Sensitive Analysis and Calibration of the SALTMED $^{V}{}_{2}$ 2008 Model Using Information from the Sugarcane Plantation Company in the Khuzestan Province of Iran

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Abstract

Irrigation management in semiarid areas requires a tool to predict changes in soil salinity, relative crop yield, leaching requirements, the soil moisture profile and nitrogen uptake due to irrigation water quality. The SALTMED model can be used in such conditions. However, before this or any other model can be used for verification and simulation in each region, a sensitive analysis and calibration is necessary. By using the crop logging data, irrigation reports and climatology data were collected from sugarcane plantation companies, sensitive analysis and calibration of SALTMED $^{V}{}_{2}$ 2008 is performed. The Farabi plantation company data from farming years 2004 and 2005 were used for the sensitive analysis stage. Sensitive analysis of SALTMED showed for all input parameters, sensitive coefficient was middle with the exception of the crop extinction coefficient. The most sensitive parameter in the SALTMED model was the amount of irrigation water followed by the salinity of the irrigation water, the maximal temperature, the maximal crop height, rainfall, the relative humidity, the soil extinction coefficient, the irrigation frequency, the fraction of the soil surface covered by irrigation, nitrogen, sunshine, the numerical stability factor, the maximal root depth, the minimal temperature, the harvest index, the wind speed and the crop extinction coefficient. For calibration of the model, the Debale Khazaee plantation company data from farming years 2006 and 2007 were used. Because the model was sensitive to the amount of irrigation water, the single crop coefficient (K_c) and dual crop coefficient (K_{cb}), which were used for the determination of evapotranspiration, were calibrated for use during the verification and simulation stages. Results showed that the average single crop coefficients of plant (virgin) sugarcane for the initial, middle and late stages of growth were 0.53, 1.38 and 0.87, respectively. Moreover, the average dual crop coefficients for the initial, middle and end stages of growth were 0.13, 1.26 and 0.66, respectively. In addition, these coefficients for ratoon sugarcane in the initial, middle and late stages of growth were 0.56, 1.34 and 0.90, respectively, for K_c and 0.16, 1.35 and 0.76, respectively, for K_{cb}. The comparison among the single and dual crop coefficients of plant (virgin) and ratoon sugarcane showed that the values of these coefficients were higher for ratoon sugarcane than plant (virgin) sugarcane. Furthermore, the values of the single and dual crop coefficients obtained in the calibration stage were higher than the values reported in the FAO 56.

Keywords: SALTMED $^{V}{}_{2}$ 2008, Sensitive analysis, Calibration, Sugarcane, Irrigation.

Introduction

More than 150,000 ha in the Khuzestan province of Iran are planted with sugarcane (Saccharum officinarum). Sugarcane plantations in this province rely on irrigation as the only water source. The brief history of the sugarcane plantations and the methods used for their cultivation has been described by Naseri et al. (2007). In this province, the annual rainfall is below 200 mm, and agriculture in the Khuzestan province depends almost completely on river water. A new irrigation method for sugarcane production has been designed and tested. In this method, the water is delivered to the farm by a buried pipe. According to this method, a flexible polyethylene gated pipe is used to distribute the water to furrows. In the new irrigation method, sugarcane is planted in two rows inside the furrows, which are spaced 1.83 m apart at the beginning. However, when the sugarcane stalk height reaches approximately 0.5 m, the furrow is replaced with a hill. As a result, the sugarcane growth zone is on the hill and inside the furrow, which is specialized for irrigation and necessary traffic. The amount of water consumption is 26,400 m3/ha. Due to water shortages as a result of soil and water development projects and draught, the irrigation water salinity has increased significantly in recent years. The increase in irrigation water salinity may be the result of increased soil salinity due to a lack of water provided for leaching. In such conditions, the sugarcane yield is greatly decreased 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 currently affected by salinity (Yeo, 1999). The loss of farmable land due to salinization directly conflicts with the needs of the world population and challenges the maintenance of the world food supplies.

