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Effects of different irrigation regimes on soil moisture availability evaluated by CSM-CERES-Maize model under semi-arid condition

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ABSTRACT

Crop models are useful tools for evaluation of management factors for any possible productivity improvement under water-deficit conditions. Such applications require an accurate simulation of the soil water balance. The main objective of this study was to evaluate the performance of CSM-CERES-Maize model for simulating soil moisture under different irrigation levels of silage-maize. This experiment was conducted in growing seasons of 2003 and 2004. Treatments were four irrigation levels (two deficit-irrigation levels at 0.7 and 0.85 soil moisture depletion (SMD), a full irrigation (SMD) and an over-irrigation treatment (1.13 SMD), indicated by W1, W2, W3 and W4, respectively). Soil moisture was measured on a daily basis in different layers of the soil profile. In the first year, gravimetric sampling method and in the second year a neutron probe were used for measuring soil moisture. Simulated soil moisture was compared with measured field values for each individual soil layer. Results indicated that root mean square error (RMSE) of the model-predicted soil moisture for different treatments, depending on depth, was 0.8–13.6%. Systematic error and the index of agreement of the model in estimating total water in 60 cm soil profile was 0.8–2.00 cm. The greatest error in estimating soil moisture always happened for top layer of the soil profile. Based on the results, it can be concluded that CSM-CERES-Maize model is able to simulate soil moisture content for wide range of soil conditions and irrigation regimes.

1. Introduction

Ecohydrology's main goal is to regulate the human modified processes (water and nutrient's cycling and energy flows) toward sustainability (Zalewski, 2014). Designing more efficient water management systems in the field under water deficit condition is an important tool for optimizing the water usage for maximizing food

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production and sustainability. Although, field studies are classic and accurate methods for investigating the effects of water management strategies on crop production, but these methods are usually expensive and time-consuming (Jones et al., 2003). It is also difficult to perform a long-term evaluation of different management scenarios with complex weather interactions, and a range of soil textures, under field conditions (Gijsman et al., 2002; He et al., 2012; Mulebeke et al., 2013). Thus, different crop models have been developed in order to simulate soil moisture and plant growth for a range of management practices and environmental conditions (Szporak-Wasilewska et al., 2015; Wang and Engel, 2000; Singh et al., 2014). During the past 25 years, crop models have demonstrated to be a powerful tool that can generalize laboratory data for very specific weather and soil conditions and a range of management scenarios (Boote et al., 2010; Lopez-Cedron et al., 2008; Dokoohaki et al., 2015; Lalika et al., 2014; Thorp et al., 2008). Crop modeling reduces field operations for achieving more efficient management strategies in long-term (Popova and Kercheva, 2005; Boote et al., 1997).

Crop models, as a promising potential tool, can be used for determining water strategies with high applied-water efficiency (Lopez-Cedron et al., 2008; Xie et al., 2001; Hoogenboom et al., 2004; Dokoohaki et al., 2016). The Decision Support System for Agrotechnology Transfer (DSSAT) software encompasses more than 28 crop models that have been widely used all over the world, because it is accurate, simple, efficient and requires minimum set of data as input (Jones et al., 2003; Hoogenboom et al., 2012).

There are mainly two approaches for modeling soil water dynamics in soil: using physically-based methods (Šimůnek et al., 1999, 2006), and employing heuristic algorithms or empirical methods (Ritchie and Otter, 1985). Numerous soil and crop models designed for soil water management (HYDRUS, HYDRUS-2D) fall within the category of physically-based models, which numerically solve Richards equation with/without presence of crop and root water uptake (Vrugt et al., 2001; Elmaloglou et al., 2013; Elmaloglou and Soulis, 2013; Soulis et al., 2015). As opposed these models, others such as DSSAT use simple and empirical methods for calculating daily soil moisture. Simplifications made in more empirical soil water management tools like DSSAT might reduce capability of these models in generating accurate results (Suleiman and Ritchie, 2004). Actually, numerous studies have shown previously that simulation of soil water content is accurate enough for irrigated conditions, while recent studies using CSM-CERES-Maize as part of DSSAT package have raised more concerns about the accuracy of the model in its simulation mode under deficit-irrigation conditions (DeJonge et al., 2011; Esmaeilian et al., 2014). DeJonge et al. (2011) reported that CSM-CERES-Maize performed better in predicting total 1.0 m soil water content (SWC) for the full irrigation treatment than for limited irrigation. In addition, the performance of CERES-Maize model under rainfed condition had less accuracy as compared to irrigated field (Saseendran et al., 2008). Several other researchers have reported a good agreement between simulated and observed soil water content under full irrigation regime (Soler et al., 2007; Asadi and Clemente, 2003).

