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Evaluation of SALTMED model performance in irrigation and drainage of sugarcane farms in Khuzestan province of Iran

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Abstract
Irrigation management in semi-arid area needs a tool to predict soil salinity changes due to irrigation water quality. In the first sight, SALTMED model can be used in such conditions. However, it is necessary to verify such model using actual data. In this paper by using crop logging data, irrigation reports and climatology data, salinity profile after irrigation and production of sugarcane were used to verify SALTMED model for south west of Iran. The period of this investigation was three years, of which two years data has been used for calibration and the rest was used to verification of the model. To help verification, samples from 0-30, 30-60 and 60-90 cm depth from the soil surface were collected and ECe was measured to compare between simulation data and measurement data. To compare simulation results with actual results, maximum error, root mean square error, coefficient of determination, modeling efficiency, coefficient of residual mass and ANOVA table were calculated. Generally, the results indicated that between simulation and measurement data there was not significant difference. Furthermore, for evaluation degree of assuredness output of model, Student t-test was used. The results of this test indicated that the significance level was 95% for yield production model. The overall results of this research confirmed that SALTMED model could be used successfully as tool for irrigation and drainage of sugarcane farms in Khuzestan province of Iran.

Key words: Model, SALTMED, salinity profile, sugarcane, drainage.

Introduction

More than 150,000 ha in Khuzestan province of Iran are planted with sugarcane (*Saccharum officinarum*). Sugarcane plantation in this province relies only on irrigation. Brief history and the method of cultivation have been described in Naseri *et al*. [3]. In this province, annual rainfall is below 200 mm and agriculture depends almost totally on the water of the rivers. A new irrigation method for sugarcane production was designed and tested. In this method, the water is delivered to the farm by buried pipe, and to distribute the water to the furrow, flexible polyethylene gated pipe is used. In the new irrigation method, sugarcane is planted in two rows inside the furrows spaced at 1.83 m at the begging. However, when the sugarcane stalk height reaches about 0.5 m, the furrow is replaced with hill. As a result, sugarcane growth zone is on the hill and inside the furrow specialized for irrigation and necessary traffic. The amount of water consumption is 26,400 m^3 per hectare. Due to water shortage because of soil and water development projects and also drought, the irrigation water salinity has been extremely increased in recent years. This may result in increasing of soil salinity due to lack of provided leaching water. In such condition, sugarcane yield is extremely declined due to salt accumulation in soils. The damaging effects of salt accumulation in agricultural soils have influenced ancient and modern civilizations. It is estimated that 20% of the irrigated land in the world is presently affected by salinity [8]. The loss of farmable land due to salinization is directly in conflict with the needs of the world population and the challenge of maintaining the world food supplies.

A model to determine the relative magnitudes of the salinity changes of the soil, due to irrigation with such saline water and poor drainage condition, is needed to identify effective water management strategies and the most suitable irrigation practice. Most existing models have designed for a specific irrigation system, specific process such as water and solute movement, infiltration, leaching or water uptake by plant roots or a combination of them. There is a shortage in models of a generic nature, models that can be used for a variety of irrigation systems, soil types, soil stratifications, crops and trees, water management strategies (blending or cyclic), leaching requirements and water quality. Ragab [6] developed a model called SALTMED that can be used in the above mentioned condition. This model employs established water and solute transport, evapotranspiration and crop water uptake equations.

Ragab *et al*. [4] validated the SALTMED model by using field data of two years studies in Egypt and Syria. The model proved its ability to handle several hydrodynamic processes acting at the same time. Using data of five complete growing seasons from Syria and Egypt, the model successfully predicted the impact of salinity on yield, water uptake, soil moisture and salinity distribution. The results of this study also indicated that the relation between both yield and water uptake as a function of irrigation water salinity is non-linear and is better described by a polynomial function of the fourth order [5].