A model to determine the relative magnitudes of salinity changes in soil resulting from irrigation with saline water and poor drainage conditions is needed to identify effective water management strategies and the most suitable irrigation practices. Most existing models have been designed for a specific irrigation system or for a specific process, such as water movement, solute movement, infiltration, leaching or water uptake by plant roots, or for a combination of a specific system and process. There is a shortage of generic models that can be used for a variety of irrigation systems, soil types, soil stratifications, crops, trees, water management strategies (blending or cyclic), leaching requirements and water quality. Ragab (2002) has developed a model called SALTMED that can be used in the above mentioned conditions. This model employs established water transport, solute transport, evapotranspiration and crop water uptake equations.

Ragab et al. (2005a) validated the SALTMED model by using field data from 2-year-long studies in Egypt and Syria. The model proved its ability to handle several hydrodynamic processes acting at the same time. Using data from five complete growing seasons in 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 relationship between both yield and water uptake as a function of irrigation water salinity is nonlinear and is better described by a polynomial function of the fourth order (Ragab et al., 2005b).

To assess the effects of management on crop production and to obtain a better understanding of irrigation with saline water (8 dS/m) and the role of crop tolerance to salinity, many experiments have been conducted at the Deir AlZoor Station (ACSAD, Syria) using mixing irrigation management, alternating (cyclic) irrigation management, traditional furrow methods, drip irrigation methods, different water qualities and different tomato varieties (Abdel Gawad et al., 2005). In the present study, a series of measured soil and plant parameters were used to validate the SALTMED model. As mentioned above, SALTMED is a mathematical model that incorporates evapotranspiration, plant water uptake, solute transport, crop yield and biomass production. A full description of this model was provided by Ragab (2002). There is agreement between the simulated and observed yields in Syria and Egypt, confirming the value of SALTMED as a tool for use by experts in the management of salt-prone irrigation systems (Flowers et al., 2005). The Khuzestan province of Iran has similar climate conditions to Syria and Egypt. Therefore, a similar model can be applied to study changes in the salinity of the soil and sugarcane yield in such conditions. Before using any model, however, a sensitive analysis and calibration should be performed. Recently, Ragab (2008) presented a new version of the SALTMED model that is more complete than the primary version.

Because of the importance of plantation sugarcane in the Khuzestan province in southwestern Iran and the necessity of a model for irrigation management, sensitivity analysis and calibration of the SALTMEDV 2 2008 model have been performed using Information from the sugarcane plantation company in the Khuzestan province of Iran.

Materials and Methods

Brief description of the SALTMED model

According to Ragab (2002), Ragab et al. (2005a; 2005b), Abdel Gawad et al. (2005) and Flowers et al. (2005), the first version of SALTMED can take different inputs through five menus. However, the new version of the SALTMED model takes inputs through 12 menus. These menus include climate, evapotranspiration, irrigation, crop, soil, nitrogen, crop growth, general, parameter, profile, set output and output location. The information required for each menu is presented in Table 1.

Table 1. SALTMED input and output variables

Type of characteristics	Type of variable
Climate	Evaporation, sunshine, daily values of temperature (maximal), temperature (minimal), relative humidity, net radiation, wind speed and daily rainfall
Evapotranspiration	Fao-56, Penman-Monteith, Read from file, Et_o from climate data and Et_o from pan factor
Irrigation	The date and amount of irrigation water applied, the salinity level of each applied irrigation, irrigation system numerical stability factor, fraction of soil surface covered by irrigation
Crop	Growth stage, single and dual crop coefficients, root depth, crop height, swing date, emergence, harvest and growing stage lengths
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
Nitrogen	Soil temperature parameters, uptake parameters, decomposition parameter and daily nitrogen input
Crop growth	Radiation interception effect, temperature effect, leaf nitrogen content effect, respiration effect and water uptake effect
General	Soil layers, Sit (latitude, longitude and elevation above sea level) and effective rainfall
Parameters	The number of compartments in both vertical and horizontal direction and the maximal time step for calculation
Profiles	Specify positions of output profiles on terms of distance from irrigation source
Set outputs and output location	Reports, graphs and specify output directory and file names

In the SALTMED model, it is possible specify whether the output information will be provided as either reports or graphs. The information that can be provided by this model is as follows: soil moisture content and profiles; soil salinity content and profiles; relative concentration; potential matrices; relative crop yield; and evaporation.

