International Journal of Plant Production 10 (2), April 2016
ISSN: 1735-6814 (Print), 1735-8043 (Online)
www.ijpp.info

GUASNR

Assessing SALTMED model for wheat experiments irrigated with basin and sprinkler systems

F. Razzaghi*, T. Ghannadi

Assistant professor and graduated MSc. Student, respectively, Water Engineering Department, Agricultural College, Shiraz University, Iran.
*Corresponding author. E-mail: razzaghi@shirazu.ac.ir

Received 14 October 2015; Accepted after revision 27 December 2015; Published online 5 March 2016

Abstract

Comprehensive agricultural models are crucial for assisting several decision making processes due to their capability for use under different conditions. SALTMED is a holistic generic model, which simulates yield, dry matter and soil water content under different irrigation managements and systems. The aim of this study was to calibrate the SALTMED model to simulate wheat yield, dry matter and soil water content of two different field experiments using different irrigation amounts and systems, namely sprinkler and basin irrigation systems. For both irrigation systems, experimentation was conducted for two consecutive years. For the sprinkler irrigation system, three irrigation treatments (wet, medium and dry) were considered. For the basin irrigation system, 50, 75 and 100% of the irrigation requirement were applied as irrigation treatments. The SALTMED model reasonably predicted the wheat yield and dry matter for both irrigation methods by small tuning of crop coefficients and some growth parameters. Besides, a good agreement between observed and simulated soil moisture content was obtained for both experiments with different irrigation treatments and systems. Comparison of the soil moisture prediction for the two different irrigation methods revealed that the SALTMED model simulated the soil moisture content better under the sprinkler system. It is concluded that SALTMED model performed better under sprinkler system rather than basin irrigation system.

Keywords: Parameterization; Yield; Dry matter; Soil moisture content.

Introduction

Iran is located in the mid-latitude belt of arid and semi-arid regions of the Earth and 85 percent of its total area is classified as an arid to semi-arid climate (Banaei et al., 2005). The average annual rainfall of Iran is 240 mm (Heshmati and Squires, 2013), which is highly variable in time, space, amount and duration and hence, water is the most important limiting factor for agricultural activities and dry land farming (Dinpashoh et al., 2004). Soil moisture stress is a limiting factor for crop growth in arid and semi-arid regions due to low and uncertain precipitation and periodic drought conditions (Rwehumbiza and Siza Tumbo, 2009). Numerous experimental studies have investigated the effect of different abiotic stresses such as drought and salinity on agricultural crop growth under field conditions (Liu et al., 2015; Mohammadi et al., 2015; Razzaghi et al., 2012; Slama et al., 2015). Experimental field studies undoubtedly serve as the most reliable method to distinguish and understand the effect of different stresses on plants growth and production, however they are costly, time consuming, laborious and disruptive and relatively impractical for large scale applications (Murthy, 2004). Several crop models exist to simulate plant response to abiotic stresses. They have the capability to simulate crop development, water and nutrient movement and also, predict grain yield and dry matter as influenced by climatic conditions, soil characteristics and environmental stresses using different irrigation methods (Adam et al., 2011; Murthy, 2004).

Different models are developed for different purposes and environmental stresses. Majority of these models are able to predict growth and yield of many crops, while some are only developed for special crops such as GOSSYM for cotton (Baker et al., 1983), CHIKPGRO for chick pea (Singh and Virmani, 1996) and WTGROWS for wheat (Aggarwal et al., 1994). Among all the existing models to apply to different conditions (water deficit, salinity stress, fertilizer application, pesticide, etc.), few were developed to simulate crop response under water stress and salinity conditions, simultaneously, such as CROPSYST (Ferrer and Stockle, 1996), AQUACROP (Steduto et al., 2009) and SALTMED (Ragab, 2002). SALTMED is a generic model which can be used for a variety of irrigation systems, soil types, water application strategies (deficit irrigation, partial root drying), different nitrogen applications, different water qualities (fresh, saline), drainage systems and shallow groundwater presence (Ragab, 2002; Ragab et al., 2005a; Ragab et al., 2005b).

Recently, several studies have used SALTMED model to calibrate and validate different crops response to different management systems (InceKaya et al., 2015; Pulvento et al., 2015; Ranjbar et al., 2015). Pulvento et al. (2013) used SALTMED model to simulate grain yield and dry matter of quinoa and soil water content treated by saline (22 dS m^{-1}) and fresh water and with three water levels of 25, 50 and 100% of field capacity. Water was supplied weekly using surface drip irrigation. SALTMED model accurately predicted yield, total dry matter and soil moisture contents during the two years of experimentation. Further, the effects of different irrigation regimes with salinity treatments using a drip irrigation system were evaluated using SALTMED model for two pepper varieties (Rameshwaran et al., 2015) under greenhouse conditions. Four irrigation levels (50, 75, 100 and 125 percent of water requirement) and four salinity levels of 1.0, 2.5, 3.5 and 6 dS m^{-1} were used as irrigation and salinity treatments, respectively. The results showed that there was reasonably good agreement between predicted and measured soil moisture contents (in all layers) and yield. The ability of the SALTMED model to simulate crop growth parameters for different irrigation management was investigated by InceKaya et al. (2015). In their study, the model was able to accurately predict soil moisture content, dry matter and grain yield of quinoa under various soil water and salinity conditions.

Wheat is one of the major and strategic cereals for food security across the world. China with an average production of more than 100 million tonnes per year is ranked first in the world for wheat production followed by United States, while Turkey and Iran are the two main wheat producers in West Asia, accounting for 75 percent of total cultivated wheat land and wheat production (Curtis, 2002). The FAO predicts that Iran's wheat production in 2015 would be around 13 million tonnes (FAO, 2015); however, there is still a need to import wheat to the country. The latter highlights the need for further research on different aspects of wheat to find out how its production can be enhanced considering the recent drought occurrence and Iran’s prevailing climatic conditions. Modeling wheat crop production under different climatic conditions, agricultural practices and cropping will facilitate decision making in sustainable water management. The present study was conducted to evaluate the ability of SALTMED model to predict soil moisture content and wheat yield under full and deficit irrigation management using basin and sprinkler systems.

Materials and Methods

Two different experiments were conducted at the experimental research station of Shiraz Agricultural College (located in Badjgah, south of Iran) during 2004-2006 by Partojoo (2006) and 2007-2009 by Fateh (2010). The research station is located at 52º 32´ E, 29º 36´ N and at an altitude of 1810 meter above mean sea level. The soil texture at the experimental site was clay loam in the upper layers and sandy loam in the lower layers. The texture, field capacity, permanent wilting point and bulk density of the sites are shown in Table 1. The wheat (cv. Shiraz) was sown in both experimental sites during 2004-2006 and 2007-2009. In the both experiments, phosphorus fertilizer was applied in the form of ammonium phosphate (equivalent to 46% P_2O_5 and 18% nitrogen) at a rate of 100 kg ha^{-1} before planting. Nitrogen fertilizer was applied as urea (equivalent to 46% nitrogen) at a rate of 200 kg ha^{-1} in two equal parts; first part applied at sowing and the second part applied at beginning of spring (when dormancy ended), respectively.

Table 1. Soil properties at two experiments sites.

Depth (cm)	FC* (cm cm^{-3})	PWP** (cm cm^{-3})	Bulk density (g cm^{-3})	Soil texture
0-30	0.33	0.13	1.575	Clay Loam
30-60	0.34	0.13	1.830	Clay Loam
60-90	0.35	0.13	1.830	Clay Loam
90-120	0.31	0.16	1.460	Silty Loam
120-150	0.31	0.16	1.460	Silty Loam

* FC: Field Capacity, ** PWP: Permanent Wilting Point.