Since water has become a scarce resource in many areas of the globe (Zalewski et al., 2003) and farmers are deliberately practicing deficit irrigation due to the shortage of water in arid and semi-arid area (Gheysari et al., 2009a), it is necessary to investigate the effects of irrigation management strategies on crop production. So far, the CSM-CERES-Maize model has only been evaluated in a few studies under semi-arid conditions for soil water simulation and mostly under no-water stress condition. Therefore, the main objective of the current study is to evaluate the soil water balance module of DSSAT for simulation of soil moisture content in individual soil layers as well as whole soil profile, under over, full and deficit-irrigation treatments.

2. Materials and methods

2.1. Study site

A silage maize experiment was conducted during 2003 and 2004 at the Agricultural Research Center, Varamin, Iran, which is located at longitude of 51°38′ E, latitude of 35°20′ N and 973 m above mean sea level (Gheysari et al., 2009a, 2015). This region has an arid and semi-arid climate, with four distinct climatic seasons. The mean annual rainfall is 170 mm, with most of it occurring during the autumn and winter months. Average minimum air temperature during the growing season was 11.2 °C in 2003 and 18.6 °C in 2004, while average maximum air temperature was 31.8 °C in 2003 and 33.2 °C in 2004 (Gheysari et al., 2009a). Groundwater table was more than 10 m deep and soil was classified as clay loam (Typic Torriorthents; 45% silt, 32% clay, and 23% sand), with a particle density of soil of 2.46 g cm^{-3} and electrical conductivity of 2.55 dS m^{-1}. Basic properties of the soil are given in Table 1.

2.2. Experimental detail

The maize hybrid SC704 was planted on August 3 in 2003 and June 25 in 2004. The irrigation system was a solid-set sprinkler. Treatments arranged in a strip-plot statistical design with randomized complete blocks and three replicates. Each block consisted of twelve treatment combinations. Plots (16 m × 16 m) were irrigated every

Table 1
Basic properties of the soil profile at the experimental site.

Layer	Depth (cm)	Silt (%)	Clay (%)	ρ_b (g cm^{-3})	OC (%)	DUL (g g^{-1})	LL (g g^{-1})
1	0–20	44	31.5	1.37	0.66	0.25	0.12
2	20–40	45	32	1.37	0.73	0.25	0.12
3	40–60	44	31.5	1.37	0.47	0.25	0.12

other day during the first 30 days after planting (DAP) in 2003 and 28 DAP in 2004. The irrigation treatments were started at 34 DAP in 2003 and at 29 DAP in 2004. Time of irrigation was determined based on the soil moisture depletion (SMD) from the root zone (Cuenca, 1989) for full irrigation treatment (Gheysari et al., 2009b). Crop evapotranspiration (ET_c) was used for estimation of the SMD in order to reduce the frequency of taking soil samples. However, time and depth of irrigation were determined based on SWC. The experiment included four irrigation treatments [two deficit irrigations (0.7 SMD and 0.85 SMD, indicated by W1 and W2), a full irrigation (SMD, W3) and an over-irrigation treatment (1.13 SMD, W4)]. While, no rainfall event happened during the study period for both years, the irrigation depth (for replenishing the depleted soil moisture in the root zone up to field capacity (FC) for W3 treatment) was calculated as:

$$I_n = \sum_{i=1}^{m} \frac{(WFC_i - WBI_i) \times \rho_{bi} \times Di}{100} \tag{1}$$

where I_n is net depth of irrigation (mm), WFC_i is soil moisture content at FC (%w), WBI_i is soil moisture content before irrigation (%w), m is soil layer number, ρ_b is bulk density and Di is soil layer thickness (mm) and then the gross depth of irrigation (I_g) was calculated, irrigation efficiency (E_a) assumed to be equal 75% (Gheysari et al., 2015).

$$I_g = \frac{I_n \cdot 100}{E_a} \tag{2}$$

In 2003, soil samples were taken to determine the gravimetric soil moisture content (Smith and Warrick, 2007). Five samples were taken per plot at depths of 0–20, 20–40, 40–60, 60–80, and 80–100 cm. Three soil samples (0–20, 20–40, and 40–60 cm) were collected one day prior and two days after irrigation during the growing season, and two soil samples (60–80, and 80–100 cm) were collected when wetting front pass this depth. In 2004, a neutron probe was used to measure daily soil water content at the center of each plot where a 2 m PVC access tube was installed. The neutron probe was calibrated and used for 0–10, 10–20, 20–40, 40–60 and 60–100 cm soil depth and soil moisture was measured from 0-to-110 cm in 10 cm increments during the growing season (Gheysari et al., 2015). Finally, the soil water measurements expressed as the volumetric basis for comparing with the model outputs.

