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Leaching Saline and Sodic Soils Along with Reclamation-Rotation Program in the Mid-Part of Khuzestan, Iran

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Abstract: The objective of this study was to study the desalination and desodification of sugarcane fields in Khuzestan plain. Leaching experiments were conducted on seven sites and intermittent ponding method was implemented for an applied water depth of 100 cm. Among four models fitted to desalinization and desodification estimations, an exponential model with a correlation coefficient of 0.735 and significance level at 1% was selected. In the second model, initial, final and equilibrium salinity, leaching efficiency and moisture content were considered and the fitted exponential model with $R^2 = 0.758$ was determined as the best desodification. A simulation model called leaching process was developed to determine the amount of water and time needed for reclamation of the whole soils of the study area. Two scenarios were presented: scenario I contained initial leaching, barely cultivation and leaving plant residual during warm seasons, scenario II proposed initial leaching and heavy disk operation and then a pre-irrigation operation. Considering lowering consumed water depth for the soil reclamation and also higher yield in the first scenario, scenario I was selected as a best choice.

Key words: Empirical model, Khuzestan plain, reclamation-rotation method, saline soil, sodic soil

INTRODUCTION

From a total 3 million ha of Khozestan plain, about 75000 ha are cultivatable and the rest of 2.25 million ha are faced with limitations such as salinification, sodification and water logging. These lands can be cultivated if one spends money for reclamations and also special if management procedures are considered. In saline soils, water absorption by the plant, which is conditioned to osmotic characteristics is scattered due to increase in salinity concentrations and this stops plant growth. In addition, existing ions in the soil such as sodium and chloride creates derangement and toxicity symptoms for plants. Generally, one of the reasons for low yields in irrigated fields in arid and semi-arid areas are due to the tendency of the soil in becoming sodic and saline. So, reclamation of the lands is highly considered in the proposed program. In order to reach a good economical efficiency both in agricultural and horticultural products, these reclamation procedures should be carried out beforehand. Before starting any reclamation program, a key question is put forward: How much water and for how long it is needed to reach the desired amount of salinity in the soil profile?

Determination of the amount of water needed for leaching is based on field tests and the derived curves. But this can be time and cost consuming. So, a better way is to use simulation models. In a proper model, it is possible to consider different managing operations and various situations and compare different scenarios, results and parameters easily and modify or change them where necessary.

Pazira *et al.* (1998) developed a model to determine the needed amount of water for leaching the soils in the east-south of Khuzestan. Soil electrical conductivity before and after leaching, equilibrium electrical conductivity and soil depth, were used as entering data for this model.

Researchers developed empirical models to determine the needed amount of water for leaching. These models are based on the soil types in the experimental location. Except for the model presented by Reeve, all other models are based on leaching using intermittent ponding method.

In intermittent ponding method, due to the unsaturated situation which is created, leaching efficiency is higher than continuous ponding method (Cote *et al.*, 2000). Ben-Gal *et al.* (2008) reported that excess in the

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yield depends on soil salinity when soil irrigated with saline water. Konukcu *et al.* (2005) showed that except for the effects of leaching on plant transpiration rate, salinity rate in the root zone is very important too.

Shani *et al.* (2007) developed a mathematical model to determine water absorption rate of the plants in high soil salinity rates. Corwin *et al.* (2007) in an economical evaluation for leaching methods, compared two kinds of methods and concluded that sustainable models such as WATSUTT are rather preferable than unsustainable ones like UNSATCHEM.

Khaksari *et al.* (2005a) in their study in Chahafzal area concluded that 80-85% of the salts can be removed from the soil by utilizing 100 cm of water. They also concluded that time intervals leaching periods, play a major role in leaching process. In another research, Khaksari *et al.* (2005b) compared the SWAP model with the LEACHC model. Their comparisons were based on derived Root Mean Square Error (RMSE), efficiency, CRM and the coefficient of determination. They showed that LEACHC gives better results as it uses different interaction transform mechanisms of the soil environments like absorption, sedimentations and dissolving rate.

Since field experiments are faced with the limitations such as being time and cost consuming, so, it is substituted by simulating models. These models can help the researchers in many aspects and gives relatively concise results too (Droogers *et al.*, 2000).

The main objective of this study was to study the desalination and desodification of Khuzestan plain soils in order to develop a reclamation-rotation program in the sugar cane fields.