First experiment (Exp. 1)

The first field experiment was conducted by Partojoo (2006) during the growing seasons of 2004-2006. Wheat seeds were sown in 15×6 m^2 plots (90 m^2) with 120 rows at the depth of 5 cm and row spacing of 25 cm in November 2004 and 2005. The experimental design was split plot design with irrigation treatments (dry (I_1), medium (I_2) and wet (I_3) treatments) as main plots and seeding rate treatments of 80, 120, 160 and 200 kg ha^{-1} in the first year (2004-2005) and 120, 160, 200 and 240 kg ha^{-1} in the second year (2005-2006) as subplots, with three replications for each treatment. The wheat crop was irrigated using the line-source sprinkler irrigation system. Irrigation with this system allows a gradual variation of irrigation, i.e., a larger amount of water is received at the irrigation source, which then gradually decreases as it gets further away from the source.

The line-source sprinkler irrigation system had 11 sprinklers with 6 m distance from each other on the main pipe. The diameter of the main pipe was 63 mm. The sprinkler type was Rain Bird (nozzle size of 11.62"×3.32") with flow rate of 0.18 $l\ s^{-1}$, operating pressure of 4.5-5 atm and 28 m diameter of throw.

Second experiment (Exp. 2)

The second field experiment was performed by Fateh (2010) during 2007-2009. Wheat seeds were sown in 4×4 m^2 plots (16 m^2) with 16 rows at the depth of 5 cm and row spacing of 25 cm in October 2007 and 2008. The experimental design was randomized-complete block design with irrigation treatments (50, 75 and 100% of irrigation requirement, denoted as IR_1, IR_2 and IR_3, respectively) as main plots and seeding rate treatments (120, 160, 200, 240 and 280 kg ha^{-1}) as subplots, with three replications for each treatment. The wheat was irrigated using basin irrigation.

Crop water requirement

The depth of irrigation water (d, mm) was calculated to refill soil water deficit back to field capacity as follows:

$$d = \frac{(\theta_{fc} - \theta_v) \times R_z}{100} \tag{1}$$

where θ_{fc} is volumetric soil water content at field capacity (%), θ_v is volumetric soil water content before irrigation (%) and R_z is root depth (mm) which was obtained by using Borg and Grimes (1986) equation:

$$R_z = RDM \times (0.5 + 0.5 \times \sin(\frac{3.03\,DAP}{DTM} - 1.44)) \tag{2}$$

where RDM is maximum root depth (mm), DAP is day after planting and DTM is the number of days for maximum root depth.

Volumetric soil water content was measured weekly using neutron scattering method before each irrigation event at different depths of 30, 60, 90, 120 and 150 cm in both experiments (Exp. 1 and 2). The neutron probe in Exp. 1 was installed at 1, 7 and 11 m distance away from the line-source sprinkler irrigation system and to a depth of 180 cm. The irrigation amount (d) was applied weekly to replenish the soil moisture deficit by refilling the soil profile up to field capacity in I_3 treatments (wet treatments).

In the Exp. 2, the neutron probe was installed to a depth of 170 cm at the center of each basin. To calculate the amount of irrigation water on volumetric basis, the depth of irrigation (d) in IR_3 (100% irrigation requirement) was determined by considering 55% as maximum allowable depletion (MAD) and then multiplied by the area of the basins. For the other two irrigation treatments (IR_1 and IR_2), the irrigation depth was calculated based on the percentage of full irrigation (50 and 75%, respectively). The timing of irrigation was determined when the amount of θ_v for full irrigation treatment was lower than the allowable moisture limit considering MAD.

The total amount of rainfall, irrigation and actual crop evapotranspiration (ET_a) for the two years of both experiments are shown in Table 2.

Table 2. Total amount of rainfall, irrigation and actual crop evapotranspiration (ET_a) during the two years of Exp. 1 and Exp. 2.

Irrigation treatments		First year			Second year		
		Rainfall (mm)	Irrigation (mm)	ET_a (mm)	Rainfall (mm)	Irrigation (mm)	ET_a (mm)
Exp. 1*	I_1	572.0	93.0	162.7	368.0	30.0	170.7
	I_2	572.0	415.0	430.3	368.0	304.0	341.8
	I_3	572.0	674.0	497.4	368.0	711.0	462.5
Exp. 2**	IR_1	127.0	550.2	629.0	187.5	492.1	611.0
	IR_2	127.0	727.1	799.2	187.5	634.1	757.7
	IR_3	127.0	904.1	967.6	187.5	782.9	902.9

Exp. 1: Experiment performed by Partojoo (2006) during 2004-2006; I_1, I_2, I_3 are dry, medium and wet irrigation treatments, respectively.
Exp. 2: Experiment performed by Fateh (2010) during 2007-2009; IR_1, IR_2, IR_3 are 50, 75 and 100% irrigation requirement treatments, respectively.

Seed and yield dry matter

In the first experiment, 12 m^2 of each plot was harvested by cutting plants at ground level during June 2005 and 2006. In the second experiment, 1 m^2 of each plot was harvested by cutting plants at ground level on 30th June and 4th July in 2008 and 2009, respectively. In both experiments, plants (seed and dry matter) were oven dried at 80 °C for 72 h and weighed.

Model Calibration

The SALTMED model is a generic model and used for different crops, soil, water and field management practices. The model considers the following main processes: evapotranspiration, plant water uptake, water and solute transport under different irrigation systems, drainage and the relationship between crop yield and water use (Ragab, 2002). In the present study, the ability of the SALTMED model to predict wheat yield and dry matter and also soil moisture content of two independent studies which had different irrigation systems was evaluated. For the theoretical background of the SALTMED model, readers are referred to Ragab (2002).

The primary required input parameters are as follows: meteorological data includes daily values of temperature (maximum), temperature (minimum), relative humidity, net radiation, wind speed and daily rainfall. Water management data includes the date and amount of irrigation water applied and the salinity level of the applied irrigation water. Plant characteristics for each growth stage include the crop coefficient (K_c, K_{cb}), root depth, crop height and maximum/potential final yield observed in the region under optimum conditions. Soil characteristics include depth of each soil horizon, saturated hydraulic conductivity, saturated soil moisture content, salt diffusion coefficient, longitudinal and transversal dispersion coefficient, initial soil moisture and salinity profiles and tabulated data of soil moisture versus soil water potential and soil moisture versus hydraulic conductivity (Ragab, 2002).

As the SALTMED model does not account for seeding rate, the seeding rate of 120 kg ha^{-1} was considered for model calibration and validation in both experiments.

Model evaluation

To validate the degree of model precision in simulating dry matter, grain yield and soil water content, the observed and simulated values were compared by F-test analysis to quantify the differences. The simulated soil water content and yield production along with the observed values were compared statistically using Willmott agreement index (*d*) (Willmott et al., 1985) and normalized root mean square error (*NRMSE*) equations as follows:

$$d = 1 - \frac{\sum (O_i - P_i)^2}{\sum (\left|P_i - \overline{O}\right| + \left|O_i - \overline{O}\right|)^2} \qquad (3)$$

$$NRMSE = \frac{\sqrt{\frac{\sum (O_i - P_i)^2}{n}}}{\overline{O}} \qquad (4)$$

where P_i is the simulated value, O_i is the observed value, $\overline{O}$ is mean of observed value and n is the number of observations.

