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Evaluation of the SALTMED model for sorghum under saline conditions in an arid region

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Abstract

SALTMED model has been developed to predict yield, soil salinity and water content under saline conditions. A two year field experiment was carried out during 2012-13 to calibrate and validate the model for sorghum. Plants were irrigated with salinity levels of 2, 6, 10 and 14 dS m^{-1}. Results showed that there were significant differences between the observed and simulated sorghum dry matter (SDM) and yield. Absolute mean differences between the observed and simulated SDM values for 2, 6, 10 and 14 dS m^{-1} were 0.45, 1.53, 0.04 and 1.07 Mgha^{-1}, respectively. Soil water contents (SWC) were overestimated at different soil depths. Mean differences between the simulated and observed SWC at 0.0-0.3, 0.3-0.6, 0.6-0.9 and 0.0-0.9 m soil depths were 0.02, 0.04, 0.02 and 0.03 m^{3}m^{-3}, respectively. As salinity increased the mean differences between the observed and simulated SWC were increased. There were no significant differences between the observed and simulated soil salinities at 0.0-0.3, 0.3-0.6, 0.6-0.9 and 0.0-0.9 m soil depths. The Willmott index of agreement value of the observed and simulated EC_e at different soil depth were between 0.92-0.96. It is concluded that following successful calibration, the SALTMED model could predict soil salinity and SWC with reasonably good accuracy at different water salinity levels. Although, SALTMED model reasonably well predicted soil salinity at different soil depth, there was a weak agreement between the observed and simulated soil water content at different soil depths. There was a fair agreement between the observed and simulated dry matter and grain yield at different water salinity levels.

Keywords: Modelling; Salt stress; Soil salinity; Soil water content.

Introduction

Crop models have the capability to predict crop development, growth and grain yield as influenced by climatic conditions, soil characteristics and agricultural practices (Fasinmirin et al., 2008; Ragab, 2002). These models can be empirical or mechanistic. Empirical models are based on the mathematical relationships between some important independent variables (e.g. growth rates, nitrogen and irrigation water, leaf area index) and a dependent variable (usually crop yield), the variations of which should be interpreted and predicted (Estes et al., 2013). Mechanistic models are instead based on the growth processes (i.e. light interception, photosynthesis, dry matter partitioning between different plant parts of the competing plants); these are obviously much more complex than the former and require an appropriate knowledge of the mechanisms and interactions involved in the crop-soil-climate system and a large amount of data or information as inputs. These mechanistic models have a limited direct practical use; however, their outputs are more comprehensive than the results of the empirical models (Estes et al., 2013; De Vos et al., 2012).

Currently, models can provide quantitative estimates of grain yield under different environmental conditions, as well as simulation of water and nutrients balance. They may also be used to test the crop response to environmental stresses, e.g. water and salinity stress (Adam et al., 2011). Since, salinity is a major factor that influences crop production (Rhoades et al., 1992); there is a need for comprehensive generic models that account for different crops, different water qualities and various field management practices under saline conditions. SALTMED model has been developed to predict crop water uptake, temporal soil water regimes, salinity distribution, crop growth and grain yield under saline conditions for different irrigation systems and soil types (Ragab, 2002; Ragab et al., 2005a; Ragab et al., 2005b). The model includes meteorological data, soil characteristics, plant traits and some other data such as water management data including the date and amount of irrigation water applied and the salinity levels of applied irrigation water (Ragab, 2002).

Data derived from five complete growing seasons in Syria and Egypt showed that SALTMED model successfully predicted the impact of salinity on yield and water uptake (Ragab et al., 2005a; Ragab et al., 2005b). Abdel Gawad et al. (2005) used mixing and cyclic irrigation managements, traditional furrow, drip irrigation methods and different water qualities to predict different tomato cultivars yield. They used measured soil and plant parameters in the SALTMED model. There was a good agreement between the simulated and observed yield data, confirming the value of SALTMED as a tool to be used by experts in the management of salt-prone irrigation systems.

SALTMED model was also used successfully as a tool for simulating soil water dynamics and crop yield of carrots (*Daucus carota* L.) and cabbage (*Brassica oleracea*) in the northeastern Brazil (Montenegro et al., 2010). Razzaghi et al. (2011b) showed a good agreement between the observed and simulated seed yield and dry matter of field-grown quinoa (*Chenopodium quinoa* Willd.) irrigated with saline and non-saline water. SALTMED model was able to simulate the water content and soil water electrical conductivity of the root zone reasonably well.

To calibrate and validate the SALTMED model, Hirich et al. (2012) used field data of three growing seasons of quinoa, chickpeas (*Cicer arietinum* L.) and sweet corn (*Zea mays* L.), which were grown in southern Morocco, subjected to six treatments of deficit irrigation with treated wastewater. The model showed a very good agreement between the observed and simulated data and was able to predict soil water content, yield and total dry matter in different treatments.

In another experiment, Pulvento et al. (2013) pointed out the ability of SALTMED model to simulate soil water contents, total dry matter and grain yield of quinoa with good precision under different irrigation strategies with saline and non-saline water. Calibration and validation of the SALTMED model also showed that the model can simulate soil water content, grain yield and total dry biomass of different chickpea cultivars in wet and dry years very accurately (Silva et al., 2013). Recently, Hirich et al. (2014) showed that, SALTMED model could be used to predict sweet corn growth and productivity under deficit irrigation strategies in the semi-arid region.

