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Simulating maize yields when irrigating with saline water, using the AquaCrop, SALTMED, and SWAP models

Mohammad Hassanli[a], Hamed Ebrahimian[b,*], Ehsan Mohammadi[c], Amirreza Rahimi[a], Amirhossein Shokouhi[a]

[a] *Graduate student of Irrigation and Drainage, Department of Irrigation and Reclamation Eng., College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran*
[b] *Assistant professor, Department of Irrigation and Reclamation Eng., College of Agriculture and Natural Resources, University of Tehran, P. O. Box 4111, Karaj 31587-77871, Iran*
[c] *Graduate student of Irrigation and Drainage, Department of Water Eng., College of Agriculture, University of Zabol, Iran*

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ABSTRACT

Using simulation models is a strategy in agricultural water use management and an effective way in predicting effect of irrigation management and water quality on crop yield provided that the accuracy of the models is proved. In this study, three different models, i.e. AquaCrop, SALTMED and SWAP, were evaluated under application of the frequency of saline water with non-saline water in order to estimate forage maize yield. For this purpose, field experiments carried out for nine treatments (under different condition of using non-saline and saline water) in Karaj region, Iran. All three models were calibrated and validated based on the experimental data. The coefficient of determination (R^2) between observed and simulated data of maize yield were obtained 0.733, 0.846 and 0.594 for the AquaCrop, SALTMED and SWAP models, respectively. Absolute relative error values varied between 2.9 and 30.8% for AquaCrop, 0.9 and 24.7% for SALTMED, and 0.3 and 19.3% for SWAP model. The SALTMED and SWAP models had better performance than the AquaCrop model in estimating maize yield under salinity stress.

1. Introduction

Sustainability of water resources largely depends on the proper management and efficient utilization of agricultural water (Fasakhodi et al., 2010). Utilization of saline water for irrigation, as an alternative, is somehow challenging. Because it can pose serious threats to agricultural sustainability and food security by creating salt buildup in the root zone if used inappropriately (Tyagi, 2003). Using simulation models is one of the management tools to predict effect of water salinity on crop yield, soil properties, groundwater and etc. For this purpose, various models have been developed for simulation of crop yield under salinity stress such as CERES-maize (Jones and Kiniry, 1986), SWAP (Kroes et al., 1999), SALTMED (Ragab, 2002), Hybrid-maize (Yang et al., 2004) and AquaCrop (Steduto et al., 2009).

Many studies have been conducted to estimate crop yield using the AquaCrop model. Heng et al. (2009) evaluated the performance of the AquaCrop model for maize using data from three studies performed under diverse environmental conditions. The model performed satisfactorily for the growth of aboveground biomass, grain yield, and canopy cover (CC) in the non-water-stress treatments and mild stress conditions, but it was less satisfactory in simulating severe water-stress treatments, especially when stress occurred during senescence. Stricevic et al. (2011) used the AquaCrop model to simulate rainfed and supplementally irrigated maize, sugar beet and sunflower in Serbia. The results showed that the model can be used in impartial decision-making and in the selection of crops to be given irrigation priority in areas where water resources are limited. Abedinpour et al. (2012) evaluated performance of the AquaCrop model for maize crop in a semi-arid environment under various water irrigation and nitrogen applications. The model prediction error in simulating the water productivity (WP) and maize biomass were varied from 2.3 to 27.5% and 8.4–17.8%, respectively, for different irrigation and nitrogen levels. Katerji et al. (2013) simulated productivity, evapotranspiration, and water use efficiency of corn and tomato by AquaCrop under different water stress conditions in the Mediterranean region of Italy. The model adequately simulated the daily biomass accumulation under all treatments for tomato and under non-stressed and moderate stressed treatments for corn. However, in the case of the

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* Corresponding author.
E-mail address: ebrahimian@ut.ac.ir (H. Ebrahimian).

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severely stressed treatment, AquaCrop did not exhibit any aptitude for simulating the corn biomass and the grain yield. Masanganise et al. (2013) tested the utility of the AquaCrop model for predicting maize yield in a changing climate of Zimbabwe. The model was adapted to simulate maize yield in past (1971–2000) and changed (2046–2065) climate conditions. Validation of AquaCrop showed there was a good fit between observed and simulated values of maize yields. Khorsand et al. (2014) evaluated performance of the AquaCrop model to predict wheat yield and soil water and solute transport under water and salinity stresses. The results indicated that the model predicted soil salinity with more error compared with soil water content and grain yield. Ziaii et al. (2014) compared the AquaCrop and CERES-Maize models in assessment of soil water balance and maize yield under fertigation and fertilization conditions. The results indicated the performance of both models was appropriate.