Linear regression line was fitted between the observed and simulated values of the soil water content during growing season, seed and dry matter yield at the end of growing season. For the regression analysis, the intercept was omitted from the equation when intercept was not significantly different from zero at 5% level of probability.

Results and Discussion

Experiment one (Exp. 1) and two (Exp. 2) were performed in two consecutive years, therefore the first year of each study was used for model calibration and the second year was used for model validation. Since, most of the parameters required in models are not usually measured during the experimental period; these parameters have to be adjusted in order to get the best simulation. The crop parameters that were calibrated in this study for the two different experiments are presented in Table 3. The initial values for calibrated parameters were obtained from the database of SALTMED model and then the best value was chosen based on trial and error and the statistical results. Several studies have reported values for the parameterized coefficient for model calibration, for example, Fghire et al. (2015) indicated that the quinoa crop coefficient for initial, middle and end of the growth period were 0.14, 1.15 and 0.7, while the photosynthesis efficiency was 1.89 g MJ^{-1}. Hirich et al. (2012) reported a photosynthesis efficiency of 1.64 g MJ^{-1} for quinoa grown in the field in Morocco. The SALTMED model was calibrated to predict wheat yield using saline water by Fazli et al. (2013) and they reported values of 0.3, 1.15 and 0.33 for K_c and 0.18, 1.1 and 0.22 for K_{cb} at initial, middle and end stage of growing season of wheat, respectively. For the same study, photosynthesis efficiency and extinction coefficient of 0.65 g MJ^{-1} and 0.50, respectively, were estimated as the best for model calibration.

Table 3. Calibrated crop parameters of SALTMED model for two different experiments (Exps. 1 and 2).

Tab	Parameters	Values for Exp. 1*	Values for Exp. 2**
Crop evapotranspiration	K_c Initial	0.34	0.30
	K_c Mid	1.29	1.27
	K_c End	0.45	0.40
	K_{cb} Initial	0.25	0.20
	K_{cb} Mid	1.2	1.12
	K_{cb} End	0.33	0.31
Crop growth factor	Photosynthesis efficiency	1.48	1.47
	Extinction coefficient	0.63	0.60

* Partojoo et al. (2006), ** Fateh et al. (2010).

Yield simulation

The amount of wheat yield in Exp. 1 increased from 1.24 ton ha^{-1} for I_1 to 3.08 ton ha^{-1} for I_3 in the first year, while in the second year the wheat yield for I_3 was 2.9 times higher than that of I_1. The latter occurred as the plants, which were closer to sprinkler systems, received more water (I_3) and produced more yield than the plants further away. The results of wheat yield calibration and validation for Exp. 1 is shown in Table 4. The results showed that the SALTMED model was able to accurately predict the wheat yield in the validation year (NRMSE of 9.4% and d of 99.8%). InceKaya et al. (2015) evaluated SALTMED model on simulation of soil water content and quinoa yield. They performed line-source sprinkler system to irrigate field grown quinoa with different levels of water including full irrigation and three deficit irrigation levels. The amount of applied water decreased with distance from sprinkler line and it changed from 310 mm to 74 mm. They showed that the SALTMED model was also able to simulate the effects of water deficits on dry matter and crop yield of quinoa with coefficient of determination (R^2) of 0.99. In Exp. 2, the maximum dry matter was 15.88 in first year and 14.19 ton ha^{-1} in second year obtained for IR_3, while the maximum yield in first and second year were 4.53 and 4.44 ton ha^{-1}, respectively. In both years of Exp. 2, wheat yield and dry matter of IR_1 were ca. 30% lower than IR_3. Further, the results of simulated wheat yield and dry matter versus the measured values for Exp. 2 are shown in Figure 1. In Exp. 2, the NRMSE and d for wheat yield in the calibration year were 6.91 and 95.16% and in the validation year were 7.14 and 92.19%, respectively, while the values for dry matter in the calibration year were 7.68 and 94.96% and in the validation year were 9.38 and 86.08%, respectively. The latter indicated that the SALTMED model was able to predict the wheat yield and dry matter quite well. Similarly, the comparison between simulated and measured quinoa yield and dry matter (by InceKaya et al., 2015) for fully irrigated (FI), 67% of FI and 33% of FI indicated the ability of the SALTMED model to simulate yield and dry matter quite well, with a relative error lower than 10%, however simulated yield and dry matter of 67% FI and 33% FI irrigation treatments were slightly higher than the measured values. Comparison of simulated wheat yield between Exp. 1 and 2 showed that the ability of the SALTMED model to predict yield using basin irrigation systems is slightly better than the sprinkler systems. Comprehensive studies were conducted in Italy (tomato and potato), Crete (tomato) and Serbia (potato) to evaluate SALTMED model for different irrigation systems (furrow, drip irrigation and sprinkler) and different water strategies of full irrigation, deficit irrigation and partial root drying (Ragab et al., 2015). They concluded that the SALTMED model successfully simulated biomass and yield production. The result of the current study is in line with Ragab et al. (2015), as the statistical indicators confirmed the ability of the model in predicting yield and dry matter in both irrigation systems. Further, Ragab et al. (2015) indicated that there is great potential for saving water when using subsurface drip irrigation system compared with sprinkler and furrow irrigation and hence recommended the use of subsurface drip irrigation system together with partial root drying (PRD) irrigation strategies. Ranjbar et al. (2015) evaluated SALTMED model for sorghum using basin irrigation system and showed that the model underestimated dry matter and yield of fully irrigated plants with water salinity level of 2 dS m^{-1} by ca. 3 and 7%, respectively.

Soil water content

In order to simulate the soil water content, some of the soil parameters in SALTMED model such as pore size distribution index (lambda), saturated hydraulic conductivity, residual water content and bubbling pressure have to be adjusted.

The observed soil water content of Exp. 1 for the I_3 treatment was higher than for the I_2 and I_1 treatments during growth period, this was expected due to the higher irrigation level. A linear regression line was fitted to the data to evaluate the ability of the SALTMED model in simulating soil moisture content for different treatments, at different depths and different dates versus the measurement values for Exp. 1 (Table 5 to 7). The model performance indicators of prediction of soil water content of Exp. 1 showed that the model was able to predict this parameter well for all the treatments at different depths. The NRMSE of the three treatments and for most of the depths for both years of calibration and validation was below 10%, except for the depth of 30-60 cm during the validation year. In agreement with this study, InceKaya et al. (2015) found a good correlation between observed and simulated soil water content for quinoa grown in silty clay loam soil and irrigated with sprinkler system. The successful soil moisture content simulation by SALTMED model in Italy by Pulvento et al. (2013) and in Morocco by Hirich et al. (2012) also confirmed the ability of the model in predicting soil water content under different conditions. Hirich et al. (2012) assessed the ability of the SALTMED model in prediction of soil water content using field data of quinoa, chickpea and sweet corn subjected to six deficit irrigation treatments. They concluded that the SALTMED model was able to predict soil water content for different treatments by dividing the soil depth into several horizons.

Table 4. Statistical analysis of wheat yield simulation by SALTMED model in Exp. 1.

	Linear regression	R^2	NRMSE (%)	d (%)
Calibration	Y=1.14X*	0.9960	17.52	98.63
Validation	Y=1.05X	0.9963	9.4	99.8

* Y: Simulated yield; X: Observed yield.