In order to asses the effects of management on crop production to obtain a better understanding of irrigation with saline water (8 dS/m) and the role of crop tolerance to salinity, many experiments were conducted at Deir AlZoor Station (ACSAD, Syria), using mixing and alternating (cyclic) irrigation management, traditional furrow and drip irrigation methods, different water qualities and different tomato varieties [1]. The measured soil and plant parameters were used to validate the SALTMED model in this study. As mentioned above, SALTMED, a mathematical model that incorporated evapotranspiration, plant water uptake and solute transport, crop yield and biomass production, was developed. Full description of this model was provided in Ragab[6]. There was good agreement between simulated and observed yield in Syria and Egypt, confirming the value of SALTMED as a tool for use by experts in the management of salt-prone irrigation systems [2]. Khuzestan province of Iran has approximately similar climate condition to Syria and Egypt. Therefore, such model can be applied to study the salinity change in the soil and sugarcane yield production in such conditions. Therefore, in this paper by using crop, irrigation and climatology data of a sugarcane plantation in south west of Iran, salinity changes in the soil profile with saline water have been simulated and verified by using SALTMED model. The main objective was to predict the amount of salt accumulation in the soil and the effect of this on the sugarcane yield reduction by using SALTMED and comparing these results with data obtained in the field.

Materials and Methods

Brief description of the SALTMED model: According to Ragab[7], Ragab *et al.*[4, 5], Abdel Gawad *et al.*[1] and Flowers *et al.*[2] the SALTMED can take different inputs through five windows. These windows are climate, irrigation, crop, soil and model necessary parameter. The information that required for each window is presented in Table 1.

In SALTMED model, there is possibility to select the type of outputs information as reports and graphs. The information, which can be provided by this model is soil moisture content and profiles, soil salinity content and profiles, relative concentration, matrices potential, relative crop yield and evaporation.

Study area and research method: Seven different sugarcane plantations have been established in Khuzestan province recently. Two of them (Shoeibieh and Dehkhoda) are located in the north of Ahvaz whereas, five of them (Amir Kabir, Mirza Kochakkhan, Debale Khazaee, Salmane Farsi and Farabi) are located in the south of Ahvaz. This study was conducted in Farabi Plantation situated at 30°54'1" to 31°3'34" eastern longitude and 48°31'5" to 48°39' northern latitude. Fig. 1 shows location of the field study in Khuzestan province.

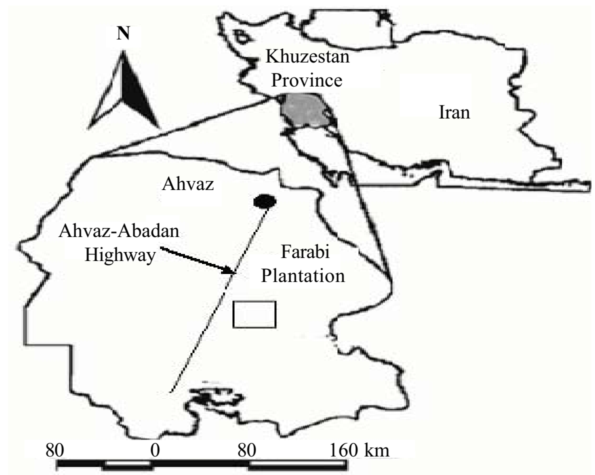

Figure 1. Location of the study area in Khuzestan province of Iran.

The land area of Farabi Plantation is 15,900 ha, and an area of 12,000 ha was used for sugarcane plantation. This region has a mean annual rainfall about 170 mm. The average of air temperature is 24°C. Generally, the climate of this region is semi-arid. The size of each farm in Farabi Plantation is 25 ha with the length of 1000 m and width of 250 m. Furrow irrigation system has been used to provide water requirement. Due to poor conditions, artificial drainage has been established in Farabi Plantation field. In this system, subsurface drainage with 60 m spacing has been installed. The soil texture is silty clay loam and the slope is 0.001-0.0003 from north to south.

In this study, six farms with different ages were selected. Those farms were as follows: plant (under first year of plantation), ratoon 1 (under second year of plantation), ratoon 2 (under third year of plantation). One sugarcane variety has been chosen in all farms. This variety was CP57-614, which is most cultivated as a commercial variety in this region. According to water table depth, these farms can be divided into three categories: A >1 m from soil surface; B 0.5-1 m from soil surface and C < 0.5 m from soil surface.

As mention above, to provide necessary information and inputs for SALTMED model in the study area, the following process were conducted. 1) Climate data such as Tmax, Tmin, evaporation,

Table 1. SALTTMED variables.