MATERIALS AND METHODS

The study area is located in the mid-part of Khuzestan plain and covers an area of about 20167 ha. These lands are restricted by Dez River in the North and from the East; it reaches to Karoon river, while in the south it is restricted to the city of Ahwaz. This research was conducted from 2006 to 2008.

Soil texture is mostly silty clay. The lands of the study area are classified in S4A4 category by Willcox nemogram (FAO, 1973) while over 90% of the lands have salinity limitations from large to relatively large scale. Seven sites were selected by primary investigation of soil salinity maps. Some physical characteristics of different soil layers before leaching are listed in Table 1.

Water amount needed for leaching was supplied from Karoon River. Intermittent ponding method (Loáiciga and Allison, 2007) was used with six double rings (in a circular area with 10 m in diameter) and total water depth was

Table 1: Some physical characteristics of the soil layers before leaching

Soil moisture deficit (cm)	Total porosity (%)	Bulk density (g cm⁻³)	Permanent wilting point	Field capacity	Water content	Soil depth (cm)
			----------------- (%) -----------------			
8.3	48.0	1.39	12.2	36.3	12.3	0-25
5.9	40.0	1.57	11.7	31.0	15.9	25-50
2.6	40.0	1.59	12.0	23.0	16.6	50-75
2.5	44.0	1.46	11.8	23.0	16.3	75-100
0.8	38.6	1.62	10.6	20.7	18.7	100-125
2.2	44.0	1.52	12.3	23.0	17.1	125-150

100 cm (4 depths of 25 cm). Soil sampling was picked (NRCS, 1992) with the following frequencies: 0-25, 25-50, 50-75, 75-100, 100-125 and 125-150 cm. Also, three replications were conducted in each treatment. Soil samples before and after leaching were analyzed in the laboratory. Some chemical characteristics of the different soil layers are listed in Table 2.

Equilibrium salinity/sodicity was measured after infiltration of 100 cm of water from 0-5 cm depth in 3 replications. Using the values in Table 1 and 2, desalinization values were extracted via the following formulas:

$$X = [D_{lw}/D_s] \qquad (1)$$

$$Y = \left[(EC_f - EC_{eq})/(EC_i - EC_{eq})\right] \qquad (2)$$

and desodification values were extracted via

$$X = [D_{lw}/D_s] \qquad (3)$$

$$Y = \left[(ESP_f - ESP_{eq})/(ESP_i - ESP_{eq})\right] \qquad (4)$$

Where:

EC_i and Ec_f : Electrical conductivity before and after leaching operation (in this study EC used to describe of the salinity)

ESP_i and ESP_f : Exchangeable sodium before and after leaching operation

Ec_{eq} : Equilibrium electrical conductivity

ESP_{eq} : Equilibrium exchangeable sodium

Four models (exponential, power, reverse and logarithmic) were fitted on all computed X and Y. Then efficiency coefficient, standard error at the significance level of 1% for each model was compared. Among them, the best fitted model with the highest efficiency were selected and presented to be implemented.

Needed water for leaching to decrease soil salinity was determined using the fitted model and both scenarios were considered. Reclamation-rotation program for the soils in the permanent sugarcane field of the study area

Table 2: Some chemical characteristics of soil layers before leaching

ESP	SO_4^-	HCO_3^-	Cl^-	$Ca^{++}+Mg^{++}$	Na^+	CEC	Gypsum	pH	EC_e (dS m^{-1})	Soil depth (cm)	Sampling time
			(meq L^{-1})				----(meq 100 g^{-1})---				
52.5	75.2	0.4	3120.0	696.0	2535.0	10.4	62.0	7.2	104.7	0-25	Before leaching
41.2	92.0	0.7	908.0	285.6	696.0	11.6	39.7	7.7	40.9	25-50	
35.0	95.4	0.7	536.0	170.4	462.0	11.4	26.1	7.9	24.4	50-75	
33.9	83.6	0.7	408.0	132.8	358.0	12.5	10.7	8.0	32.6	75-100	
32.0	85.2	0.9	380.0	132.4	338.0	11.2	9.7	7.9	30.7	100-125	
36.5	81.6	0.9	348.0	120.8	309.0	12.2	13.9	8.0	29.6	125-150	
9.0	42.0	1.2	804.0	27.7	20.7	12.3	56.8	7.9	3.3	0-25	After leaching
9.8	40.0	1.2	8.0	25.0	20.9	11.6	33.0	7.9	3.4	25-50	
24.6	60.5	1.2	1306.0	36.7	34.4	11.2	34.8	7.9	5.7	50-75	
35.6	84.0	0.9	210.0	84.0	215.5	11.8	28.4	8.0	15.4	75-100	
39.7	82.0	0.9	380.0	140.4	310.0	11.0	22.0	7.9	26.4	100-125	
41.1	80.0	0.9	334.0	129.0	276.0	10.7	21.8	7.9	29.5	125-150	

was presented while in the scenario I, regarding initial salinity of the layers of 0-25, 25-50, 50-75, 75-100, 100-125 and 125-150 cm which are 104.7, 40.9, 34.4, 32.6, 30.7 and 29.6 dS m^{-1}.