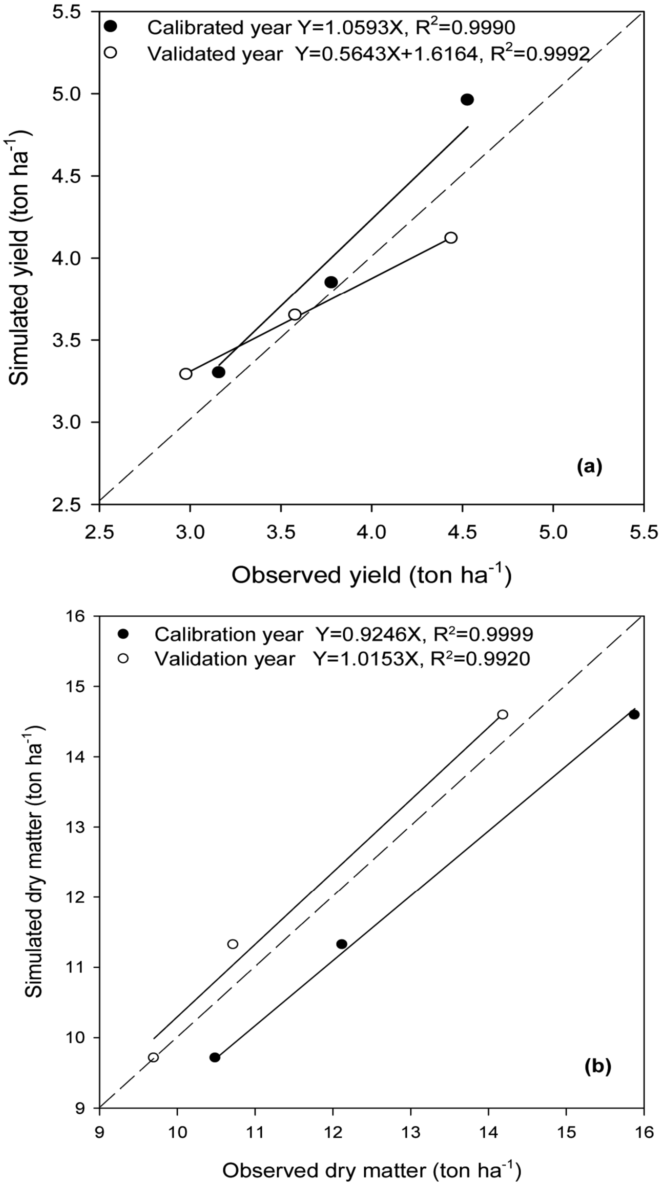

Figure 1. Relation between simulated and observed wheat yield (a) and dry matter (b) for Exp.2.

Table 5. Relation between simulated (Y) and measured (X) soil water content values for dry treatment (I_1) in Exp. 1.

	Depth	Linear regression	R^2	NRMSE (%)	d (%)
Calibration	0-30 cm	Y=1.0073X	0.9977	4.87	93.98
Validation		Y=0.964X	0.9983	5.34	90.82
Calibration	30-60 cm	Y=1.0081X	0.9945	7.60	91.44
Validation		Y=0.9341X	0.9908	11.2	80.09
Calibration	60-90 cm	Y=1.0149X	0.9957	6.79	90.91
Validation		Y=1.0074X	0.9956	6.78	86.55
Calibration	90-120 cm	Y=0.9517X	0.9960	7.76	91.52
Validation		Y=0.935X	0.9991	7.03	73.20

Figure 2 shows the change of soil water content with soil depth for two different dates during the first year of Exp. 1 (calibration year). The trend of observed and simulated soil water content at different depths for different treatments illustrated that the SALTMED model was able to predict the soil water content during the experiment for all the treatments. The result of validation (second year) which is shown in Figure 3 confirmed that SALTMED managed to predict the soil moisture content, however the soil water prediction for dry treatment (I_1) was not as good as I_3.

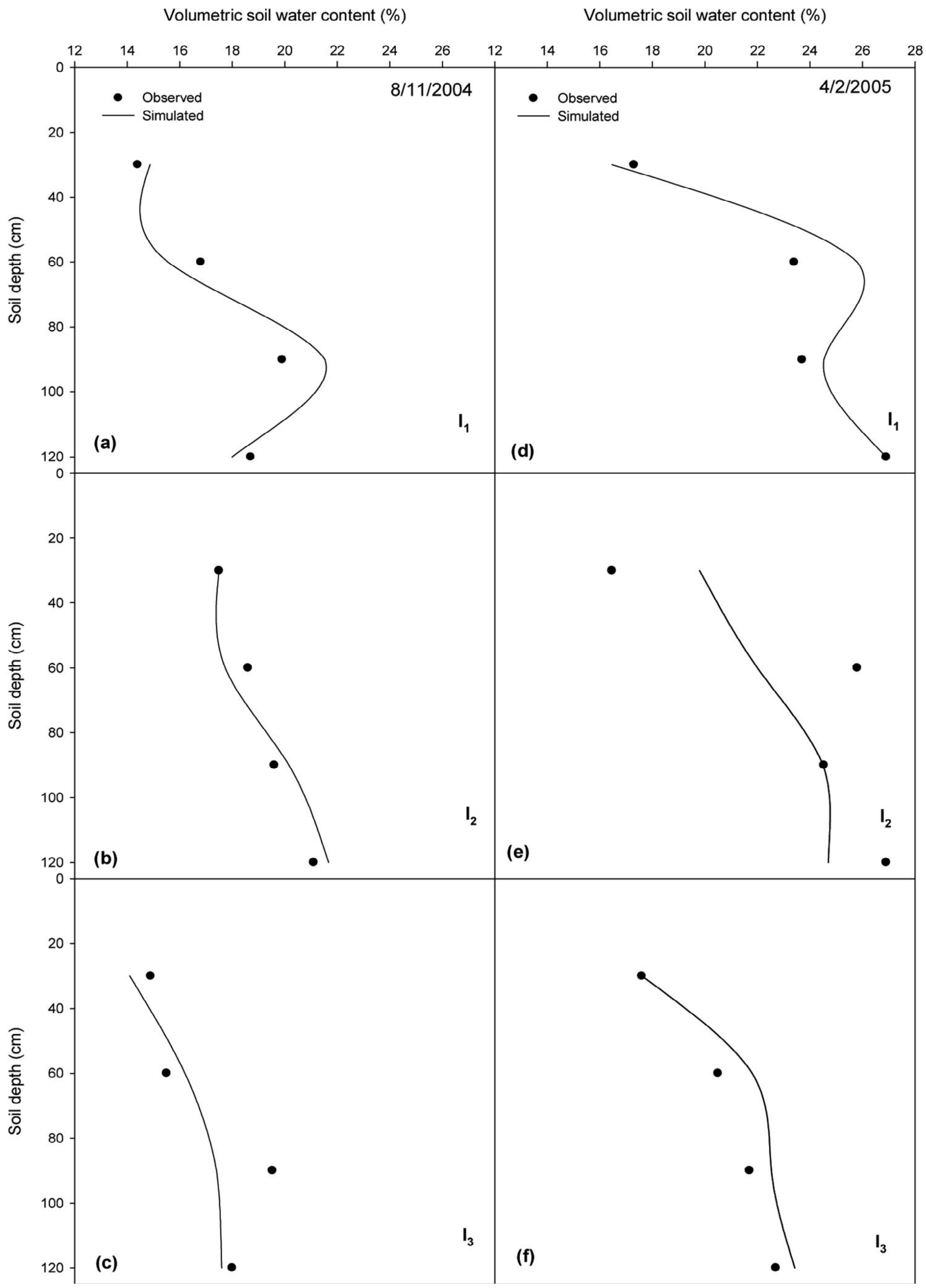

Figure 2. Observed and simulated soil water content at different depths during growing season in first year (calibration) of Exp. 1 for dry treatments (I_1, a and d), medium treatment (I_2, b and e) and wet treatment (I_3, c and f).

