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Investigating the Effect of Applying Drainaged-water on Wheat Yield Using SALTMED Model

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ABSTRACT: Occurrence of drought stress at the end of the wheat growing season (grain filling stage) is one of the most common stresses in the Khuzestan province. At this stage of plant growth, on one hand rainfall and water resources are reduced and on the other hand temperature and crop water requirement increase. At this stage using drainaged-water of the farms (saline water) for irrigation could be a suitable solution. First the SALTMED model was calibrated and verified by using the data from field experiments and then it was used to simulate effect of saline water (drainage ed-water) on the wheat yield and accumulation of salts in the soil profile. Model evaluation results showed that the model is reasonably able to simulate the effect of saline water on wheat yield and accumulation of salts in the root zone soil profile with a good performance. The values of evaluation indices of RMSE, MPE, D-index and r^2 between simulated and measured yields were 409 kg, 5%, 0.84 and 0.99, respectively and the values of cited indices between the soil salinity simulated by the model and the measured soil salinity were 1 dS/m, 12%, 0.89 and 0.92, respectively. The simulation results showed that in the case of restriction of irrigation water (non-saline) at grain filling stages (no irrigation water restrictions in the early stages of growth), the saline water with EC≤4 dS/m can be used in heavy soils (loam - clay) and the saline water with EC≤6 dS/m can be used in light soils. Whereas farms have appropriate drainage canal and the leaching water requirement should be considered for leaching salts before the start of the next cropping season.

***Keywords*:** SALTMED model, drainaged-water, wheat yield, soil salinity

INTRODUCTION

In the climatic conditions of Khuzestan, available water in the rivers and networks usually cover water requirements of wheat from planting time to heading stage (except in years with low rainfall), but from flowering to physiological maturity (March to end of April) a wide range of wheat fields which are located in the southern regions of the Khuzestan (43%) are faced with drought stress due to increased water demand of wheat fields, presence of competing crops and limited water availability (2). Farmers in these areas irrigate their farms by using drainaged-water (water salinity range from 4 to 15 dS/m) directly or combined with non-saline water to reduce the impact of drought stress on wheat yields. In addition to plant breeding strategies for coping with drought stress, the use of drainaged-water in insensitive stages of plant by conducting specific management (due to plant responses and changes in soil physical and chemical properties) can also be an effective strategy (3, 9, 10, 11, 12, 13, 15 ,17, 23 and 24). There is a great deal of experience in the world about application of saline water, both in the farmer communities and in the research studies. Kiani and Asadi (11) in Golestan province of Iran showed that irrigation with saline water (14 dS/m) reduced wheat grain yield only 10% compared to irrigation with non-saline water. Although the application of saline water led to an increase in soil salinity at end of cropping season, the autumn rains reduced soil salinity at the beginning of next cropping season. Ma et al (12) stated that 91% of wheat yield under using fresh water conditions can be obtained by the use of saline water (EC = 5.4 dS/m) and considering leaching water requirement. Due to the application of saline water the levels of salinity was rapidly increased to a depth of 80 cm of soil, where the problem of accumulation of salts was solved at the start of the next cropping season with leaching of the soil profile to a depth of 150 cm.

Sharma et al., (26) analyzed the effects of irrigation using drainaged-water with different levels of salinity (6, 9, 12, 18 and 27 dS/m) on the soil salinity and on the growth and yield of wheat in a seven year experiment (first irrigation with non-saline water). Their results showed that the use of saline water with a salinity of 6, 9, 12, 18 and 22 dS/m causes yield decrease an average 4, 10, 16 and 24%, respectively compared to irrigation with non-saline water.

Chauhan et al., (4) concluded from their experiments that the use of saline water (EC=8 dS/m) is possible for irrigation of wheat in India except for the germination stage. Irrigation with water with an electrical conductivity between 8 to 12 dS/m can be used twice as supplemental irrigation of wheat. Under such conditions, more than 90% of yield under applying fresh water is obtainable. They stated that irrigation with saline water (except in the germination stage) in decreased rainfall conditions will increase the yield compared to no irrigation conditions.