2.3. DSSAT model

In this study, the Crop Environment Resource Synthesis (CERES-Maize) model was used (Jones and Kiniry, 1986). This model has been designed to simulate crop growth and development within the framework of DSSAT v4.5 (Hoogenboom et al., 2012). DSSAT includes the Cropping System Model (CSM; Jones et al., 2003) that encompasses crop modules for simulation of growth, development and yield of more than 28 crops (Hoogenboom et al., 2012).

The soil water balance model developed for CERES-Wheat (Ritchie and Otter, 1985) was adapted for use by all of the DSSAT v3.5 crop models (Jones and Ritchie, 1991; Jones, 1993; Ritchie, 1998). The current soil water submodule in DSSAT4.5 uses the Ritchie (1998) one-dimensional method. This model calculates daily changes in soil water content by soil layer due to infiltration of irrigation and rainfall, vertical drainage, unsaturated flow, soil evaporation, and root water uptake processes. The model uses a "tipping bucket" approach for computing soil water drainage. In this method, the excess water above the FC of a layer is passed directly to the layer below. Unsaturated upward flow is also computed using a conservative estimate of the soil water diffusivity and differences in volumetric soil water content of adjacent layers (Ritchie, 1998). The SCS method (Soil Conservation Service, 1972) is used to partition rainfall into runoff and infiltration, based on a "curve number" that attempts to account for texture, slope, and tillage. The default Priestley–Taylor (1972) method, available as an option in DSSAT, was used to calculate ETc. CERES-Maize partitions the potential ET into potential soil evaporation and potential plant transpiration. Actual soil evaporation and plant transpiration rates depend on the soil water availability to meet the potential values (Lopez-Cedron et al., 2008; DeJonge et al., 2011). In addition, a new method called "extended SR" has been implemented into current version for calculation of soil water evaporation and redistribution under high water content conditions (Ritchie et al., 2007).

2.4. Model setup, calibration and evaluation

Soil file was created using the information presented in Table 1 and the experimental file using the field information presented above. The CSM-CERES-Maize model was calibrated with the data obtained from a plot with no water or nutrient stress in 2004 and was evaluated with data from other treatments in 2004 and 2003. Calibration was performed manually to optimize the six cultivar coefficients (Jones and Kiniry, 1986) of CSM-CERES-Maize using the observed data (Table 2). The cultivar coefficients used in the CERES-Maize model control the growth and development of the crop and by affecting the root growth and root water uptake indirectly impact the soil water content.

One of the main objectives of this study was to assess the performance of the model by comparing the simulated

Table 2
Cultivar coefficients of Single Cross 704 maize hybrid following calibration.

P1 (°C day)	P2	P5 (°C day)	G2 (–)	G3 (mg day^{-1})	PHINT (°C day)
295	0.364	790	833	8.5	50

P1: degree days (based on 8 °C) from emergence to the end of juvenile phase; P2: photoperiod sensitivity coefficient (0–1.0); P5: degree days (based on 8 °C) from silking to physiological maturity; G2: potential kernel number; G3: potential kernel growth rate (mg day^{-1}); PHINT: degree days required for a leaf tip to appear (phyllochron interval) (based on 8 °C).

data with field measurements. Therefore, several statistical criteria were used (Willmott, 1982). These statics include root mean square error (RMSE):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N}} \tag{3}$$

Relative error (RE):

$$RE = \frac{P_i - O_i}{O_i} \tag{4}$$

Normalized root mean square error:

$$NRMSE = \frac{RMSE}{O_{avg}} \tag{5}$$

Index of agreement:

$$d = 1 - \left[\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(|P_i'| + |O_i'|)^2}\right] \tag{6}$$

In these equations, P_i and O_i are predicted and observed values, respectively, N is number of cases and O_{avg} is average of the observed data, O_i' is $(O_i - O_{avg})$, and P_i' is $(P_i - O_{avg})$.

Willmott (1982) recommended using d-index, $RMSE_s$ (root mean square error systematic) and $RMSE_u$ (root mean square error unsystematic), and RMSE for model evaluation:

$$RMSE_s = \sqrt{\frac{\sum_{i=1}^{N}(\hat{P}_i - O_i)^2}{N}} \tag{7}$$

$$RMSE_u = \sqrt{\frac{\sum_{i=1}^{N}(P_i - \hat{P}_i)^2}{N}} \tag{8}$$

where $\hat{P} = a + bO_i$ the y-intercept a and slop b of the resulting straight line are calculated to describe the regressed prediction for each observation.