Study area and method of research

Seven different sugarcane plantations were recently established in the Khuzestan province. Two of the plantations (Shoeibieh and Dehkhoda) were located north of Ahvaz, whereas five of the plantations (Amir Kabir, Mirza Kochakkhan, Debale Khazaee, Salmane Farsi and Farabi) were located south of Ahvaz. This study was conducted in the Farabi plantation company and the Debale Khazaee plantation company. Figure 1 shows the location of the study area in the Khuzestan province.

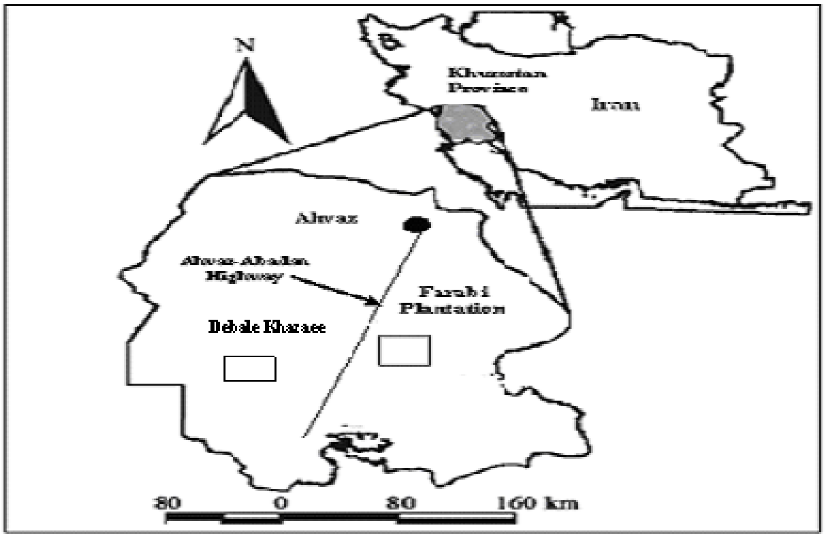

Figure 1. Location of the study area in Khuzestan province of Iran.

The land area of each company (Farabi and Debale Khazaee) was 15,900 ha, and 12,000 ha were used for sugarcane cultivation. This region had a mean annual rainfall of approximately 170 mm, and the average air temperature was 240C. Generally, the climate of this region was semiarid. The size of each farm was 25 ha with a length of 1,000 m and a width of 250 m. A furrow irrigation system was used to provide water. Due to poor conditions, artificial drainage was established in the Farabi plantation field. In this system, subsurface drainage with a spacing of 60 m was installed. The soil texture was silty clay loam, and the slope was 0.001 to 0.0003 from north to south.

In this study, four farms of the Farabi plantation company were selected from farming years 2004 and 2005. The study farm variety was CP57-614 (plant, ratoon 1, ratoon 2 and ratoon 3), which was the most cultivated commercial variety in this region. The model was run using climate, irrigation, crop, soil, nitrogen and crop growth information from this farm. The results of the model in this step were basic outputs. The sensitive analysis was then performed on the following parameters in each farm: the amount of irrigation water, the salinity of irrigation water, the maximal temperature, the maximal crop height, rainfall, relative humidity, the extinction coefficient of the soil, the irrigation frequency, the fraction of the soil surface that was covered by irrigation, the nitrogen level, the sunshine exposure, the numerical stability factor, the maximal root depth, the minimal temperature, the harvest index, the wind speed and extinction. The increase and decrease of each input parameters was +50%. The sensitive coefficients were calculated according to Liu et al. (2007) with the following equation:

$$S_c = \frac{\frac{\Delta W}{\overline{W}}}{\frac{\Delta P}{\overline{P}}} \tag{1}$$

Where Sc is the sensitive coefficient, ΔW is the difference between the output parameter before and after the change input, $\overline{W}$ is the average of the output parameter before and after the change input, ΔP is the difference in the model inputs and $\overline{P}$ is the average of the model inputs.