Considering the noted status, a simulated model called leaching process was developed and both scenarios were considered. Needed water for initial leaching necessary to decrease soil salinity down to the suitable threshold for barley and sugarcane cultivation was determined using the simulated model. The following data were used in the model as input:

- Initial salinity of different soil layers
- Leaching efficiency coefficient (0.27)
- Equilibrium soil electrical conductivity (EC_{eq} = 2.2 dS m^{-1})
- Soil moisture content (0.31) as soil moisture at this level is a little more than the field capacity, desalination would be carried on better
- Final electrical conductivity (EC_f)

RESULTS AND DISCUSSION

Desalination and desodification of the soils: In order to implement desalination and desodification of the soils, empirical models were considered to develop a new model for the study area. An exponential model with the efficiency coefficient (R^2) equal to 0.735 and Standard Error (SE) of 0.68 significance level at 1% was chosen as the best fitted model as relation (4).

$$Y = 0.222 * \exp[-1.047 * x]$$

where, X and Y were explained as relations 1 and 2.

Leaching efficiency of the soil profile (f) and soil moisture content (θ_v) were derived from the Eq. 5:

$$Y = 0.222 * \exp\left[-1.047\left(f/\theta_y\right) - \left(D_s/D_{lw}\right)\right] \qquad (5)$$
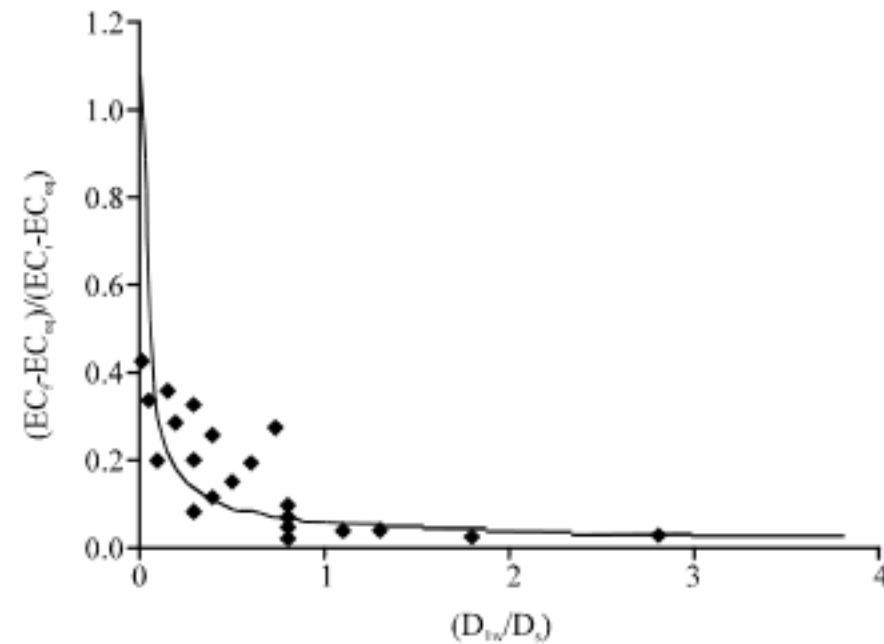

Fig. 1: Soil desalinization curve in the study area

As soil texture of the study area is heavy, (f) would be equal to 0.27 and the soil moisture content was estimated to be equal to 0.31. When the desalinization process was considered according to the field experiments, the Eq. 6 was developed with $R^2 = 0.758$.

$$Y = 0.689 * \exp[-0.723 * X] \qquad (6)$$

where, X and Y were explained as relations 3 and 4.

Final equation was conducted as relation 7.

$$\left(ESP_f - ESP_{eq}\right)/\left(ESP_i - ESP_{eq}\right) = 0.689 * \exp\left[-0.723 * \left(f/\theta_v\right)/\left(D_{lw}/D_s\right)\right] \qquad (7)$$

Desalinization and desodification curves were presented in Fig. 1 and 2. Using these results, net water depth (D_{lw}) needed for decreasing soil salinity and exchangeable sodium can be determined.