Characteristics	Variables
Climate	Evaporation, sun shine, daily values of temperature (maximum), temperature (minimum), relative humidity, net radiation, wind speed, daily rainfall
Irrigation	The date and amount of irrigation water applied, the salinity level of each applied irrigation and irrigation system
Crop	Growth stage, crop coefficient, root depth and lateral expansion, crop height and maximum/potential final yield
Soil	Depth of each soil horizon, saturated hydraulic conductivity, saturated soil moisture content, salt diffusion coefficient, longitudinal and transversal dispersion coefficient and initial soil moisture and salinity profiles
Model parameters	The number of compartments in both vertical and horizontal direction and the maximum time step for calculation

wind speed, sunshine and rainfall were obtained using climatology station in Farabi Plantation. 2) Required irrigation data such as water amount, irrigation start and end time and salinity of irrigation water were measured during irrigation practices in Farabi Plantation. 3) Crop informations were selected from database of the model. This information included maximum height, root depth, crop factors and growth stage, and the local cultivation data has been imported from crop logging reports. 4) The soil texture of these farms was measured and its type was selected from soil window of the model. However, soil properties were obtained from database of the model. 5) To calculate different parameters two different ways of calculation were selected: a) full model option was selected for model operation; b) calculation mode was selected for hydraulic parameters and effective rainfall. In this part, latitude, longitude, site elevation above see level and start and end dates of simulating should be inputted. Furthermore, the type of the output information such as soil salinity content and profiles and relative crop yield should be selected.

The study was conducted on the 3 years period, from 2004 to 2006, and all necessary information was collected during this period of time. Information and data of two years were used to calibrate the model and the third year information was used for simulation. To compare the results of simulation using SALTMED, the necessary information was obtained from field study. In this study soil physical and chemical properties were measured in three different layers. These layers were 0-30, 30-60 and 60-90 cm depth from the soil surface.

For quantitative comparison of experimental and simulated, analysis of residual errors, differences between measured and simulated values can be used to evaluate model performance. These are maximum error (ME), root mean square error (RMSE), coefficient of determination (CD or R^2), modeling efficiency (EF) and coefficient of residual mass (CRM). The mathematical expressions of these statistics are as follows:

$$ME = Max\left|P_i - O_i\right|_{i=1}^{n} \quad (1)$$

$$RMSE = \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}\right]^{1/2} \times \frac{100}{\overline{O}} \quad (2)$$

$$R^2 = \frac{\sum_{i=1}^{n}\left(P_i - \overline{O}\right)^2}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2} \quad (3)$$

$$EF = \frac{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2 - \sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2} \quad (4)$$

$$CRM = \frac{\sum_{i=1}^{n}O_i - \sum_{i=1}^{n}P_i}{\sum_{i=1}^{n}O_i} \quad (5)$$

where P_i is the predicted data, O_i the measured data and n is the number of samples. For each farm, statistical factors mentioned above between the results of model and laboratory experiment were calculated. Then, degree of each statistical factor for selected farms was determined. Finally, sum of degree and ranking for each farm were determined. In addition, for obtain information about significance level ANOVA table was calculated for each farm. Regarding to evaluation of sugarcane yield production, t distribution was used.

Results and Discussion

The electrical conductivity of soil extracts (EC_e) was measured in three different layers (0-30 cm, 30-60 cm and 60-90 cm) in farms A-06, A-11, B-02, B-06, C-10 and C-11. The results of these measurements are shown in Table 2. As can be seen from this table, the EC_e values varied between 2.02 and 3.5 dS/m in all cases. This indicates that the soils after several irrigations are in different salinity and this may be because of the effect of several different factors. These factors, such as crop, climate condition, irrigation and soil properties, were measured and can be used for simulation by SALTMED model. This information described in last section was inputted in the model in different format as explained in Ragab[6]. The aim was to simulate the salinity profile of the above mentioned farm and to compare the results of measurements and simulation. This can show the sensitivity of SALTMED. Fig. 2 shows the simulated salinity profile results obtained by SALTMED model. As can be seen from this figure, the simulated EC_e of the soil in all cases of similar depth was between 3.15 and 2 dS/m. These results are very close to those obtained from the field study. In addition, Fig. 2 indicates the results of salt distribution in these three groups of farms approximately similar and in sugarcane salinity tolerance range. These results could not be obtained unless the drainage system was in good condition and functional. This system is able to remove salt from the soil profile using extra irrigation water. Fig. 3 shows the comparison of both measured and simulation results for similar farms. As can be seen from this figure, in all cases the simulated EC_e was less than measured EC_e. This may happen due to the effects of some parameters that are not included in simulation processors.