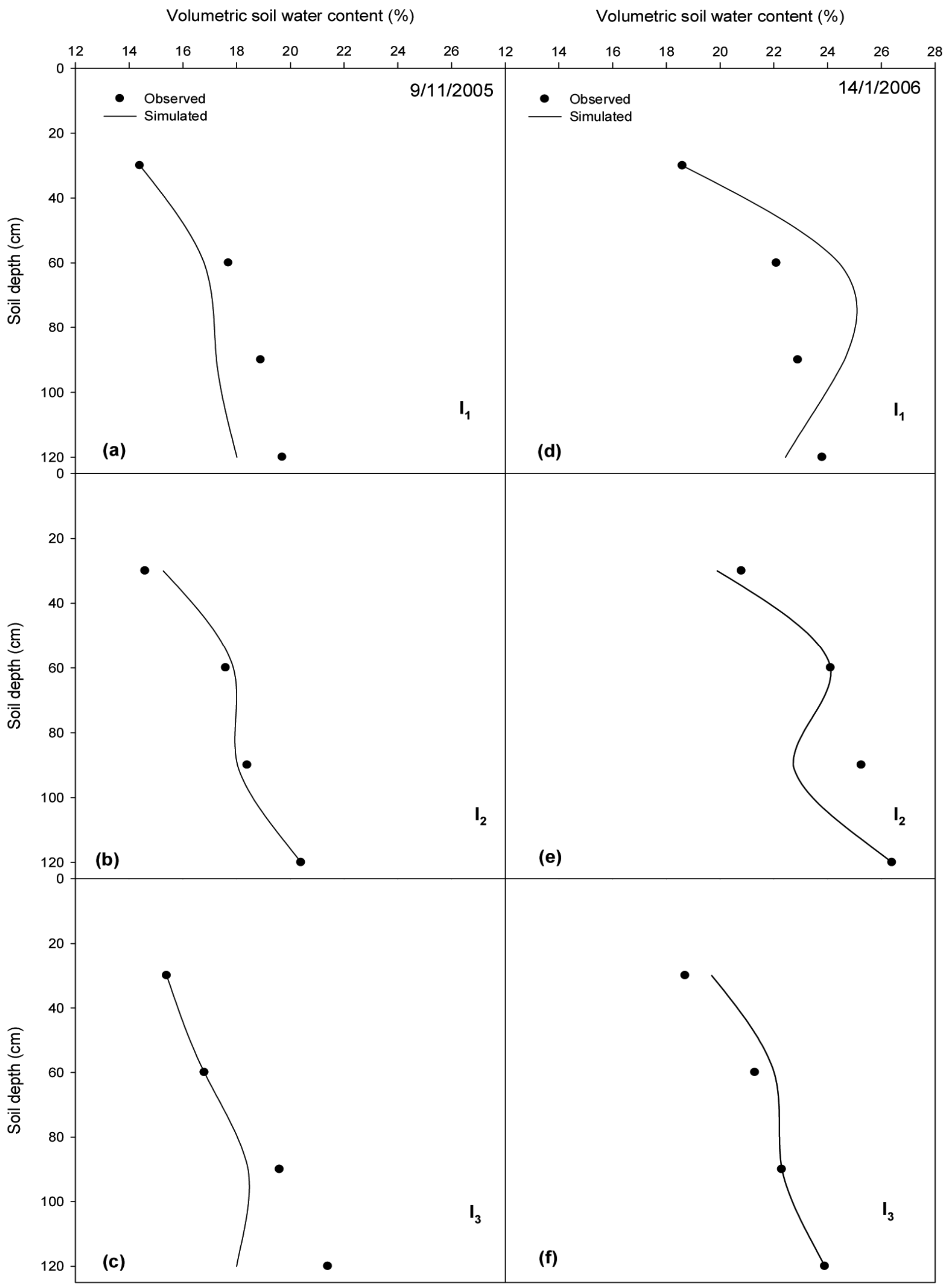

Figure 3. Observed and simulated soil water content at different depths during growing season in second year (validation) of Exp. 1 for dry treatments (I_1, a and d), medium treatment (I_2, b and e) and wet treatment (I_3, c and f).

The relation between the observed and simulated soil water content related to Exp. 2 for the calibration year is shown in Figure 4(a-e). Although the slope of the regression line was close to 1 and the R^2 value was quite high for all treatments at different depths, the best prediction for all treatments was obtained at the depth of 0-30 cm (4a). However, the NRMSE for the rest of the treatments was below 15% Figure 4(b-e). Statistical analysis of soil moisture content of the second experiment in the second year (validation year) for the basin irrigation system showed that the model predicted the soil water content reasonably well (Table 8). The NRMSE for calibration and validation year of Exp. 2 varied between 2.16 and 19.66%, which in comparison with NRMSE values for soil water content of Exp. 1, indicated that the SALTMED model predicted the soil moisture content under sprinkler irrigation system with higher accuracy, though both irrigation systems use the one dimensional flow equation to calculate the water flow (Ragab, 2002). Soil water content variation with soil depth for both the calibration and validation years of Exp. 2 are shown in Figures 5 and 6, respectively. Comparison between Figures 2 and 3 of Exp. 1 with Figures 5 and 6 of Exp. 2 also confirmed the latter assertion that the model predicted the soil water content under sprinkler irrigation system better. Several studies have calibrated SALTMED model for field experiment using drip irrigation system in their experiments (Aly et al., 2015; Fghire et al., 2015; Kaya et al., 2015; Ragab et al., 2015). Both sprinkler and drip irrigation systems have higher water application efficiency than basin irrigation and this may be the reason for the higher accuracy in model performance. Fghire et al. (2015) applied the SALTMED model to predict soil water content of three irrigation treatments including 100% of crop evapotranspiration (ET_c), 50% ET_c and 33% ET_c for field grown quinoa using drip irrigation system. The results of model validation indicated a good agreement between the simulated and observed soil moisture content data for each soil layer, especially with high coefficient of correlation. SALTMED model was calibrated under irrigation regimes ranging from rainfed to 100% crop water requirements for dry and wet year condition using Chickpea by Silva et al. (2013) using drip irrigation system. They found that for all depths, there was a good agreement between simulated and observed values, with R^2 over 78 %.

Table 6. Relation between simulated (Y) and measured (X) soil water content values for medium treatment (I_2) in Exp. 1.

	Depth	Linear regression	R^2	NRMSE (%)	d (%)
Calibration	0-30 cm	Y=0.9778X	0.9979	4.94	93.68
Validation		Y=0.9424X	0.9976	7.62	87.48
Calibration	30-60 cm	Y=0.9678X	0.9975	5.80	91.86
Validation		Y=0.9549X	0.9984	5.92	89.73
Calibration	60-90 cm	Y=1.0182X	0.9988	3.97	94.15
Validation		Y=0.9448X	0.9982	6.84	87.33
Calibration	90-120 cm	Y=1.0095X	0.9991	3.15	93.91
Validation		Y=0.9714X	0.9991	4.10	90.99

Table 7. Relation between simulated (Y) and measured (X) soil water content values for wet treatment (I_3) in Exp. 1.