Great attention must be paid to application of saline water for irrigation of crops and specific management should be applied to taking account plant characteristics, climate and soil conditions. Because the lack of a proper management not only may not lead to increase crop yield but also may result in salinization and degradation of soil and pollution of groundwater (7, 13, 14, 19, 24 and 28), on the other hand soil salinity is a gradual and long-term process which the short-term experiments are not able to show the effects of water salinity on soil. For this reason, models have been developed for predicting long-term effects of salinity on soil and environment, crop yield, soil moisture and soil profile salinity under different irrigation strategies (mixture of saline and non-saline water, alternative use of saline and non-saline water), irrigation water and leaching requirements in parallel with farm and greenhouse experiments (19, 20, 22 and 28) and used as a beneficial tool for managing irrigation water to prevent increasing salt concentration in the root zone. Some of the existing models are designed for a specific purpose, in particular processes such as the movement of water and solutes, penetration, leaching or water uptake by plant roots or a combination of them. These models are not capable to simulate and predict effect of all factors influencing water, soil and plant systems which play an important role in irrigation management especially application of saline water. SALTMED model is a comprehensive model which consider water, soil and plant systems and the effective factors. It can be used for a variety of soils, various crop and application of chemical fertilizers in different climatic conditions (19, 20 and 22). This model simulates dry matter and yield of crops, soil salinity, soil moisture profiles, leaching requirements and soil nitrogen dynamics, soil temperature, water uptake and evapotranspiration.

Ragab et al., (20 and 21) calibrated and validated SALTMED model for management of saline water application for tomato under in Egypt and Syria. They stated that this model can serve as a very useful tool for management of water, crop and soil under field conditions. They showed that the model was able to simulate the effect of water salinity on yield, water uptake, soil water content and soil salinity distribution properly. Their results showed that a single irrigation with saline water (7 dS/m) reduced yield by 50%.

Flowers et al., (5) studied the possible irrigation strategies using the SALTMED model in Mediterranean regions that were prone to salinity. The results indicated the robustness of the model in simulating crop yield. In other words, there was a good agreement between predicted and measured yields.

Montnegro et al., (15) used the SALTMED model for the management of water application in a semiarid region of Brazil. They calibrated and validated the model for carrot and lettuce and stated that the model could simulate soil water dynamics and crop yields in a favorable manner. Using this model, they investigated the effect of amounts of application irrigation water, number of irrigations and soil type on the crop yield. Simulation results showed that deficit irrigation is a useful method to save water in this region. The number of irrigations influenced the crop water consumption and depending on the soil type it was variable.

Razzaghi et al., (23) evaluated the SALTMED model for simulating growth and yield of quinoa to soil salinity. Their results showed that the model simulates the above-ground biomass, grain yield, moisture and the salinity of the soil satisfactorily.

Hirich et al., (8) used the SALTMED model to simulate effect of deficit irrigation on growth and yield of three crops of quinoa, chickpeas and sweet corn in Morocco and showed that the model is able to simulate the soil moisture, above-ground biomass and grain yield under different deficit irrigation strategies.

Thus, the aim of this study was to investigate the effects of drainaged-water (saline water) application during grain filling on grain yield and salts concentration in the soil profile and expansion of the results of field experiments to the other environmental conditions and designation of simulation experiments using SALTMED model.

MATERIALS AND METHODS

SALTMED model is designed to taking account a number of physical processes that occur simultaneously under field conditions. This model includes key processes of evapotranspiration, plant water uptake, water and solutes transport under different irrigation systems, drainage and relationship between crop yield and water use (19, 20 and 22).
It is so weak. Develop it more as possible.