To compare the simulation results with measurement data, statistical analysis such as ME, RMSE, CD, EF, CRM, F and significance level have been calculated and the results are shown in Table 3. As can be seen from this table, ME in farm A-06 was 0.2 dS/m, which is the minimum of all cases. The ME indicates the worst case performance of the model. RMSE value shows how much the simulation overestimates or underestimates the measurements. This parameter in farm A-06 was 4.71 dS/m which is in minimum condition whereas in farm C-11, 11.32 dS/m was maximum of all cases. The CD or R^2 gives the ratio between the scattering of simulated and measured results. R^2 of farm A-06 and C-11 was 0.99 and 0.79, respectively. Comparison between the simulated data to the average measured values was determined with EF. This parameter in the farm B-06 was -0.16 and 0.96 in farm A-06, these values were minimum and maximum, respectively. The CRM is a measure of the tendency of the model to overestimate or underestimate the measurements. The CRM of A-06 was minimum (0.04) and in farm, C-11 maximum (0.09). Generally, the best result performance of the model was obtained in farm A-06 and the other farms ranged as follows: B-06, A-11, B-02, C-10 and C-11. According to F value, there were no significant differences between simulation results and measurement data and SALTMED model can be used for such conditions.

Table 2. The electrical conductivity of soil extracts (EC_e) of study farms.

Farm	Depth (cm) 0-30	30-60	60-90
	EC_e (dS/m)		
A-06	3.5	2.2	2.02
A-11	3.3	2.3	2.10
B-02	3.3	2.4	2.01
B-06	2.5	2.2	2.05
C-10	3.3	2.5	2.06
C-11	3.0	2.5	2.06