The advantage of $RMSE_s$ is that it indicates the bias (deviation of the actual slope from the 1:1 line) in a particular model, compared with the random error ($RMSE_u$) that may occur. The index of agreement (scale 0–1) is a standardized measure of the degree to which a model's predictions are error free. This statistic reflects the degree to which the observed variable is accurately estimated by the predicted variable. At last, the simulation is done significantly well with a NRMSE < 10%, good if 20 > NRMSE > 10, fair if 30 > NRMSE > 20, and poor if NRMSE >30% (Jamieson et al., 1991).

3. Results and discussion

The efficiency the CSM-CERES-Maize model in simulating the soil moisture content was considered from two perspectives: (1) evaluation of the individual soil layers and (2) evaluation of the total soil water content.

3.1. Simulation of moisture in the soil layers

The results of simulated soil moisture for three layers in 2003 and 2004 and four irrigation treatments are presented in Table 3. The RMSE, NRMSE and d-indices are used for comparing the results of simulations.

By considering the 30% NRMSE as the critical limit of error in the predictions (Jamieson et al., 1991), the results of simulation for extreme deficit-irrigation treatment (W1) showed that the simulated SWC was in the acceptable range for layers 2–3 in 2003 (Table 3), while the model performed very well in 2004 (Table 3). In this treatment,

Table 3
A comparison between simulated and observed soil moisture content for 0–20, 20–40, and 40–60 cm soil layer for two deficit irrigation levels (W1 and W2), full (W3) and over (W4) irrigation levels in 2003 and 2004.

	2003			2004			
	Layer 1 (0–20 cm)	Layer 2 (20–40 cm)	Layer 3 (40–60 cm)	Layer 1 (0–20 cm)	Layer 2 (20–40 cm)	Layer 3 (40–60 cm)	
Mean observed (%)	19.50	16.40	16.40	22.16	20.2	19.6	W1 (0.7SMD)
Mean simulated (%)	21.77	16.75	16.30	21.9	19	18.45	
RMSE (%)	7.73	3.25	3.00	3.57	2.15	1.9	
d-Index	0.60	0.24	0.06	0.76	0.84	0.86	
NRMSE (%)	39.65	19.82	18.29	16.1	10.61	9.685	
Mean observed (%)	21.37	19.95	17.10	23.6	22.45	19.5	W2 (0.85SMD)
Mean simulated (%)	24.33	17.90	16.35	24.4	21.25	18.4	
RMSE (%)	8.40	4.75	3.75	2.86	3	2.3	
d-Index	0.64	0.51	0.24	0.87	0.62	0.81	
NRMSE (%)	39.17	23.70	21.93	12.13	13.36	7.77	
Mean observed (%)	21.90	24.05	24.90	27.6	27.55	25.55	W3 (SMD)
Mean simulated (%)	26.43	24.50	22.55	28.7	27.75	24.55	
RMSE (%)	9.17	4.85	6.00	3.8	2.45	2.4	
d-Index	0.65	0.80	0.76	0.63	0.69	0.87	
NRMSE (%)	41.85	20.14	24.09	13.7	8.89	9.38	
Mean observed (%)	24.20	24.70	22.50	26.9	26.2	24.5	W4 (1.13SMD)
Mean simulated (%)	25.97	24.95	22.70	27.8	27.1	25.15	
RMSE (%)	6.73	4.55	4.35	3.1	2.15	2.05	
d-Index	0.66	0.80	0.83	0.84	0.9	0.93	
NRMSE (%)	27.80	18.42	19.33	11.5	8.18	8.38	

RMSE: root mean square error; NRMSE: normalized RMSE; SMD: soil moisture depletion.

the NRMSE for layers 20–40 and 40–60 cm was in the range of 18.3–19.82% in 2003, and for layers 0–20, 20–40, and 40–60 cm was in the range of 9.7–16.1% in 2004. The results clearly indicated that for the W1 treatment the amplitude of cyclic changes of SWC was high in the top soil layers (<20 cm) and it was lower for deeper soil layers (Figs. 1 and 2). After applying irrigation regime (30 DAP) in W1, soil moisture for layers 2–3 did not change much, because of the small amount of water that was applied and the associated small amount of infiltration. The model simulated vertical downward flow to a maximum depth of 20 cm for this treatment and the predicted SWC showed almost no fluctuation for the lower layers while some variability can be seen for the observed SWC.

The NRMSE for simulation of SWC for the moderate deficit-irrigation treatment (W2) was in a satisfactory range for layers with depth of >20 cm in both years. The NRMSE for W2 treatment ranged from 7.77 to 23.7% for both years and it was 39.17 for layer 1 in 2003. The *d*-index for W2 varied between 0.24 and 0.87 for both years.

The NRMSE for fully irrigation treatment (W3) ranged from 20.14 to 41.85% in 2003 and from 8.89 to 13.7% in 2004 (Table 3). The accuracy of the model was in the acceptable range for layers with depth of >20 cm 2003. While, there was a good simulation of SWC for all layers in 2004. The results indicated that simulation results for 2004 data were better than 2003. For 2003, *d*-index ranged from 0.65 to 0.80, while for 2004, *d*-index was 0.63–0.87.