Some studies have been also conducted about the SALTMED model. Ragab et al. (2005) calibrated and validated the SALTMED model under management of alternating and mixing use of fresh and saline water under drip and furrow irrigation systems on tomato yield and growth, in Egypt and Syria. The results proved that the model can be considered a useful tool in the management of water, crop and soil under field conditions. Montenegro et al. (2010) reported that the SALTMED model adequately simulated soil moisture and carrot and cabbage yields in the semi-arid region of Brazil. Razzaghi et al. (2011) simulated quinoa yield under various irrigation water salinity in a field-lysimeter experiment in Denmark. The results showed that the model has good ability to simulate seed yield and total dry matter. Oster et al. (2012) compared ENVIRO-GRO, HYDRUS, SALTMED, SWAP and UNSATCHEM in simulating forage corn yield from a common set of soil and water conditions. The SALTMED model simulated lower relative yields than the other models for all salinity levels of irrigation water. The results of the HYDRUS and SWAP models were very similar. Mehanna et al. (2012) stated that the SALTMED model was able to simulate snap bean yield successfully under different conditions of drought and fertilizer in Egypt. Hirich et al. (2012) calibrated and validated the SALTMED model under deficit irrigation with treated wastewater for quinoa, chickpeas and sweet corn in Morocco. The model proved its ability to predict soil moisture, yield and total dry matter. Silva et al. (2013) reported that the SALTMED model could accurately simulate soil moisture content, grain yield, and total dry biomass of chickpea under wet and dry year conditions and different irrigation regimes in southern Portugal. Rameshwaran et al. (2014) investigated the performance of the SALTMED model under saline irrigation conditions for pepper crop yield in Turkey. The predicted relative yield results were in good agreement with the measured data. Aly et al. (2015) used the SALTMED model for simulation of cucumber yield, soil salinity and soil moisture in a greenhouse experiment under deficit irrigation regimes in Saudi Arabia. The model adequately simulated the mentioned parameters.

The SWAP model has been evaluated to simulate crop yield in many studies. Eitzinger et al. (2004) compared the CERES (Ritchie, 1998), WOFOST (Supit et al., 1994) and SWAP models for simulating soil moisture content and crop yield of winter wheat and spring barley under different soil conditions in Austria. CERES and SWAP, in contrast to WOFOST, simulated the grain yield of barley and wheat well. All three models simulated water content in the soil profile with similar results. Noory et al. (2011) evaluated the SWAP model in simulating crop yield, water and salt movement in soil for wheat and fodder maize under simultaneous condition of water and salinity limitations in Iran. Values of statistical indexes showed that the estimated values of crop yield by SWAP had good agreements with the observed values. Verma et al. (2012) evaluated the SWAP model to simulate wheat growth and soil salinity profiles under various combinations of fresh and saline water use for irrigation at Agra (India), located in a semiarid monsoon climatic region having a deep water table. A close agreement was observed between the measured and simulated values for the relative yield. Kumar et al. (2015) simulated salt dynamics in the root zone and wheat yield under varying saline water irrigation regimes via using the SWAP model in India. The results showed that the model performed better for prediction of relative yield of salt tolerant varieties as compared to the salt non-tolerant variety.

A few studies have compared different models to estimate crop yield under salinity stress. Oster et al. (2012) compared various simulation models to estimate maize yield under salinity stress without using field data. On the other hand, a new version of the AquaCrop model considering salt stress and solute transport has been less evaluated. Therefore, the aim of this study was to evaluate the AquaCrop, SALTMED and SWAP models under cyclic use of saline and non-saline irrigation water for forage maize in Karaj region of Iran to find the ability and performance of the mentioned models in the estimation of crop yield under different management of saline and non-saline irrigation water use.

2. Materials and methods

2.1. Field experiments

Field experiments were carried out in 2012 for maize production at Soil and Water Research Center, University of Tehran, Karaj, which is located on 50°59′E and 35°48′N at an altitude of 1337 m above sea level. Karaj has a Mediterranean climate with annual precipitation of 265 mm. Total rainfall during the growing season was 20.5 mm occurred in germination stage before applying treatments. These rainfalls were subtracted from crop water requirements. Soil texture of the experimental field was mainly clay loam and there was a gravel layer at depths greater than 60 cm. Bulk density was 1.35 g cm^{-3}. The studied crop was maize (Single Cross 704) for fodder purpose. The crop was sown on 14th July. Seeding operations performed without any tillage with using direct planting machine (No tillage).

Nine field treatments were laid out in a Randomized Complete Block Design (RCBD) with three replications in 27 plots. Dimensions of each plot were 2.85 m × 3 m consisted of four maize planted rows. A row of crop was planted beside the plots to remove marginal effect. The irrigation system was trickle (tape). A main pipe was placed across the field and lateral pipes were branched to each plot. A small controlling valve was inserted in every plot to adjust irrigation inflow. The volume of water per plot was adjusted using a volumetric flow meter. The treatments are described in Table 1. Where letters of F, S1 and S2 are related to water salinity level of 0.4, 3.5 and 5.7 dS m^{-1}, respectively, and the numbers before the letters indicates its frequency. Only one salinity level was constantly used for irrigation during the growing season in the F, S1 and S2 treatments (Table 1).

Salinity levels of 3.5 and 5.7 dS m^{-1} were based on 25 and 50 percent reduction in maize yield production, respectively (Allen et al., 1998). After seeding, all treatments were irrigated to field capacity. From seeding until eight-leaf stage of maize, irrigation in each plot was based on soil moisture and crop water requirement. According to soil characteristics of the field and water requirement of maize, irrigation interval considered four days. Crop coefficient (K_c) of maize during initial, mid-season and the end of season stage were 0.3, 1.2 and 0.6, respectively (Allen et al., 1998). Root depth of maize due to the limited soil layer was determined 60 cm. The values of ET_0 during the growing season were calculated by CROPWAT 8.0 using daily meteorological data. Due to reduction in evapotranspiration under salinity stress, a factor must be applied in ET_0.