2.1. Field experiments

The following field experiments were used to calibrate and validate the SALTMED model. A field experiment was conducted in randomized complete block design over the cropping year of 2010-2011 in Agricultural Research Station of Ahvaz (latitude 31°2' North and longitude 48°4' East and 23 m above sea level). In this experiment, all experimental plots were irrigated equally with canal waters (non-saline EC=2 dS/m) to anthesis. Then at in the start of grain filling stage irrigation treatments include: 1- irrigation with canal water (non-saline) 2- No irrigation 3- irrigation with moderately saline water (EC=4 dS/m) 4- irrigation with saline water (EC=6 dS/m) 5- irrigation with saline water (EC=8 dS/m) 6- irrigation with saline water (EC=10 dS/m) and 7- irrigation with saline water (EC=12 dS/m) were applied. In order to provide the required water with different salinities, saline drainaged-water (EC=32 dS/m) was diluted with canal water (non-saline EC=2) to reach the desired EC. Water salinity was set by the portable EC-meter. Also the soil profile was sampled to the depth of root development (1.2 m) before planting and EC values of soil saturation extract were measured. In this experiment, cultivar Chamran (bread wheat) was planted with a seed density of 400 seeds per square meter and in 6 lines with a length of 3 m and line spacing of 0.2 m. All plots were managed (nutrition, weed control, etc.) uniformly. At the time of maturity, biological production, grain yield, yield components and EC values of soil saturation extract in effective rooting depth were measured. After harvest, the required irrigation for leaching the accumulated salts was performed and then EC values of saturation extract in the root zone were measured. The obtained results were analyzed by MSTATC software and variance analysis and mean comparison were performed using LSD method.

Data from another experiment which was carried out by Goosheh et al with the title of "optimum irrigation regime for wheat based on the reduction of soil moisture in different water salinity conditions" (6) were used to model evaluation as well. This experiment was performed in Agricultural Research Station of Shavoor, located 60 km to the north of Ahvaz city with the geographical location of 31 degrees northern latitude and 48°27' eastern longitude and 32 m above sea level. This experiment was conducted in randomized complete block factorial design. The first factor was irrigation intervals based on the soil moisture less than the field capacity including three levels of 70%, 50% and 30% of field capacity. The second factor was salinity levels of irrigation water including: 1- electrical conductivity of less than 2 dS/m, 2- electrical conductivity between 3-5 dS/m and 3- electrical conductivity between 6-8 dS/m.
The model was calibrated and vegetation parameters of cultivar Chamran were determined by using the data from 70% water requirement treatment and its different salinities. Then the model validation was performed by using the data from treatments with 50% and 30% of field capacity and the data from Ahvaz experiment (2010-2011). Evaluation indexes of root mean square error (RMSE), mean bias error (MBE), Willmott agreement index (d), linear regression and 1:1 line were used to compare the simulated data with the data obtained from the field experiments.

$$RMSE = \left[\sum_{i=1}^{n} \frac{(P_i - O_i)^2}{n} \right]^{0.5} \quad (1)$$

$$MBE = \frac{\sum_{i=1}^{n} (Pi - Oi)}{n} \quad (2)$$

$$d = \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum \left(\left| P_i - O_{i_{avg}} \right| + \left| Oi - Oi_{avg} \right| \right)^2} \quad (3)$$

P_i and O_i are the predicted and observed values, respectively, n is the number of observations and O_{iavg} is the average of observed values.

2.2. Simulation experiment design

A simulation experiment was defined as temporal analysis of application saline water on wheat yield and soil salinity. In this experiment the objective was irrigating wheat with saline waters at start of grain filling stage over 12 years. The irrigation treatments consist of 1- irrigation with canal water (EC=2 dS/m), 2- no irrigation 3- irrigation with saline water (EC=4 dS/m), 4- irrigation with saline water (EC=6 dS/m), 5- irrigation with saline water (EC=8 dS/m), 6- irrigation with saline water (EC=10 dS/m), 7- irrigation with saline water (EC=12 dS/m), 8- irrigation with saline water (EC=14 dS/m), 9- irrigation with saline water (EC=16 dS/m), 10- irrigation with saline water (EC=18 dS/m) and 11- irrigation with saline water (EC=20 dS/m), which were performed in heavy soil (silt, clay, loam) and light soil (sandy-loam) independently over 12 successive years. The model outputs were analyzed by box plot analysis in Sigmaplot software.