The results of comparison between existing empirical models and the proposed model (Eq. 4) were listed in Table 3. Initial salinity in the depth of 150 cm is equal to 45 dS m^{-1} and final salinity would be around 8 dS m^{-1}. It is possible to conclude that models of Pazira *et al*. (1998), after the proposed model of this research consume less

Table 3: Results after application different empirical models

| | | Needed water for soil reclamation (cm) | | | | | |
| | | Soil depth (D_s) (cm) | | | | Empirical model | |
Rank*	Weighted mean needed water (cm)	100	75	50	25	Year	Models
1	33.0	13.0	27.0	40.0	54.0	2008	Proposed model
2	39.0	13.0	26.0	39.0	51.0	1998	Pazira and Keshavarz
6	58.0	19.0	39.0	58.0	78.0	1989	Verma and Gupta
4	51.0	17.0	34.0	51.0	67.0	1981	Pazira and Kawachi
5	55.0	18.0	37.0	55.0	74.0	1980	Hoffman
3	46.0	15.0	30.0	46.0	61.0	1977	Leffelar and Shama
8	150.0	50.0	100.0	150.0	200.0	1963	Dieleman
7	122.0	41.0	83.0	122.0	163.0	1957	Reeve

*Based on amount of needed water
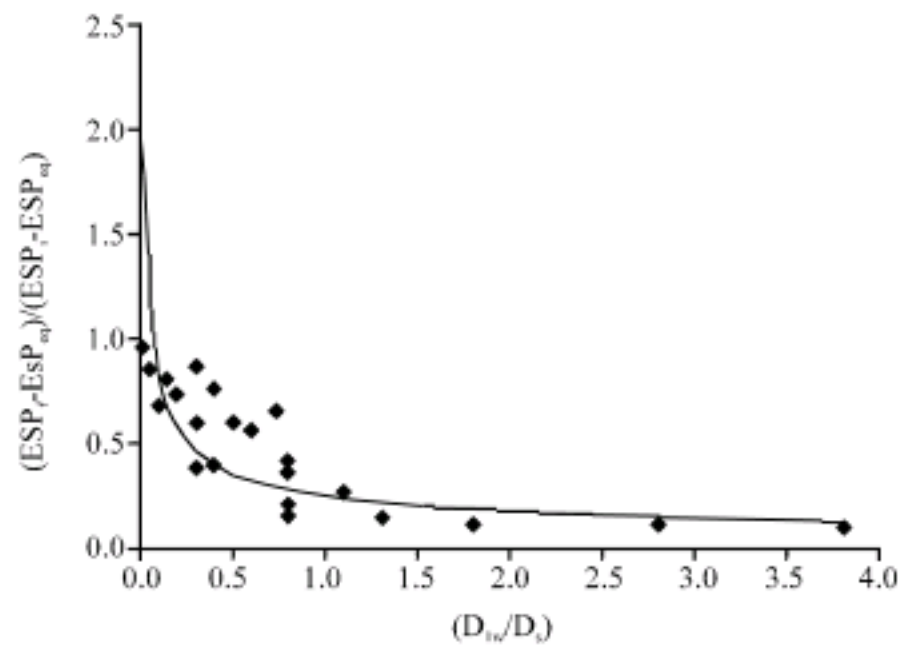
Fig. 2: Soil desodification curve in the study area

Fig. 3: Salinity changes in the soil profile after initial leaching

water in the leaching process, respectively. Also other models such as Verma and Gupta, Reeve and Dieleman can not be fitted at all regarding to the soil and water characteristics of the study area. Table 3 shows the results after the application of the proposed model along with its order in the fitting status in the study area.

Proposed reclamatin-rotation program

Scenario I: Based on the proposed model, the amount of water needed to leach for removing the salinity out of the 25 cm layer and reaching to final electrical conductivity equal to 8 dS m^{-1} (where the yield efficiency for barley is 100%), was estimated to be around 37.5 cm. As deep percolation in the field ponding was estimated about 1.3 cm day^{-1}, maximum needed time for percolation of 37.5 cm water would be 29 days.

