	0.722	0.962	1.443
18	0.108	0.216	0.324	0.431	0.647	40	0.249	0.498	0.747	0.996	1.494
20	0.126	0.252	0.379	0.505	0.757	42	0.257	0.514	0.771	1.028	1.542
22	0.143	0.287	0.430	0.573	0.860	44	0.264	0.529	0.793	1.057	1.586
24	0.159	0.318	0.477	0.636	0.954	46	0.271	0.542	0.874	1.085	1.627
26	0.174	0.347	0.521	0.695	1.042						

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