The range of sensitive coefficient variation is indicated in Table 2.

Table 2. The range of sensitive coefficient variation (Liu et al., 2007)

$S_C=0$	Without sensitive
$0< S_c<0.3$	Low sensitive
$0.3< S_c<1.5$	Middle sensitive
$1.5< S_c$	High sensitive

After calculating the sensitive coefficients, the results were compared with the range shown in Table 2. In the sensitive analysis stage, the results showed that the model was sensitive to the amount of irrigation water. Therefore, single crop and dual crop coefficients were calibrated in the study area.

The calibration included reducing the difference between measured values and values of the model calculation. The Debale Khazaee plantation company data from farming years 2006 and 2007 were used in the calibration stage. Four farms with similar sensitive analyses (plant variety CP57-614, ratoon 1, ratoon 2 and ratoon 3) were selected.

The following data were required: climate, irrigation, crop, soil, nitrogen, crop growth and yield production. By using the above mentioned data, the model was applied, and the simulation yield was compared with the actual yield production. Because the single and dual crop coefficients (Kc and Kcb) are used for the calculation of evapotranspiration and these coefficients directly related to the amount of irrigation water, these coefficients have been changed. Moreover, the model was performed several times. In each stage, the actual and simulated yield productions were compared until the accuracy of the simulation was consistently acceptable. Furthermore, the averages of the KC and Kcb values were calculated using the values of these coefficients reported in the FAO 56 and values obtained from the model. The model was then performed with the averages of the KC and Kcb values, and the results were evaluated.

Results and Discussion

The results of the sensitive analyses are shown in Figure 2 and Figure 3.

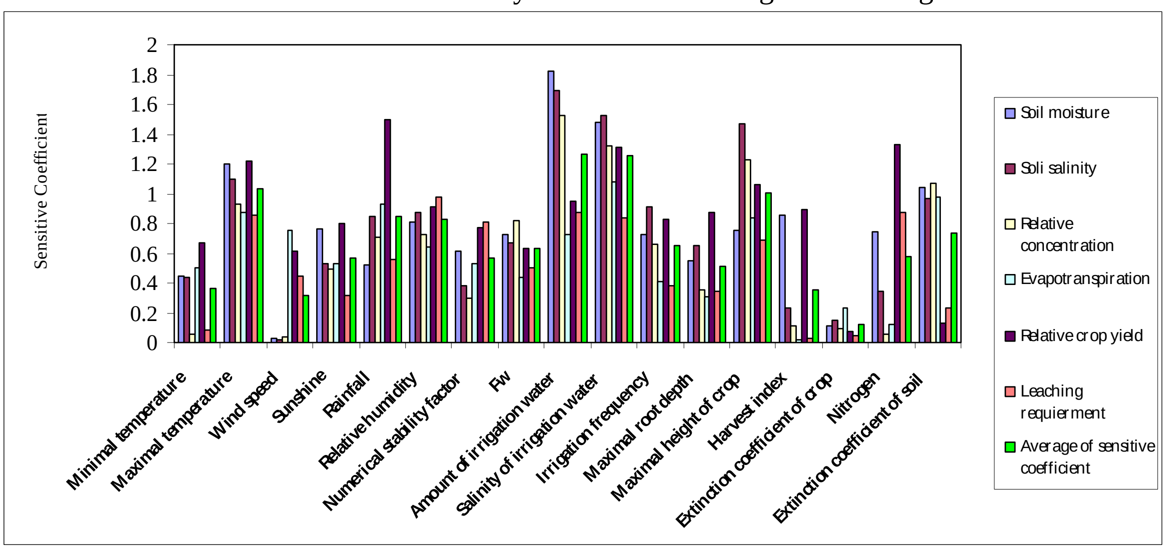

Figure 2. The average sensitive coefficient of input of SALTMED model (%-50)