	Depth	Linear regression	R^2	NRMSE (%)	d (%)
Calibration	0-30 cm	Y=1.007X	0.9962	6.32	94.31
Validation		Y=0.641X+0.066	0.8877	9.54	88.26
Calibration	30-60 cm	Y=0.9677X	0.9972	6.12	94.21
Validation		Y=0.9701X	0.9963	6.71	94.49
Calibration	60-90 cm	Y=0.9996X	0.9965	6.00	94.22
Validation		Y=0.9713X	0.9975	5.70	94.12
Calibration	90-120 cm	Y=0.999X	0.9972	5.29	95.43
Validation		Y=0.9656X	0.9948	7.82	92.19

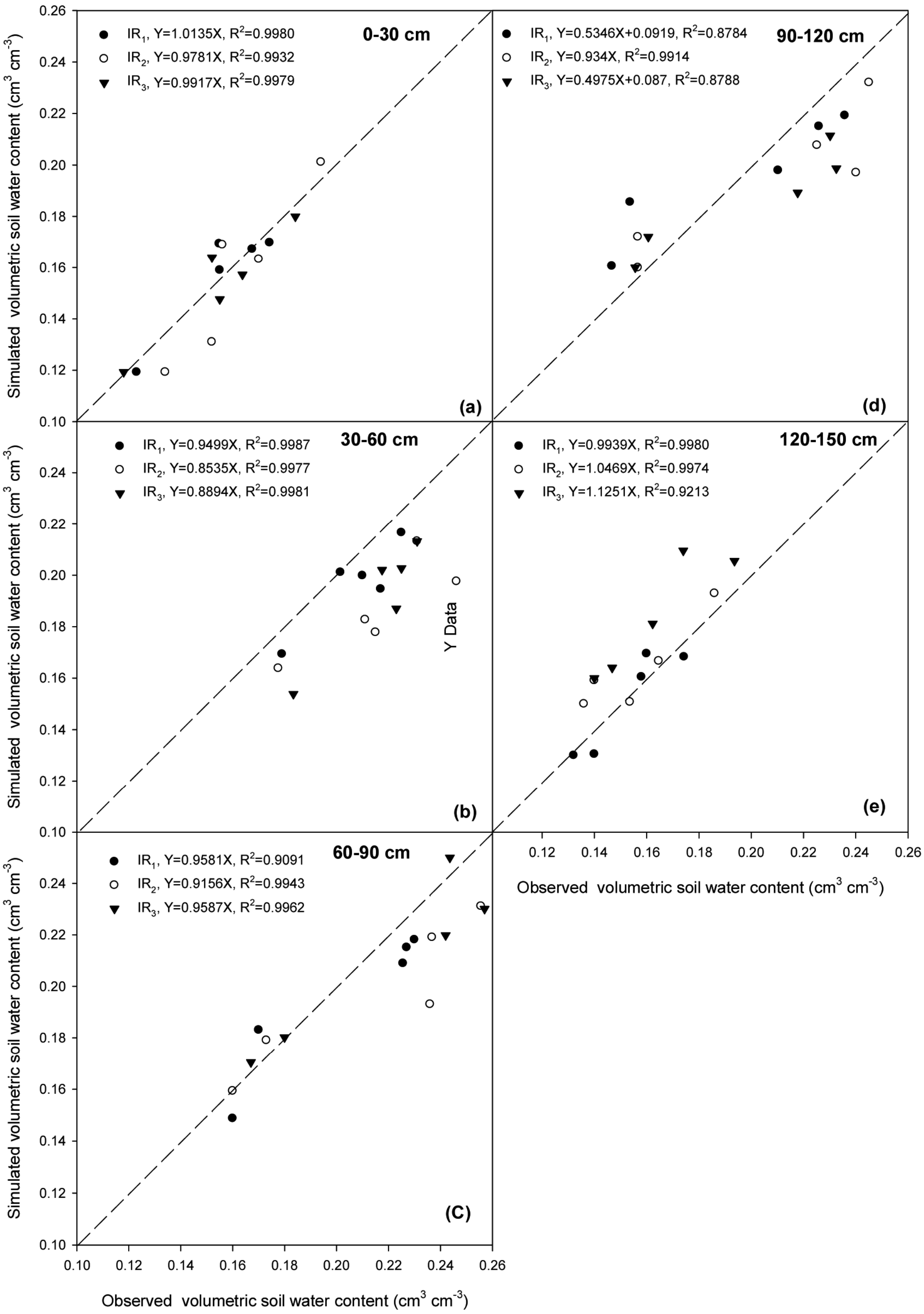

Figure 4. Relation between simulated soil water content versus the observed values for different irrigation treatments at depth of 0-30cm (a), 30-60 (b), 60-90 (c), 90-120 (d) and 120-150 cm (e) for Exp. 2 (calibration year).

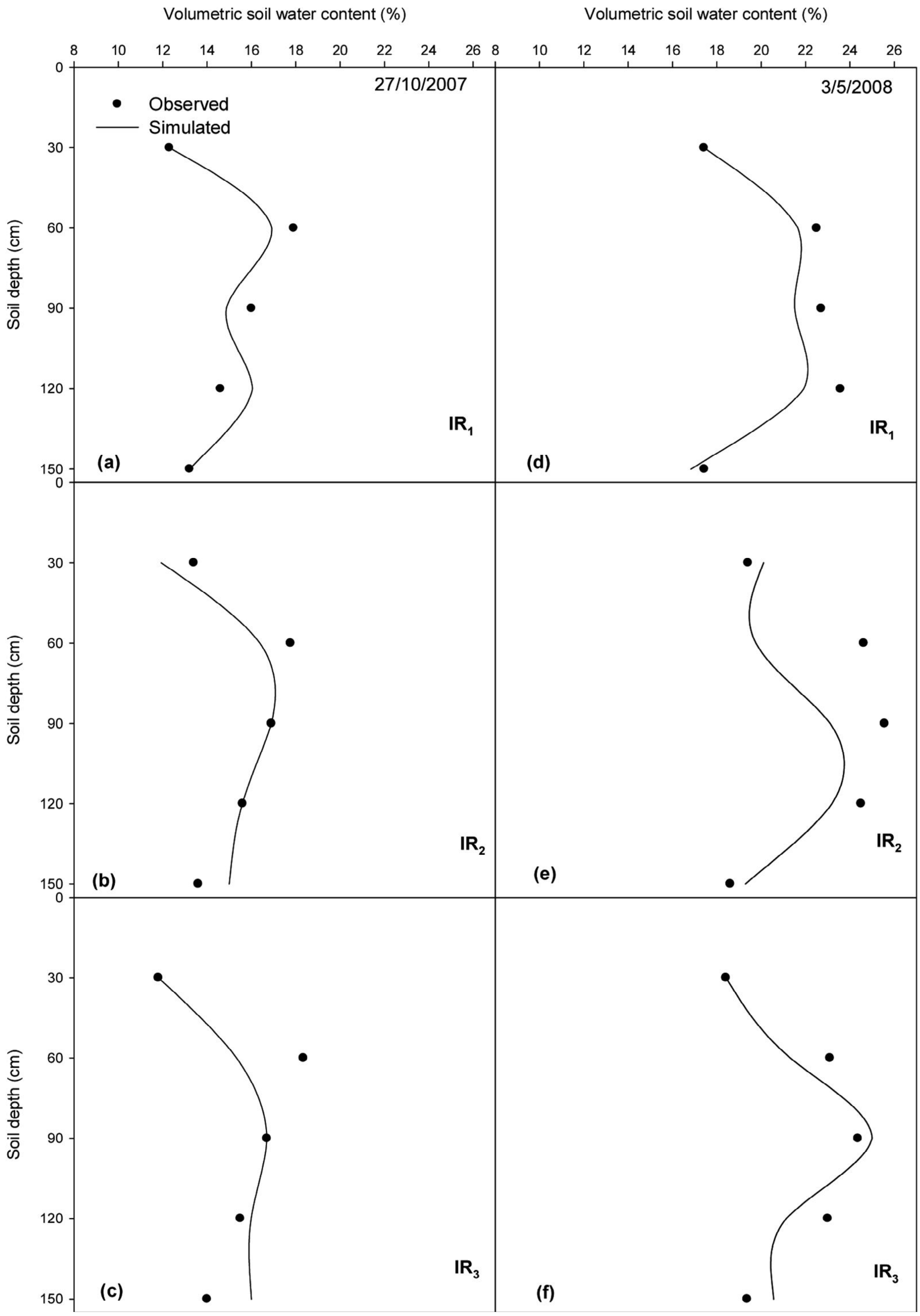

Figure 5. Observed and simulated soil water content at different depths during growing season in first year (calibration) of Exp. 2 for 50% (IR_1, a and d), 75% (IR_2, b and e) and 100% (IR_3, c and f) of irrigation requirement.