3-1. Field experiment

ANOVA table shows that the effect of saline water application at grain filling stage on above-ground dry matter, grain yield, thousand grain weights and the concentration of salts in the soil profile was significant.

Table 1. Analysis of variance of the measured variables

Source of variation	Degree of freedom	Mean of squares			
		Above-ground dry matter (kg/ha)	Grain yield (kg/ha)	Thousand grain weight (g)	Soil salinity (dS/m) (0-60 cm)
Replication	2	2162920**	3320.8**	9.14*	21**
Saline water	6	46038**	69081**	11.4**	7.3**
Error	12	1316	221	0.31	0.285
CV%		2.8	4.8	1.3	11

**: significant at 1% probability level

*: significant at 5% probability level

Maximum and minimum of above-ground dry matter production were belong to treatments of canal water application (EC=2 dS/m) and saline water application (EC=12 dS/m), respectively. No irrigation at grain filling stage resulted in a 1% decrease (equivalent to 137 kg per hectare) of dry matter. The use of relatively saline water (EC=4 dS/m) resulted in a 0.8% decrease (109 kg per hectare) of dry matter. Which indicates that the use of relatively saline water (EC=4 dS/m) can partially compensate the effects of drought in this stage. While the use of saline waters with EC= 6, 8, 10 & 12 dS/m, reduced the dry matter 1.5, 2, 2.4 & 2.6%, respectively and it intensified drought stress in this stage (Table 2). Since the saline water is used in the grain filling stage, the effect appears only on the component of thousand grain weight. As the mean comparisons table (Table 2) indicates, the use of saline water with EC=4 dS/m in Ahvaz climatic conditions can reduce the effect of drought stress during grain filling grain weight. While, application of saline water with EC>4 dS/m under such conditions not only does not have a positive effect on grain weight but also intensifies effect of drought stress and reduces grain weight. At the end of crop growing season accumulation of salts in the soil profile (rooting depth) increased along with the increase in salinity of water. Although there is no significant difference between accumulation of salts in treatments of irrigation with saline water (EC=4 dS/m) and with canal water.

Table 2. Mean comparisons of treatments

Treatment	Above-ground dry matter (kg/ha)	Grain yield (kg/ha)	Thousand grain weight (g)	Soil salinity (dS/m)
Irrigation with canal water in all stages	13302a	5321a	43.6a	2.96e
No irrigation in the grain filling stage	13165b	5266b	42.3bc	3.6e
Irrigation with saline water (EC=4 dS/m) in the grain filling stage	13193b	5277b	43ab	3.8e
Irrigation with saline water (EC=6 dS/m) in the grain filling stage	13096c	5238c	41.6c	4.5cd
Irrigation with saline water (EC=8 dS/m) in the grain filling stage	13033cd	5213ed	40.6d	5.4bc
Irrigation with saline water (EC=10 dS/m) in the grain filling stage	12987de	5194de	39.3e	6.3b
Irrigation with saline water (EC=12 dS/m) in the grain filling stage	12955e	5181e	38.3f	7.2a
LSD	64.5	26.4	0.99	0.94

3.2. Model Calibration

SALTMED model was calibrated for cultivar Chamran based on the observations and data obtained from study of Gooshe et al., (2010) and other eco-physiological characteristics of this cultivar.