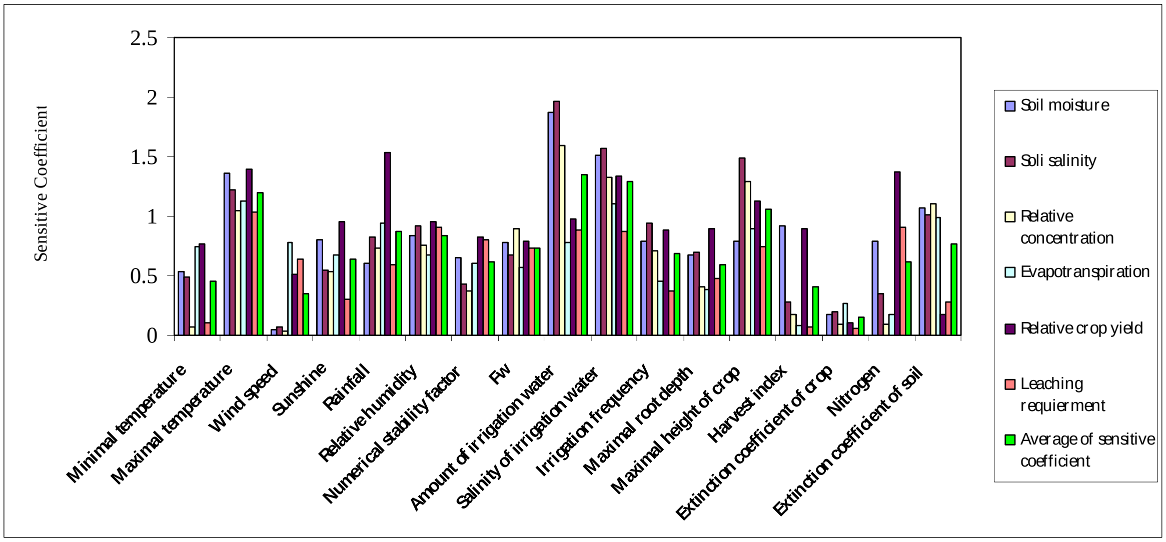

Figure 3. The average sensitive coefficient of input of SALTMED model (%+50)

The results indicated that the maximal temperature and wind speed climatology parameters were the maximal and minimal sensitive factors, respectively. The crop factors including maximal height, maximal root depth, harvest index and extinction coefficient were evaluated for sensitive analysis. In the irrigation window, the amount of irrigation water, salinity of irrigation water, fraction of soil surface covered by irrigation, numerical stability factor and irrigation frequency were applied as the main factors, and the amount and salinity of irrigation water were the sensitive factors. Generally, for the verification of the SALTMED model in an area, such as the Khuzestan province, the amount of irrigation water, salinity of irrigation water, maximal temperature and maximal height of the crop should be exactly measured.

As mentioned above, the SALTMED model was more sensitive to the amount of irrigation water compared to the other requirement inputs. Therefore, the single and dual crop coefficients (Kc and Kcb) were selected for calibration of the model. The calibration was primarily focused on yield. The results from this stage are shown in Table 3 and 4. These values can be used for simulation, verification and irrigation management.

Table 3. Single and dual crop coefficients in the calibration stage for plant (virgin) sugarcane

	K_c			K_{cb}		
	Initial stage	**Middle stage**	**Late stage**	**Initial stage**	**Middle stage**	**Late stage**
Value in FAO56	0.40	1.25	0.75	0.15	1.20	0.70
The best Value	0.66	1.51	0.99	0.10	1.32	0.63
Average	0.53	1.38	0.87	0.13	1.26	0.66

Table 4. Single and dual crop coefficients in the calibration stage for ratoon sugarcane

	K_c			K_{cb}		
	Initial stage	**Middle stage**	**Late stage**	**Initial stage**	**Middle stage**	**Late stage**
Value in FAO56	0.40	1.25	0.75	0.15	1.20	0.70
The best Value	0.71	1.43	1.05	0.17	1.51	0.81
Average	0.56	1.34	0.90	0.16	1.35	0.76