For over-irrigation treatment (W4), the model predicted SWC accurately, in some cases even better than the other treatments (Table 3). For this treatment, the NRMSE for layers 2–3 had an acceptable range in 2003. For 2004, the NRMSE ranged from 8.18 to 11.5%, which suggests an extremely good estimation. Similar to other treatments, the top layer had the highest NRMSE. It can be concluded that the model simulated the timing and magnitudes of the extreme values for layers 2–3 (Figs. 1 and 2).

As results showed the simulation results were better in 2004 compared to 2003, it might have to do with the fact that in 2004 we had a larger, sample size with more frequent measurements. Also, the planting date was vary for both years; the natural climate variability that caused differences in evaporative demand, differences in the amount of available energy during both years, different planting density in 2003 and 2004, and may be wind drift changing base ETc values.

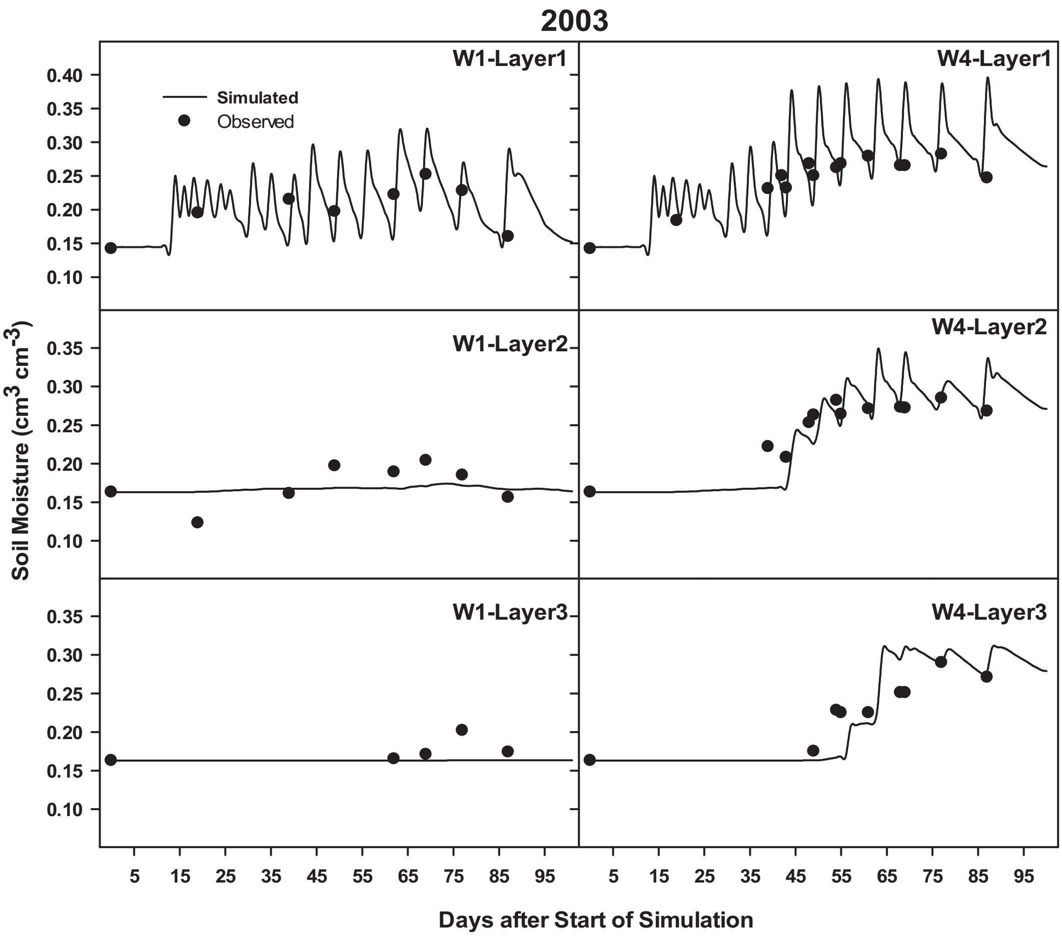

Fig. 1. Comparison between observed and simulated soil moisture in extreme deficit and over irrigation treatments for soil layers of 0–20, 20–40, and 40–60 cm in 2003.