Table 3. Calibrated parameters for Chamran wheat cultivar

Growth Stage Lenths	Day	GDD	Kc	Kcb	Fc	$\prod_{50}$(dS/m)
Initial stage	20	150	0.3	0.18	0.23	11
Development stage	30	750	-	-	-	-
Mid stage	55	900	1.15	1.1	0.9	9
End stage	30	600	0.33	0.22	0.3	9
Crop growth parameters						
	Radiation interception Effect		2 g/MJ			
	Photosynthesis Efficiency		0.65			
	Extinction Coefficient		0.50			
	PAR Ratio					
	Leaf Nitrogen Content Effect		0.2			
	Leaf-N fraction		0.3			
	Leaf Biomass fraction		0.2 gN/g dry weight			
	N_{max}		0.001 gN/g dry weight			
	N_{min}					
			20 °C			
	Respiration Effect					
	Base Temperature					
	Q_{10}		2.0			
	Respiration Coefficient		0.01			
	Harvest index		0.4			
	Water uptake Effect					
	Reduction from potential to actual water uptake		0.75			
	Temperature Effect					
	T_{max}					
			45 °C			
	T_{opt2}		35 °C			
	T_{opt1}		15 °C			
	T_{min}		2 °C			

3.3. Model Validation

The results of the model performance showed that it is reasoably able to simulate the grain yield and accumulation of salts in the root zone of the soil profile. The values of evaluation indices of RMSE, MPE, D-index and r^2 between simulated and measured yields were 409 kg, 5%, 0.84 and 0.99, respectively Figure 1 (a). and the values of the indices of RMSE, MPE, D-index and r^2 between the soil salinity simulated by the model and the measured soil salinity were 1 dS/m, 12%, 0.89 and 0.92, respectively Figure 1 (b). Therefore, same as the model evaluation by other researchers (8, 15, 21 and 23), the model robustness was approved in this study, and it can be used for simulation purposes of the effects using saline water on the yield and the soil salinity.

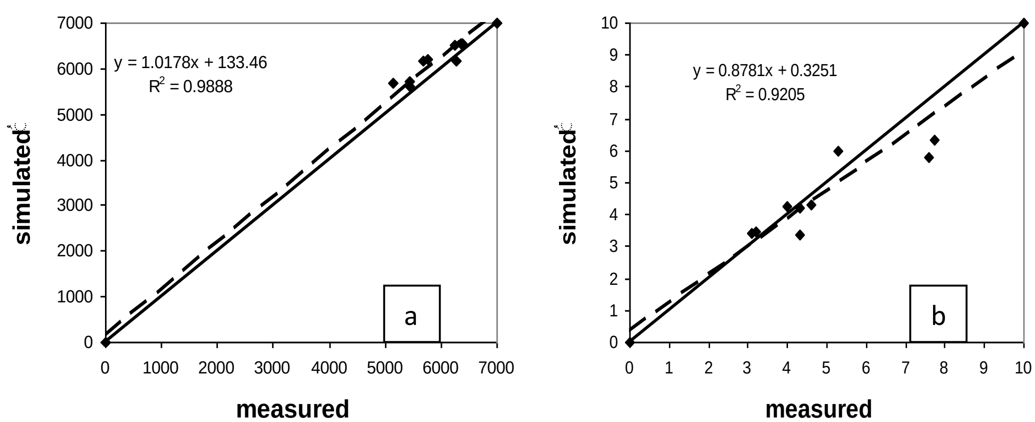

Figure 1. Comparison of the simulated and measured grain yield (a) and simulated and measured soil salinities at the end of the growing season (b)