The averages of the single crop coefficients for plant (virgin) sugarcane for the initial, middle and late stages of growth were 0.53, 1.38 and 0.87, respectively. Moreover, the averages of the dual crop coefficients for the initial, middle and end stages of growth were 0.13, 1.26 and 0.66, respectively. In addition, these coefficients for ratoon sugarcane for the initial, middle and late stages were 0.56, 1.34 and 0.90, respectively, for Kc and 0.16, 1.35 and 0.76, respectively, for Kcb. The comparison of the single and dual crop coefficients between the plant (virgin) and ratoon sugarcane showed that the values of these coefficients for the ratoon sugarcane were higher than the values for the plant (virgin) sugarcane. Moreover, the single and dual crop coefficient values obtained in the calibration stage were greater than the values reported in the FAO 56, which may be related to the climatology conditions. The coefficient values reported by the FAO are often local, whereas the crop coefficients are functions of wind speed, relative humidity and plant height in specific regions. Therefore, the application of these coefficients is suggested in a region study.

Conclusion

The results of this paper are summarized as follows:

1- The maximal temperature and wind speed are the maximal and minimal sensitive factors of climatology.

2- The maximal height of crops and maximal root of crops are the most important crop factors in the SALTMED model.

3- The amount of irrigation water and the salinity of the irrigation water are the most sensitive parameters of the SALTMED model.

4- For application of the SALTMED model in irrigation networks, drainage networks and irrigation management, the amount of irrigation water, the salinity of the irrigation water, the maximal temperature and the maximal crop height should be measured exactly.

5- The averages of the single crop coefficients were 0.53, 1.38 and 0.87 for the initial, middle and late stages of growth, respectively. Moreover, the averages of dual crop coefficients for the initial, middle and late stages of growth were 0.13, 1.26 and 0.66, respectively. These values were usable for simulation, verification and irrigation management of plant (virgin) sugarcane.

6- The averages of single crop coefficients for ratoon sugarcane were 0.56, 1.34 and 0.90 for the initial, middle and late stages of growth, respectively. Moreover, the averages of dual crop coefficients for the initial, middle and late stages of growth were 0.16, 1.35 and 0.76, respectively.

Finally, it can be concluded that the sensitive analysis and calibration results, which are demonstrated in this paper, can be used in the SALTMED model as a management tool for sugarcane production in the Khuzestan province and similar regions.

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References

- Abdel Gawad, G., Arslan, A. Gaihbe, A. Kadouri, F., 2005. The effects of saline irrigation water management and salt tolerant tomato varieties on sustainable production of tomato in Syria (1999–2002). Agricultural Water Management 78, 39–53.

- Flowers, T.J. , Ragab, R., Malash, N. , Abdel Gawad, G., Cuartero, J. , Arslan, A., 2005. Sustainable strategies for irrigation in salt-prone Mediterranean: SALTMED. Agricultural Water Management 78, 3–14.

- Liu, H. F., M. Genard, S. Guichard and N. Bertin, 2007, Model assisted analysis of tomato fruit growth in relation to carbon and water fluxes, Journal of Experimental Botany, Vol 58, No. 13, pp. 3567-3580.

- Naseri, A. A., Jafari, S., Alimohammadi, M. 2007. Soil compaction due to sugarcane (Saccharum officianarum) mechanical harvesting and the effects of subsoiling on the improvement of soil physical properties. Journal of Applied Sciences 7 (23): 3639-3648.

- Ragab , R., Malash, N., Abdel Gawad, G., Arslan, A., Ghaibeh, A., 2005a. A holistic generic integrated approach for irrigation, crop and field management 1. The SALTMED model and its calibration using field data from Egypt and Syria. Agricultural Water Management 78, 67–88.

- Ragab , R., Malash, N., Abdel Gawad, G., Arslan, A., Ghaibeh, A., 2005b. A holistic generic integrated approach for irrigation, crop and field management 2. The SALTMED model validation using field data of five growing seasons from Egypt and Syria. Agricultural Water Management 78, 89–107.

- Ragab, R., 2002. A holistic generic integrated approach for irrigation, crop and field management: the SALTMED model, Environmental Modelling & Software 17, 345–361.

- Yeo, A.R. (1999) Predicting the interaction between the effects of salinity and climate change on crop plants. Sci. Hortic. (Amsterdam) 78, 159–174