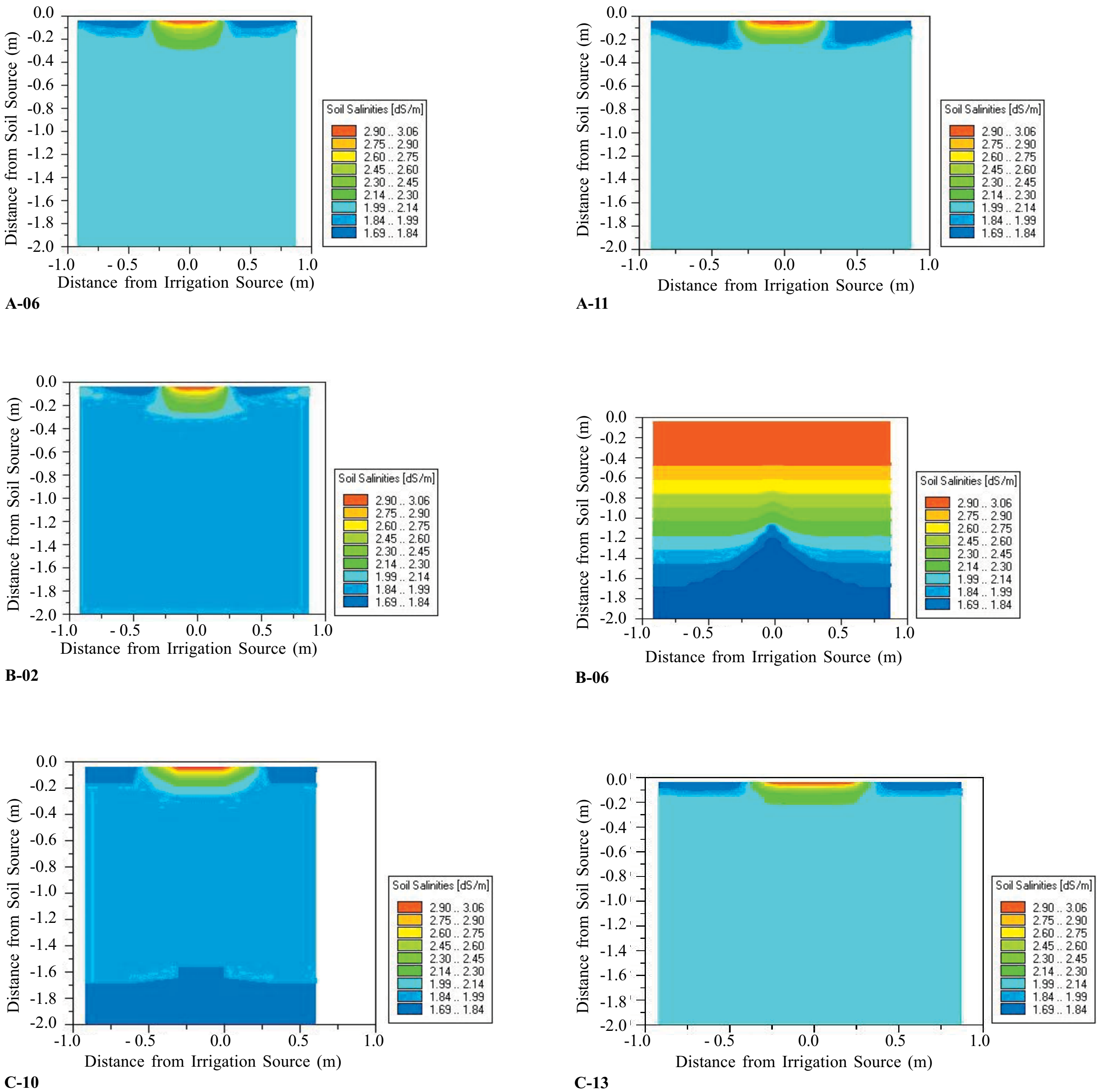

Figure 2. Salinity profiles of simulation stage.

Table 3. Results of statistical analysis.

Field name	ME (dS/m)	RMSE (dS/m)	R^2	EF	CRM	Sum of degree	Final ranking	F	Sig.
A-06	0.2(1)*	4.71(1)	0.99(1)	0.96(6)	0.04(1)	2	1	90.331	0.006
A-11	0.31(3)	8.16(3)	0.98(2)	0.82(5)	0.07(2)	3	3	82.578	0.012
B-02	0.40(4)	5.84(2)	0.91(3)	0.80(4)	0.07(2)	3	3	22.966	0.041
B-06	0.30(2)	8.51(4)	0.90(4)	-0.16(1)	0.07(2)	2.6	2	18.893	0.049
C-10	0.50(5)	10.41(5)	0.88(5)	0.73(3)	0.07(3)	4.2	4	14.415	0.063
C-11	0.50(5)	11.32(6)	0.79(6)	0.49(2)	0.09(4)	4.6	5	7.562	0.111