3.4. SALTMED model application for simulating use of saline water for irrigation of wheat

The simulation results for one season using fresh (canal) water (irrigation with non-saline water according to plant in sandy-loam soil and silty-clay-loam soil indicate that grain yield and concentration of salts in the soil profile at end of season depending on the climatic conditions in different agronomic seasons were variable. For example, the production yield in irrigation treatment with canal water, over the 12 seasons, depending on environmental conditions (year) ranged from 5040 to 6220 kg per hectare in silty-clay-loam soil and ranged from 4980 to 6080 kg per hectare in sandy-loam soil (Figure 2). This changes indicate the effect of environmental factors, particularly temperature on evapotranspiration and crop water demand and the amount and distribution of precipitation as a source of supplying a part of the crop water requirement which varied in different years. Risk analysis of the simulation results indicate that in irrigation treatment with canal water (EC=2 dS/m) in all stages of the plant growth in silty-clay-loam soil, with a probability of 90, 75, 50, 25 and 10% of the years, attainable is 5080, 5350, 5760, 5950 and 6195, respectively. Whereas in absence of irrigation at grain filling stage the attainable yield is 4940, 5210, 5580, 5890 and 5995 kg per hectare with a probability of 90, 75, 50, 25 and 10%, respectively. The results indicate that during the normal years, precipitation more than 200 mm, irrigation at the emergence, seedling and tillering, stem elongation, and anthesis stages and no irrigation at grain filling stage in silty-clay-loam soil reduces the yield at about 160 kg per hectare (2.8%) and in sandy-loam soil about 170 kg per hectare (3%), in other words the effect of drought stress is negligible. While in dry years, irrigation at stem elongation and grain filling stages is essential to maintain high performance of wheat crop. In case of lack of access to canal water (non-saline water) grain filling stage, under such circumstances, the use of saline water with EC≤4 dS/m in silty-clay-loam soil and EC≤6 dS/m in sandy-loam soil could compensate a part of the yield loss caused by drought stress. While the use of saline water with EC>4 dS/m in farms with silty-clay-loam texture and EC>6 dS/m in farms with sandy-loam texture under these conditions not only do not have a positive impact on yield but also reduces the yield due to the negative effects on water uptake by the roots (Figure 2). However, it is possible that during very dry and low rainfall years the process of yield response to water salinity changes, and application of saline water with even higher ECs be justified and recommended. Simulation results in silty-clay-loam soil compared with a fairly light soil (sandy-loam) showed that the soil texture plays an important role in water storage and the delay in incidence of drought stress in the plant. In a relatively light soil due to the low water holding capacity, under conditions of drought stress irrigation with saline water EC≤6 dS/m is also recommendable at grain filling stages and can reduce the negative impact of drought stress to some extent.

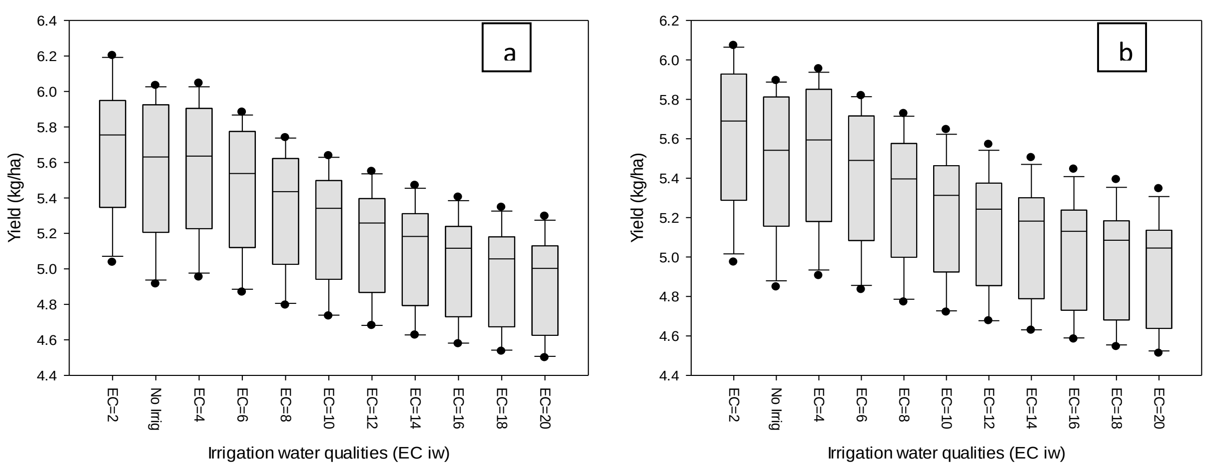

Figure 2. The probability of yield production in different treatments of saline water application at grain filling stage in silty-clay-loam soil (a) and sandy-loam soil (b) over different years (1998-2009)

Simulation of salts concentration in the soil profile at the end of the growing season is in proportion to the amount of salinity of the applied water both in the heavy and the light soils. In all treatments considering the constant amount of applied water, the highest concentration of salts occurs in the depth of 5-20 cm of soil profile. And the accumulated salts in the soil profile are leached out of the soil with one time irrigation (about 100 mm) before the start of the next cropping season, and the soil bed conditions are favorable for planting and germination of the next crop (Figure 3).