Evaporation during summer is very high. For example, data derived from class A evaporation pan shows values of 521.7 and 410.7 mm in August and September, respectively, while during autumn season, they reach to 283.3 and 167.8 mm in October and November, respectively. So it is better to implement leaching operation in the months with lower evaporation rate. Calculations shows that during percolation time, average 107.2 mm evaporation occurs, so total gross needed water
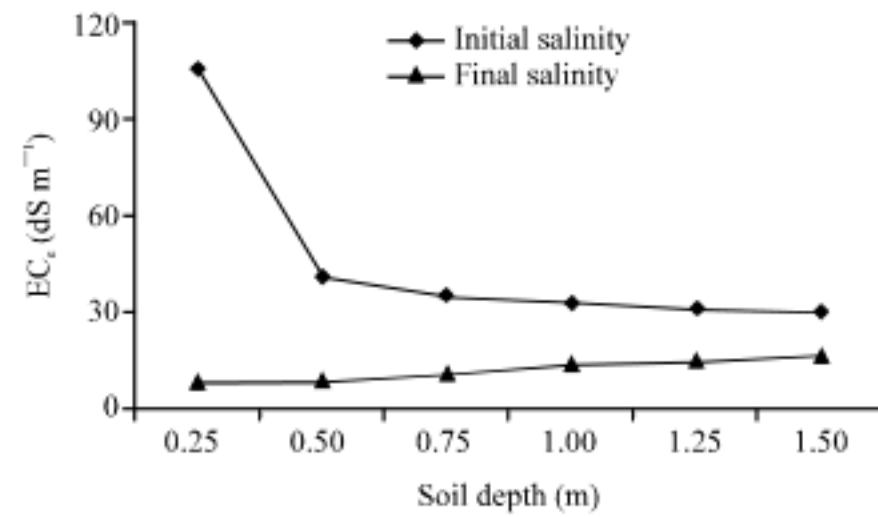
for leaching would be 51.7 cm. It is recommended to use 4 alterations (13 cm depth water for each). Three days are considered for water percolation between the time intervals. Therefore, it is proposed to start leaching procedure on October 1 and end it on November 22. Figure 3 shows salinity changes of the soil layers after initial leaching.

Figure 3 shows after leaching operations, final salinity in the lower layers of the soil profile has been increased. This is a cause of leaching procedures of the higher layers and salt transformation to the lower layers. So, after leaching operation, when soil moisture reaches to the field capacity, barely should be cultivated in late November. At this time, Barley seeds can use normal precipitation effectively. Water requirement for barely in the study area was estimated about 3377 m^3 ha^{-1} (with the efficiency of 53%). Out of this amount, a total of 12.84 cm is removed from the root zone as deep percolation occurs and so it causes more decrease in salinity of the soil layers too. Figure 4 shows salinity changes of the soil layers after a percolation of some 12.84 cm over 160 days since barely cultivation. During growing seasons, salinity in the soil profile may be increased up to 16 dS m^{-1}. Considering the salinity of the applied water (1.37 dS m^{-1}), leaching requirement (LR), was determined (0.035), so that, the soil salinity during cultivation in the first soil layer,
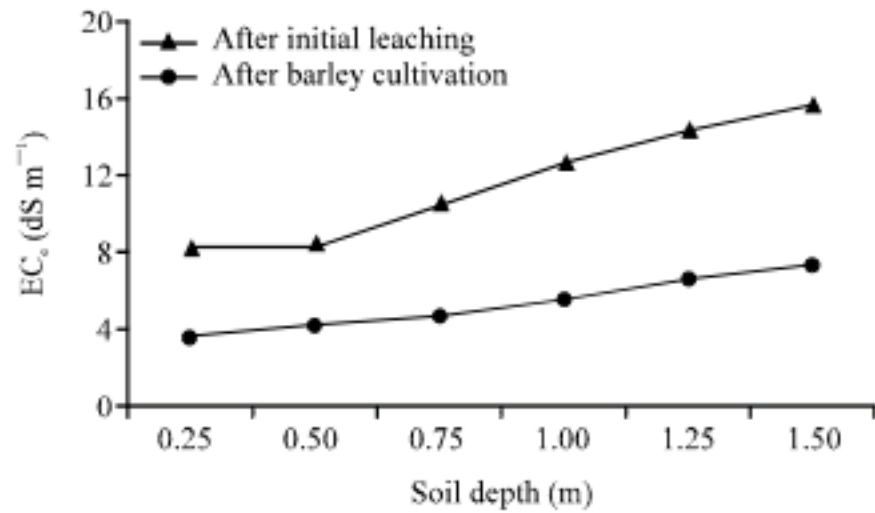
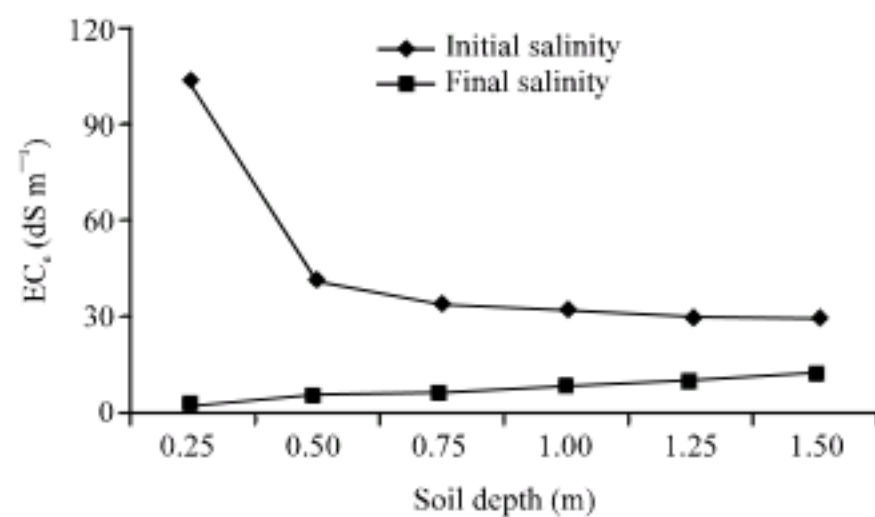Fig. 4: Salinity changes in the soil profile after barely cultivation