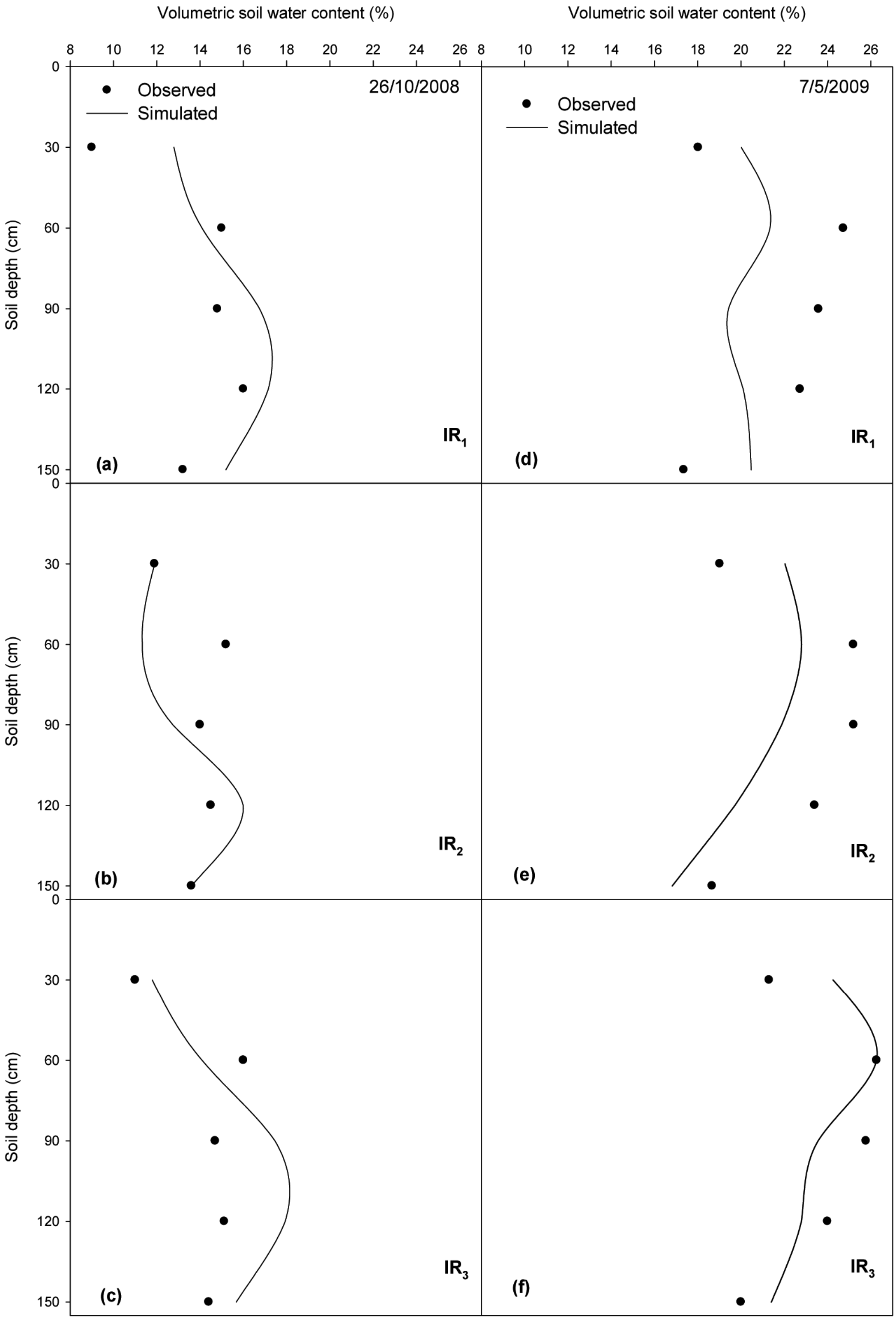

Figure 6. Observed and simulated soil water content at different depths during growing season in second year (validation) of Exp. 2 for 50% (IR_1, a and d), 75% (IR_2, b and e) and 100% (IR_3, c and f) of irrigation requirement.

Table 8. Relation between simulated (Y) and measured (X) soil water content values for different treatments at different depths in second year of Exp. 2 (validation year).

Irrigation treatments	Depth	Linear regression	R^2	NRMSE (%)	d (%)
	0-30 cm	Y=1.1714X	0.9944	19.66	79.80
	30-60 cm	Y=0.9413X	0.9952	8.87	91.88
IR_1*	60-90 cm	Y=0.2757X + 0.1235	0.8335	17.31	64.60
	90-120 cm	Y=0.9685X	0.9956	7.19	89.09
	120-150 cm	Y=1.148X	0.9984	15.55	62.24
	0-30 cm	Y=1.1399X	0.9935	16.93	81.85
	30-60 cm	Y=0.9595X	0.9852	12.63	90.93
IR_2	60-90 cm	Y=0.8401X	0.9932	17.77	80.97
	90-120 cm	Y=0.4614X + 0.0849	0.8442	14.72	74.80
	120-150 cm	Y=0.9218X	0.9972	9.25	74.65
	0-30 cm	Y=1.1657X	0.9932	19.52	83.44
	30-60 cm	Y=0.9385X	0.9929	10.16	91.19
IR_3	60-90 cm	Y=0.4684X + 0.1127	0.8092	2.16	99.98
	90-120 cm	Y=0.441X + 0.1126	0.8484	9.66	84.00
	120-150cm	Y=1.0273X	0.9977	5.65	93.83

* IR_1=50% of irrigation requirement, IR_2=75% of irrigation requirement and IR_3=100% of irrigation requirement.

Conclusion

This study calibrated and validated the SALTMED model for two different wheat field experiments and with different water managements and irrigation systems. The model accurately simulated the yield and dry matter for two different irrigation systems (basin and sprinkler irrigation systems) and different levels of water irrigation. Comparison of the soil moisture content simulated by the SALTMED model and the observed values during the experiments, confirmed the accuracy of the model in prediction of soil water content. It is concluded that the ability of the model for simulating yield, dry matter and soil water content under sprinkler system is slightly better than basin irrigation systems, although a one-dimensional flow equations was used for both systems.

Acknowledgement

Authors would like to than Professor Ali Akbar Kamgar-Haghighi for providing the raw data and his instructive comments during this work.

Reference

Adam, M., Van Bussel, L., Leffelaar, P., Van Keulen, H., Ewert, F., 2011. Effects of modelling detail on simulated potential crop yields under a wide range of climatic conditions. Ecol. model. 222, 131-143.