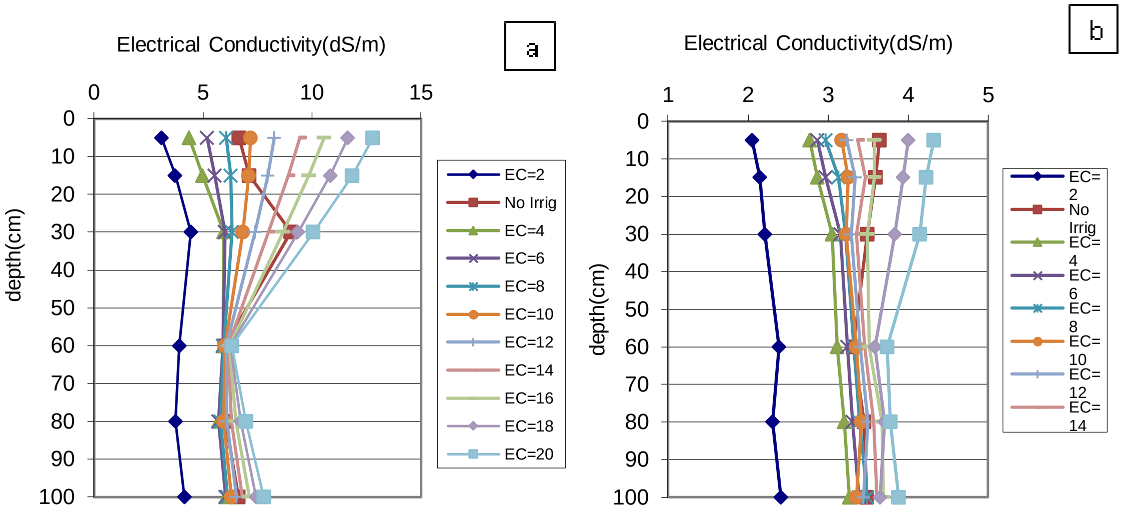

Figure 3. Accumulation of salts in the soil profile at the end of growing season (a) and after leaching (b) in the twelfth year

Considering salinization of the soil is a gradual and long term process, the model was run consecutively and with daily steps for a period of 12 years, and the simulation was conducted for evaluation of different scenarios of saline water application (various salinities). The results showed that with the increase in salinity irrigation water more than 4 dS/m at grain filling stage grain yield has a decreasing trend and accumulation of salts in the root zone at the end of the cropping season has an increasing trend (Figure 4). The simulation results at the end of the twelfth cropping year showed that the process of changes in the grain yield and accumulation of salts in the soil profile are the same as the first year (Figure 4) and by appropriate management options such as considering the volume of leaching, accumulation of salts in the soil profile and its harmful effects can be avoided. Therefore, in soils with appropriate drainage canal application of saline water (even with EC=16 dS/m) at grain filling stage cannot have serious negative effects on soil quality and wheat yield, because the accumulated salts are easily leached out of the root zone. As shown in Figure 5 the grain yield in treatment of saline water application with EC=16 dS/m decreased only 8.8% in silty-clay-loam soil and only 7.4% in sandy-loam soil in comparison with the use of canal water. Thus in the years that severe drought stress may occur during grain filling period wheat due to a decrease in rainfall and limitation of water resources and decrease the grain yield more than 10%, application of saline water with EC=16 dS/m may be effective.