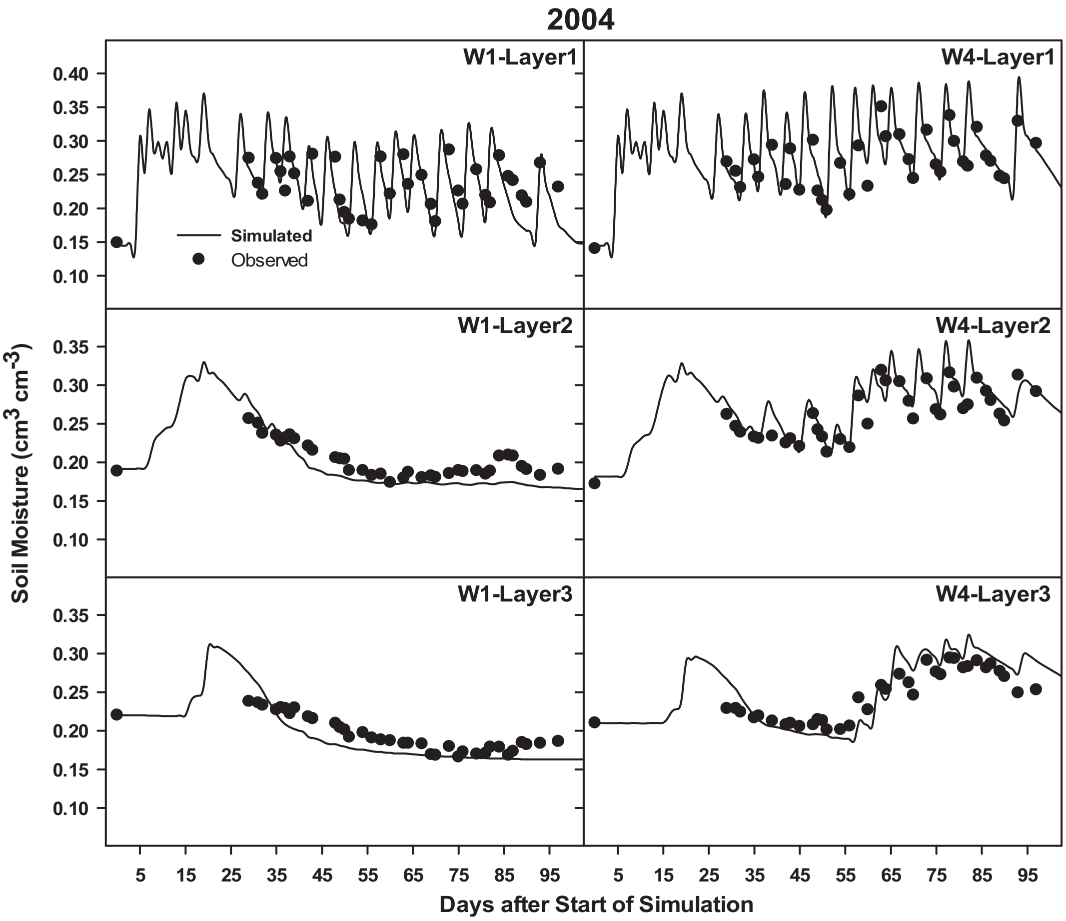

Fig. 2. Comparison between observed and simulated soil moisture in extreme deficit and over irrigation treatments for soil layers of 0–20, 20–40, and 40–60 cm in 2004.

Overall, the most accurate simulation of SWC for each of the individual layers was for over- irrigation treatment (W4) for both years. While, the worst simulations for each of the individual layers were for extreme deficit-irrigation treatment (W1). However, results also showed that the model's performance in simulation of total water content in both years for deficit irrigation treatments were in satisfactory range.

Similar to the results obtained by other researches (e.g., Liu et al., 2014), maximum error for all treatments always occurred at the beginning of the growing season for the surface layer. Similar results have been found by Jamieson et al. (1998) and Eitzinger et al. (2004). Although, Ritchie et al. (2007) reported that the model tended to over-predict SWC for the surface layer. The range of RMSE for soil moisture for different soil layers, in the two years, was 1.9–9.17%. The error in our study was less than Xevi et al. (1996) results, which expressed the accuracy of CERES-Maize for estimating soil moisture as 9.8–16.6% of volumetric moisture content, depending on soil depth. Garrison (1999) used the CERES-Maize model for a loamy soil and reported RMSE values between 3 and 5.4 of volume percent. Meng and Quiring (2008) reported that the RMSE values between actual volumetric moisture contents and stimulated ones were 3–14%.