Aggarwal, P., Kalra, N., Singh, A., Sinha, S., 1994. Analyzing the limitations set by climatic factors, genotype, water and nitrogen availability on productivity of wheat I. The model description, parametrization and validation. Field Crop Res. 38, 73-91.

Aly, A., Al-Omran, A., Khasha, A., 2015. Water management for cucumber: Greenhouse experiment in Saudi Arabia and modeling study using SALTMED model. J. Soil Water Conserv. 70, 1-11.

Baker, D.N., Lambert, J.R., McKinion, J.M., 1983. GOSSYM: A simulator of cotton crop growth and yield. Technical bulletin 1089, South Carolina Agricultural Experiment Station, 134p.

Banaei, M., Moameni, A., Bybordi, M., Malakouti, M., 2005. The soils of Iran: new achievements in perception, management and use. Soil and Water Research Institute: Tehran, Iran, 481p. (In Persian)

Curtis, B.C., 2002. Wheat in the world. In: Curtis, B.C, Rajaram, S., Machpherson, H.G. (Eds.), Bread Wheat: Improvement and Production, FAO Plant Production and Protection, Series. No. 30. Rome, FAO, pp. 1-19.

Dinpashoh, Y., Fakheri-Fard, A., Moghaddam, M., Jahanbakhsh, S., Mirnia, M., 2004. Selection of variables for the purpose of regionalization of Iran's precipitation climate using multivariate methods. J. Hydrol. 297, 109-123.

FAO., 2015. GIEWS country Brief. Available from: http://www.fao.org/giews/countrybrief/country.jsp?code=IRN GIEWS Country Brief on Iran. 24/07/2015.

Fateh, M., 2010. Investigate the effect of different water levels and seed density on Wheat yield (CV. Shiraz) using basin irrigation system in Badjgah climate condition (Fars Province). Dissertation for M.Sc. degree in Agricultural College. Shiraz University, Iran. (In Persian)

Fazli, R.A., Gholami, A., Andarzian, B., Ghoosheh, M., 2013. Investigating the Effect of Applying Drainaged-water on Wheat Yield Using SALTMED Model. J. .Nov. Appl. Sci. 2, 1003-1011.

Ferrer, F., Stockle, C., 1996. A model for assessing crop response and water management in saline conditions. In: Irrigation Scheduling: From Theory to Practice, Proceeding ICID/FAO Workshop, Sept. 1995, Rome, Water Reports No. 8, FAO, Rome.

Fghire, R., Wahbi, S., Anaya, F., Issa Ali, O., Benlhabib, O., Ragab, R., 2015. Response of quinoa to different water management strategies: field experiments and SALTMED model application results. Irrig. Drain. 64, 29-40.

Heshmati, G.A., Squires, V., 2013. Combating Desertification in Asia, Africa and the Middle East: Proven practices. Springer Netherlands. 476p.

Hirich, A., Choukr-Allah, R., Ragab, R., Jacobsen, S.-E., El Youssfi, L., El Omari, H., 2012. The SALTMED model calibration and validation using field data from Morocco. J. Mater. Environ. Sci. 3, 342-359.

InceKaya, Ç., Yazar, A., Sezen, S.M., 2015. SALTMED Model Performance on Simulation of Soil Moisture and Crop Yield for Quinoa Irrigated Using Different Irrigation Systems, Irrigation Strategies and Water Qualities in Turkey. Agric. Agric. Sci. Procedia. 4, 108-118.

Liu, C., Rubæk, G.H., Liu, F., Andersen, M.N., 2015. Effect of partial root zone drying and deficit irrigation on nitrogen and phosphorus uptake in potato. Agr. Water Manage. 159, 66-76.

Mohammadi, R., Sadeghzadeh, B., Ahmadi, H., Bahrami, N., Amri, A., 2015. Field evaluation of durum wheat landraces for prevailing abiotic and biotic stresses in highland rainfed regions of Iran. Crop J. 3, 423-433.

Murthy, V.R.K., 2004. Crop growth modeling and its applications in agricultural meteorology. In: Sivakumar, M.V.K., Ryo P.S., Harmsen K., Saha, S.K. (Eds.), Satellite remote sensing and GIS applications in agricultural meteorology. World Meteorological Organisation, Geneva, Switzerland, pp. 235-261.

Partojoo, F., 2006. Investigate the effect of different water levels and seed density on Wheat yield (CV. Shiraz) in Badjgah climate condition (Fars Province). Dissertation for M.Sc. degree in Agricultural College. Shiraz University, Iran. (In Persian)

Pulvento, C., Riccardi, M., Lavini, A., D'andria, R., Ragab, R., 2013. SALTMED model to simulate yield and dry matter for quinoa crop and soil moisture content under different irrigation strategies in south Italy. Irrig. Drain. 62, 229-238.

Pulvento, C., Riccardi, M., Lavini, A., D'andria, R., Ragab, R., 2015. Parameterization and field validation of SALTMED Model for grain amaranth tested in South Italy. Irrig. Drain. 64, 59-68.

Ragab, R., 2002. A holistic generic integrated approach for irrigation, crop and field management: the SALTMED model. Environ. Modell. Softw. 17, 345-361.

Ragab, R., Battilani, A., Matovic, G., Stikic, R., Psarras, G., Chartzoulakis, K., 2015. SALTMED Model as an Integrated Management Tool for Water, Crop, Soil and N-Fertilizer Water Management Strategies and Productivity: Field and Simulation Study. Irrig. Drain. 64, 13-28.

Ragab, R., Malash, N., Gawad, G.A., 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. Agr. Water Manage. 78, 67-88.

Ragab, R., Malash, N., Gawad, G.A., 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. Agr. Water Manage. 78, 89-107.

Rameshwaran, P., Tepe, A., Ragab, R., 2015. The effect of saline irrigation water on the yield of pepper: experimental and modelling study. Irrig. Drain. 64, 41-49.

Ranjbar, G., Ghadiri, H., Razzaghi, F., Sepaskhah, A., Edalat, M., 2015. Evaluation of the SALTMED model for sorghum under saline conditions in an arid region. Int. J. Plant Prod. 9, 373-392.

Razzaghi, F., Plauborg, F., Jacobsen, S.-E., Jensen, C.R., Andersen, M.N., 2012. Effect of nitrogen and water availability of three soil types on yield, radiation use efficiency and evapotranspiration in field-grown quinoa. Agr. Water Manage. 109, 20-29.

Rwehumbiza, F.B., Siza Tumbo, S., 2009. Rainwater harvesting in the managemnt of Agro-Eco System. Rainwater harvesting: a lifeline for human well-being, Barron, J. (Ed.). United Nations Environment Programme and Stockholm Environment Institute, pp. 23-34.

Silva, L., Ragab, R., Duarte, I., Lourenço, E., Simões, N., Chaves, M., 2013. Calibration and validation of SALTMED model under dry and wet year conditions using chickpea field data from Southern Portugal. Irrigation Sci. 31, 651-659.

Singh, P., Virmani, S., 1996. Modeling growth and yield of chickpea (*Cicer arietinum* L.). Field Crop Res. 46, 41-59.

Slama, I., M'Rabet, R., Ksouri, R., Talbi, O., Debez, A., Abdelly, C., 2015. Water deficit stress applied only or combined with salinity affects physiological parameters and antioxidant capacity in Sesuvium portulacastrum. Flora. 213, 69-76.

Steduto, P., Hsiao, T.C., Raes, D., Fereres, E., 2009. AquaCrop-The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. Agron. J. 101, 426-437.

Willmott, C.J., Rowe, C.M., Mintz, Y., 1985. Climatology of the terrestrial seasonal water cycle. J. Climate. 5, 589-606.