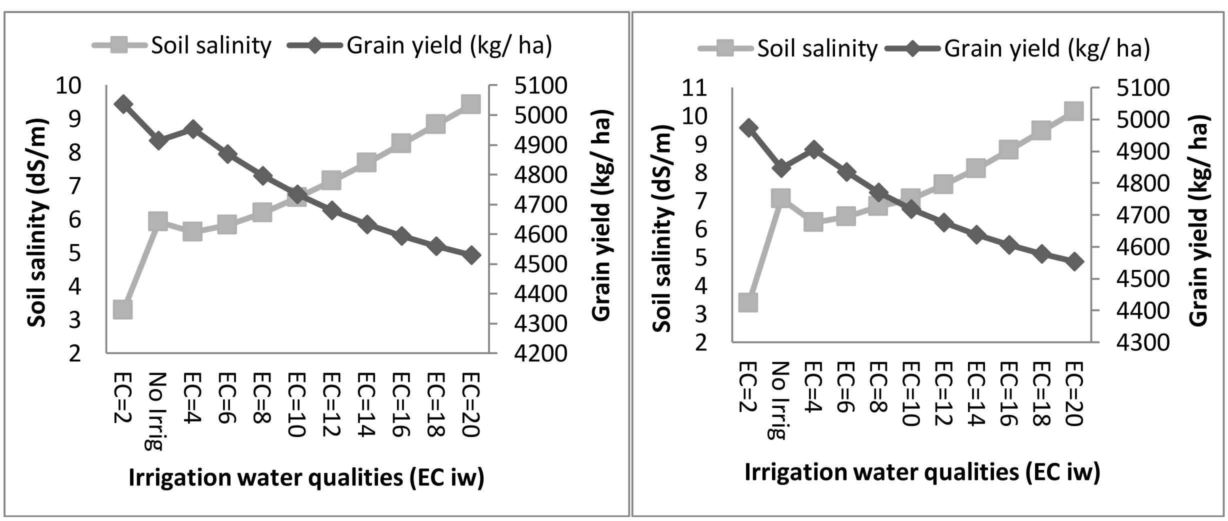

Figure 4. Response of wheat yield and salt accumulation in the soil profile (effective depth of the root) to different levels of the water salinity at the end of the growing season in the twelfth year in silty-clay-loam soil

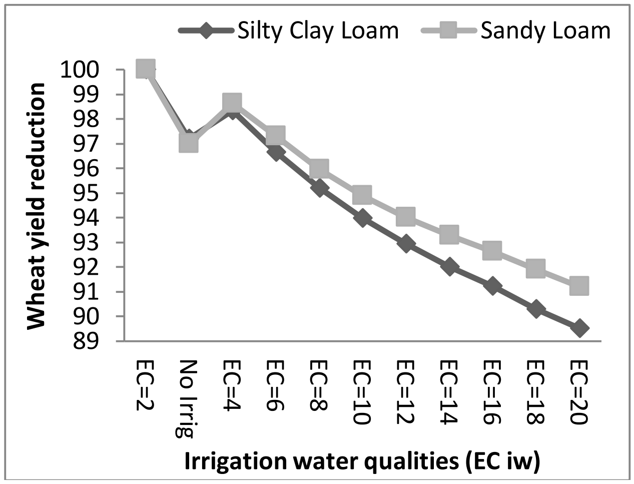

Figure 5. Comparison of wheat yield reduction at different levels of saline water in two kinds of soil

CONCULSION

1- SALTMED model can serve as a useful tool for evaluation of the effect of irrigation water salinity on wheat yield and soil salinity.
2- In case of irrigation water restrictions (non-saline) at grain filling saline water with EC≤4 dS/m can be used in heavy soils and saline water with EC≤6 dS/m in light soils.
3- In case of occurrence of severe drought stress that leads to a intensive loss of yield, the use of drainaged-water with higher salinity, more than 6 dS/m may recommended reasonably.

All the above decisions are applicable in conditions that the farms have proper drainage canal and the leaching requirement water is considered for leaching of salts before the start of the next cropping season.

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