As previously stated, the results showed that maximum RMSE in all the treatments and for the two years of 2003 and 2004 happened in the top soil layer. Saseendran et al. (2008) and Soldevilla-Martinez et al. (2014) also expressed that soil water simulations in the top soil layer were less accurate than the lower layers. On the other hand, Ritchie et al. (2007) reported that soil water distribution near the surface was in good agreement with measurements in a sandy loam soil. There are many potential causes for this inconsistency. As Saseendran et al. (2008) have stated, it could be due to high heterogeneity in soil properties in surface layer or high spatial variability in crop residues cover in the field. This error also could be generated because of the weakness of neutron probe in measuring SWC in the soil surface. Since the neutron tube was installed between the ridge and furrow for measuring soil moisture (Gheysari et al., 2009b), the discrepancy in depths of measurement between what was performed in the field and what was considered by DSSAT model can be another cause of inaccuracy. Another possibility is that soil evaporation estimated by the model can be a cause for this inaccuracy; since, evaporation is a unique process that the model considers for the first layer in comparison to the other lower layers.

By increasing the level of applied irrigation (from extreme deficit-irrigation treatment (W1) to over-irrigation treatment (W4)), the error of the model in estimating soil moisture decreased in 2004.

3.2. Simulation of total water in the soil profile

The CERES-Maize model was able to simulate accurately the total amount of soil water in the entire soil profile during the growing season, especially for 2004, as can be seen from the low NRMSE values (Fig. 3 and Table 4).

RMSE of the total soil water content in the soil profile varied between 1.5 and 3.5 cm for all irrigation treatments during 2003 and 2004 (Table 4). The lowest $RMSE_s$ was 1.2 cm for over-irrigation treatment and the highest $RMSE_s$ was 2.00 cm for deficit-irrigation level (W2) in 2003. In 2004, minimum and maximum $RMSE_s$ occurred in over-irrigation and extreme deficit-irrigation treatments (0.8 and 1.7 cm, respectively).

The highest value of *d*-index was found for over-irrigation treatments and these values were 0.86 for 2003 and 0.83 for 2004. The lowest value for *d*-index was 0.7 for W1 in 2003 and 0.54 for W2 in 2004, respectively (Table 4).

As Table 4 indicates, based on NRMSE values in both years, the accuracy of simulations has increased by increasing the applied water from W1 to W4, except in W1 in 2003. This is similar to the results found for simulation of individual soil layers. According to our results, it seems that the accuracy of simulations is better in 2004 than 2003, which may be due to more data availability or the experimental data measurement. In 2004 we had a larger, sample size with more frequent measurements.

The outputs of our simulations were similar, and even slightly better than those obtained by DeJonge et al. (2011). They reported a range of 14.4–24.5% for NRMSE for total water for the top 1.0 m, while in our study, NRMSE varied between 9.1 and 30.6% for total water in the 60 cm soil profile. It has been found that CSM-CERES-Maize model estimated total water content for the entire growing season good and well (Jamieson et al., 1991) for full irrigation treatment and fair and good (Jamieson et al., 1991) for deficit irrigation treatments in 2003 and 2004, respectively. However, the simulated SWC was always less than measured SWC in 2004. The general tendency of the CSM-CERES-Maize model for extracting more water was also reported by Garrison et al. (1999) and DeJonge et al. (2011). Jamieson et al. (1998) used CERES model for winter wheat and showed that this model underestimated soil moisture content. Part of this underestimation might be due to selection of Priestley–Taylor (PT) method for calculating potential evapotranspiration in the model. Sau et al. (2004) and Nielsen et al. (2002) found that the PT method estimated a value for ET that was higher than the actual measured ET. However, our study has insufficient data to support this observation. On the other hand, Li et al. (2013, 2015) and Chisanga et al. (2015) found the DSSAT model to be overestimating soil water content using PT method. As the other researchers have pointed out