* Degree

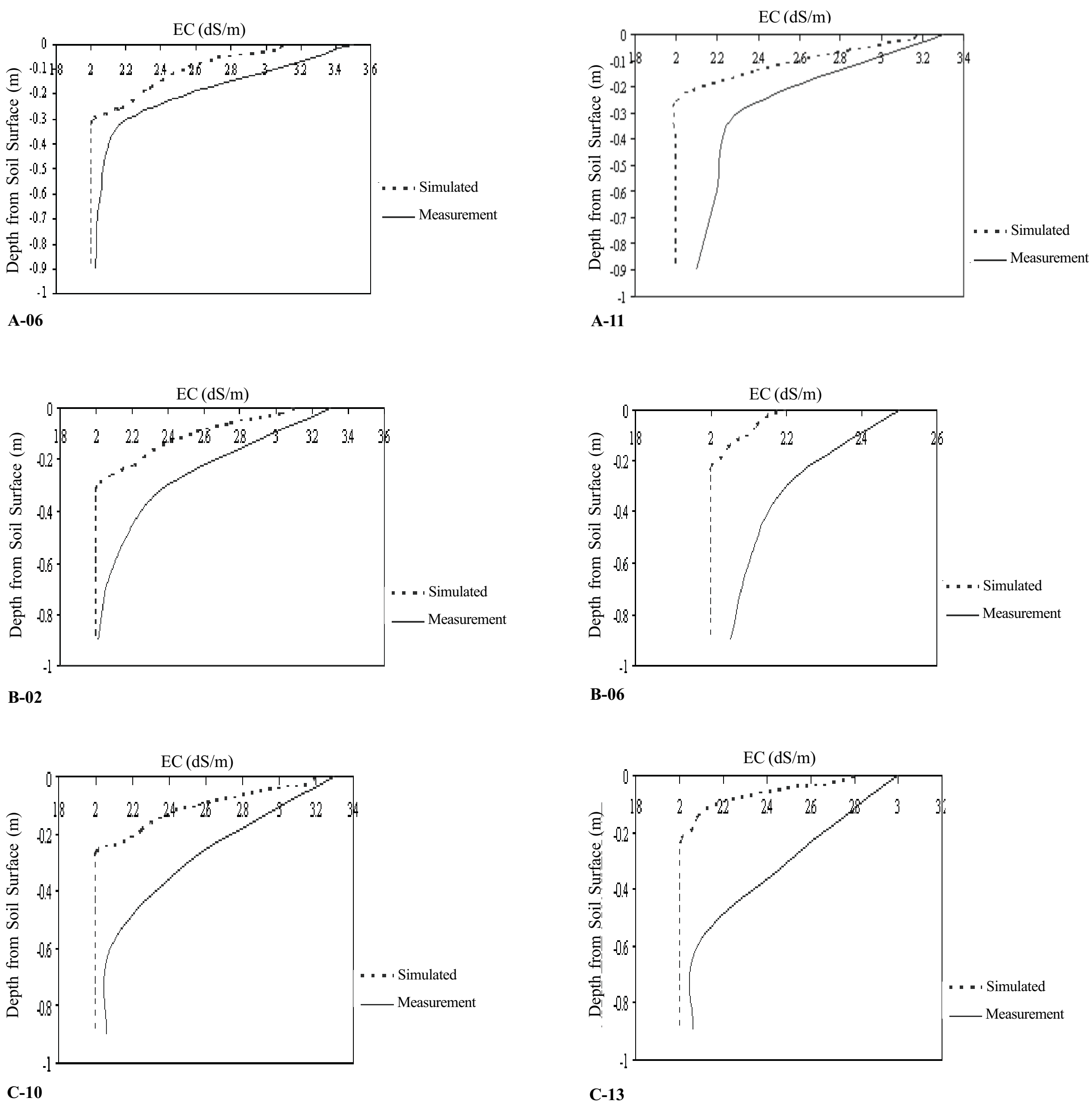

Figure 3. Comparison between simulated and measured data.

Fig. 4 indicates predicted crop and root uptake on simulation stage. To evaluate degree of assuredness and compare between output of model and actual amount of sugarcane yield production in field condition statistical analysis was used. Since two samples that belong to one statistical universe, t test was used to compare simulation results and measurement data. By using t test correlation and significance level were obtained for evaluation the following two hypotheses: H_1 (alternative hypothesis) measurement data of production is equal to simulation results; H_0 (null hypothesis) measurement data of production is not equal to simulation results. Table 4 represents the results of statistical calculation. Fig. 4 indicates that during simulation period potential root uptake decreased and crop yield increased. Results in Table 4 show that significance level is greater than 0.05 and therefore, actual and simulated amount of production with 95% level of assuredness are similar and H_0 hypothesis is acceptable. Value of t in Table 4 indicates that calculated t is higher than t of the distribution table. Hence, this shows that the relationships of samples are significant. In addition, correlation in B group and ratoon 1 are higher than in other groups. The simulation results were close to measured data using SALTMED model for water table of 0.5-1 m and ratoon 1. Nevertheless, the results for other groups are acceptable.

Table 4. Results of statistical analysis of yield.

Description	Paired sample correlation			
	Correlation	Sig.	t	Sig.
Compare total mean	0.379	0.100	-1.520	0.145
Compare mean of group A	0.115	0.786	-0.507	0.628
Compare mean of group B	0.561	0.247	-1.574	0.176
Compare mean of group C	0.396	0.437	-0.573	0.591
Compare mean of plant fields	0.014	0.976	-0.389	0.214
Compare mean of ratoon 1 fields	0.577	0.175	-0.504	0.632
Compare mean of ratoon 2 fields	-0.173	0.744	-0.436	0.681