Fig. 5: Salinity changes in the soil profile after initial leaching

can be controlled at 8 dS m^{-1}. Regarding to deep percolation rate causing by barely cultivation, there is no need to consider leaching requirement in the irrigation process.

In the sodification process, all procedures are similar to the desalinization ones. For instance, exchangeable sodium the layer of 25 cm of the soil profile is about 52.5% and equilibrium sodification of the area is 4.2%. While proceed the scenario I, it would be decreased down to 17.15. During the soil and land reclamation, it is recommended to cover the fields with plant residuals especially during the first year of the program. As plant residual helps preventing salinity to return to the soil surface.

Considering the above noted statements, reclamation program is including initial leaching, barley cultivation and using plant residuals and finally an irrigation process before the bed preparedness for sugarcane cuttages.

Scenario II: Soil reclamation procedures should be ended before planting sugarcane cuttages take place. Using the proposed model, needed fresh water depth for a decrease in dissolved salts from 104.7 dS m^{-1} down to 3.4 dS m^{-1} (at this salinity rate, the yield efficiency would be 90%) in depth 25 cm was determined. It was estimated to be around 81 cm. As deep percolation is about 1.3 cm day^{-1},

the needed time for the percolation of the mentioned amount would be maximum 63 days. Due to high evaporation during April to late January in the region, it is recommended to implement initial leaching from February to mid-May. During the percolation period (63 days), average evaporation would be about 273.7 mm. By adding evaporation rate with 5.74 cm water depth needed to compensate soil moisture deficit and subtracting 64 mm rainfall from net water depth, total applied water depth for leaching layer of 25 cm would be 108 cm. It is proposed to use this amount in 4 alterations (27 cm in each). So, starting point of leaching operation would be on January 20 and it would be ended on April 23. Figure 5 shows final salinity in the soil layers profile after initial leaching.

After initial leaching, it is recommended to use a heavy disk to break the probable existing crusts. This would minimize capillary current and then evaporation from the soil surface would be decreased. If during the fallow period (even after heavy disk), still surface evaporation happened, salinity of the layer of 25 cm has been increased up to 3.68 dS m^{-1}. As during soil treatment for planting sugarcane cuttages, irrigation is implemented, the salinity of soil surface layer is estimated to be around 3.4 dS m^{-1}. Besides, continuous leaching via deep percolation is still in progress and it would lower it in the soil profile. Considering the above noted, we can conclude that soil reclamation program using scenario II is including: initial leaching, heavy disk and then an irrigation before preparing the bed for planting sugarcane cuttages.

CONCLUSION

It is quite clear that scenario (I) is a better choice because barley cultivation would remove the remained salts and then soil profile would reach a relevant and bearable amount of salinity so that sugarcane can grow easily. Also consumed water during reclamation procedures in this scenario is much lower compared to the other scenario while the yield is higher as well. It must be noted that the continuation of the soil productivity and prevention from a recurrence of salinity concentration is conditioned by the implantation of proper management and depends on relevant utilization of the soil and water sources.

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