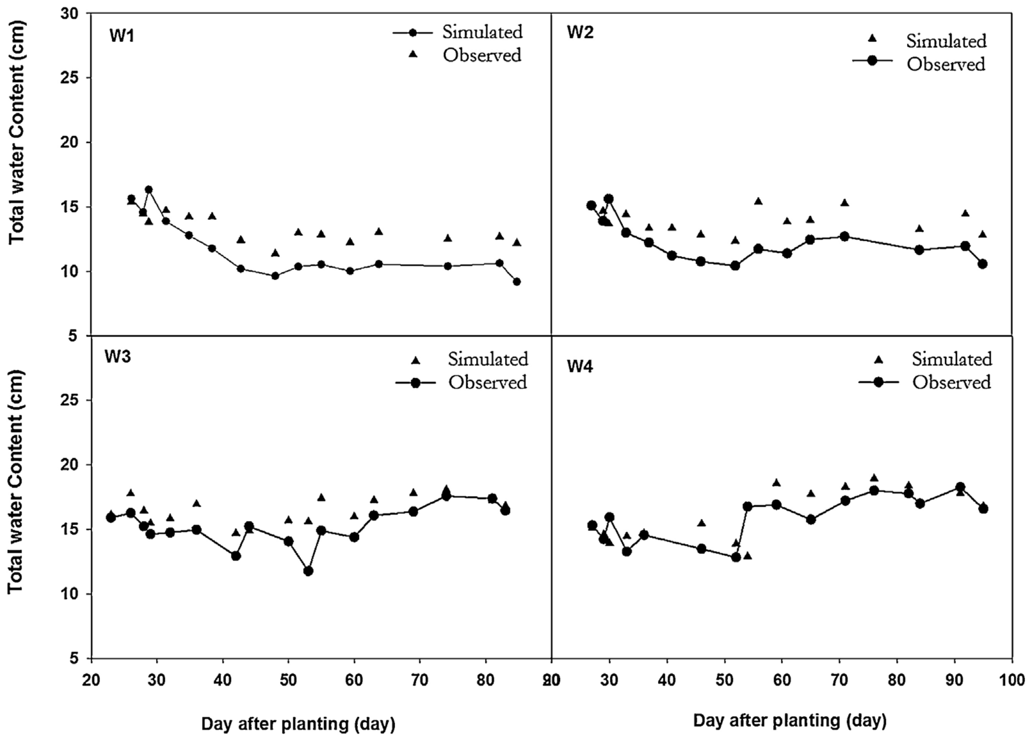

Fig. 3. Comparison of observed and simulated amount of total water in the soil profile during growing season for two deficit irrigation levels (W1, W2), full (W3), and over (W4) irrigation levels.

Table 4
A comparison between simulated and observed total soil moisture content for two deficit irrigation levels (W1 and W2), full (W3) and over (W4) irrigation levels in 2003 and 2004.

2003	W1 (0.7 SMD)		W2 (0.85 SMD)		W3 (SMD)		W4 (1.13 SMD)	
	Obs	Sim	Obs	Sim	Obs	Sim	Obs	Sim
Mean (cm)	10.4	11.3	13.2	13.1	14.3	15.1	14.4	14.7
Max (cm)	12.5	12.8	20.8	13.3	16.8	19.8	17.1	20.8
Min (cm)	6.2	9.5	6.2	13.0	6.2	9.5	6.2	9.5
RMSE (cm)	1.9		3.5		2.9		2.7	
d-Index	0.7		0.86		0.85		0.86	
$RMSE_s$ (cm)	1.7		2.0		1.9		1.2	
$RMSE_u$ (cm)	0.99		2.94		2.30		2.48	
NRMSE (%)	18.9		30.6		21.0		19.2	
2004	**W1 (0.7 SMD)**		**W2 (0.85 SMD)**		**W3 (SMD)**		**W4 (1.13 SMD)**	
	Obs	Sim	Obs	Sim	Obs	Sim	Obs	Sim
Mean (cm)	13.2	11.7	13.8	12.2	16.4	15.2	16.1	15.8
Max (cm)	15.3	16.3	15.3	15.5	18.0	17.5	18.9	18.2
Min (cm)	11.3	9.1	12.3	10.3	14.6	11.7	12.9	12.8
RMSE (cm)	2.0		2.0		1.5		1.4	
d-Index	0.67		0.54		0.66		0.83	
$RMSE_s$ (cm)	1.7		1.5		1.2		0.8	
$RMSE_u$ (cm)	1.10		1.3		0.9		1.2	
NRMSE (%)	15.5		14.6		9.6		9.1	

Obs: observed; Sim: simulated; SMD: soil moisture depletion; RMSEs: root mean square error systematic; RMSEu: root mean square error unsystematic; RMSE: root mean square error; NRMSE: normalized RMSE.

(Soldevilla-Martinez et al., 2014), employing more mechanistic approaches on soil evaporation as well as soil water fluxes may help DSSAT model to have better prediction of water budget of the soil profile.

4. Conclusions

The results of this two-year study showed that CSM-CERES-Maize model was able to simulate soil moisture content accurately for over, full and deficit-irrigation treatment for maize grown under a semi-arid condition. The best performance of the model was found for over-irrigation treatment. The most accurate simulation of SWC for each of the individual layers was for over- irrigation treatment. While, the worst simulations for each of the individual layers were for extreme deficit-irrigation treatment. The accuracy of soil moisture estimation increased for each layer of soil by increasing the depth of irrigation water in the second year. The model was also able to simulate the trend of soil water changes during the whole growth period. The overall amount of systematic error and *d*-index in simulation total soil water content for deficit irrigation treatment were not out of range. It was concluded that under deficit irrigation management for semi-arid conditions, the model cannot be used for simulation of SWC for each of the individual soil layers, however it can be used for simulating total soil water content in the root zone.

Conflict of interest

The equipment was delivered by Isfahan University of Technology where authors are employed.

Ethical statement

Authors state that the research was conducted according to ethical standards.

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