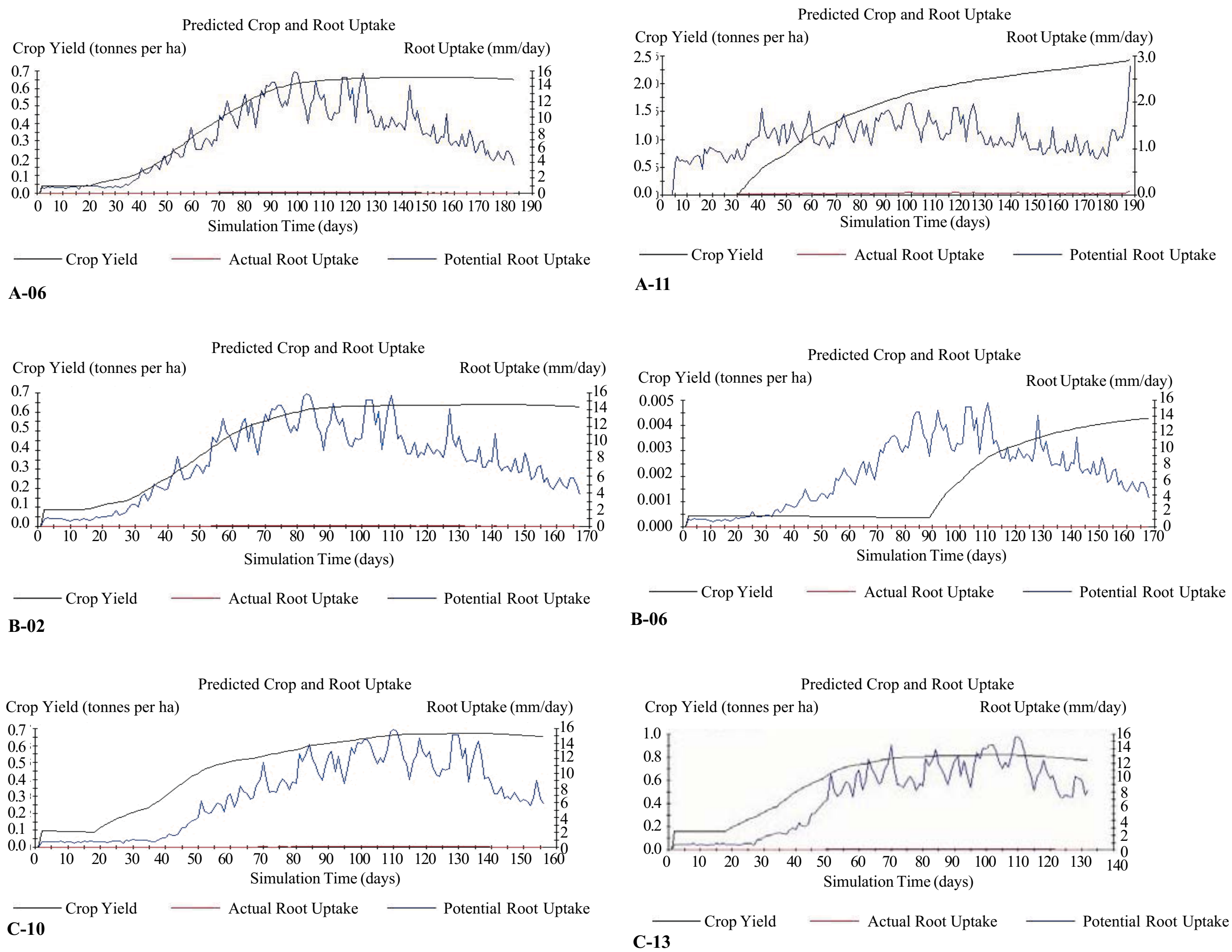

Figure 4. Predicted crop and root uptake.

Conclusions

Generally, the results of this paper are summarized below. 1) Statistical analysis between measurement and simulation data indicates that: i) best results of salinity profile were obtained in farm A-06 (age of sugarcane is plant and water table level > 1 m); ii) best results of production were obtained in the farms of B group, (age of sugarcane is ratoon 1 and water table level 0.5-1 m). 2) The results indicate that SALTMED model predicts salinity profiles lower than actual amount. This is because of some uncontrolled factors that exited in nature and are not in model or some error in measurement stage. 3) SALTMED model can simulate and predict production with 95% degree of assuredness. 4) Salinity profiles represent EC values in root zone suitable for growth of sugarcane. 5) Since EC of irrigation water was 0.86-2.2 dS/m, salinity profiles showed that drainage system was able to control salinity in the tolerance range of sugarcane. Finally, it can be concluded that SALTMED model can be used as a management tool in Khuzestan province for sugarcane production.

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