Sorghum, the fifth most important cereal in the world, is a C_4 grass well adapted to semi-arid and arid regions (Igartua et al., 1995) where salinity is one of the major problems in plant production. Although the crop tolerates salt moderately, salinity severely limits plant growth and productivity (Maas et al., 1986). The objective of this study was to calibrate and validate SALTMED model by using two consecutive years of sorghum field data [*Sorghum bicolor* (L.) Moench].

Materials and Methods

Brief description of the SALTMED model

SALTMED model has been developed as a generic model that can be used for a variety of irrigation systems, soil types, crops and trees, water application strategies, different nitrogen applications and different water qualities (such as fresh, wastewater, saline, brackish and drainage water (Ragab, 2002).

Evapotranspiration, plant water uptake, water and solute transport, nitrogen dynamics, dry matter and biomass production, drainage and shallow groundwater are the key processes in the model. Evapotranspiration has been calculated using the Penman-Monteith equation according to the modified version of FAO-56 (Allen et al., 1998). The model can also calculate the net radiation from solar radiation according to the FAO-56 (Allen et al., 1998) procedure if net radiation data is not available. Actual water uptake rate in the presence of saline water is calculated according to Cardon and Letey (1992).

Soil hydraulic parameters, i.e. water and solute transport were also calculated according to van Genuchten (1980). Due to the unique and strong relationship between water uptake and biomass production and hence the final yield, the relative crop yield (*RY*) is estimated as the sum of the actual water uptake over the season divided by the sum of the maximum water uptake (under no water and salinity stress conditions) as:

$$RY = \frac{\sum S(x,z,t)}{\sum S_{\max}(x,z,t)} \tag{1}$$

where S is actual water uptake rate (mm day^{-1}), x and z are the horizontal and vertical coordinates of each grid cell that contain roots, respectively and t is root depth. The actual yield (AY) is simply obtainable by:

$$AY = RY \times Y_{\max} \tag{2}$$

where Y_{max} is the maximum obtainable yield in a given region under optimum and stress-free condition.

Field experiment

Two field experiments were carried out during 2012 and 2013 at the Sadough Salinity Research Farm, National Salinity Research Centre, Yazd, Iran (32° 03′ 22″ N, 54° 14′ 02″ E, 1134 m above the mean sea level) in a sandy loam soil, designed as randomized complete blocks with three replicates. Treatments were irrigation water salinity levels (2, 6, 10 and 14 dS m^{-1}). Sorghum (cv. Sepideh) seeds were planted in plots with 6 rows × 7 m long with 0.5 m inter row spacing and 0.2 m plant spacing within rows. Based on the soil analysis (Table 1), to assure adequate N fertility, 180 kg N ha^{-1} as urea was equally splitted and applied at sowing, 30 and 60 days after planting. Different salinities of irrigation water (Table 2) were obtained by mixing proper proportion of two well waters (2 and 14 dS m^{-1}).

During the growing season, all plots were irrigated at the same time based on the crop water requirement. For this reason, before each irrigation event, soil samples were taken during growing seasons based on the crop root depth to determine their gravimetric water contents (p_m). Depth of net irrigation water (d_n) was calculated as follows:

$$d_n = \frac{(\theta_{FC} - (p_m \times \rho_b)) \times R_d}{100} \tag{3}$$

where θ_{FC} is the volumetric soil water content (%) at field capacity, ρ_b is the averaged bulk density in the soil profile in root depth and R_d is the root depth varied during the growing season and was calculated as follows (Borg and Grimes, 1986):

$$R_d = R_{d\max}[0.5 + 0.5\sin(3.03\frac{D_{ag}}{D_{tm}} - 1.47)] \tag{4}$$

where $R_{d\ max}$ is the maximum root depth, D_{ag} is the number of days after germination, D_{tm} is the number of days from germination to maximum effective root depth and the sine function is in radians. To consider depth of seed planting (P_d) in calculation, Eq. (6) was converted as follows:

$$R_d = P_d + R_{d\max}[0.5 + 0.5\sin(3.03\frac{D_{ag}}{D_{tm}} - 1.47)] \tag{5}$$

Table 1. Chemical analysis of the soil at the research field before planting.

Trait	Unit	Soil depth		Trait	Unit	Soil depth	
		0-0.3 m	0.3-0.6 m			0-0.3 m	0.3-0.6 m
EC_e*	dS m^{-1}	15.24	9.75	SAR†	-	21.95	19.23
pH	-	7.43	7.54	P	µg g^{-1}	15.05	9.62
Na^+	meq L^{-1}	107.96	71.44	K	µg g^{-1}	134.00	121.00
Mg^{2+}	meq L^{-1}	26.80	14.00	Zn	µg g^{-1}	1.49	0.87
Ca^{2+}	meq L^{-1}	21.60	13.6	Mn	µg g^{-1}	0.71	6.17
Cl^-	meq L^{-1}	135.50	82.5	Fe	µg g^{-1}	4.71	4.42
HCO_3^-	meq L^{-1}	3.00	2.75	O.C. ‡	%	0.35	0.31
SO_4^{2-}	meq L^{-1}	18.71	16.59	Total N	%	0.03	0.03

* Electrical conductivity of soil saturation extract, † Sodium adsorption ratio, ‡ Organic carbon.

Table 2. Chemical properties of the used saline water.

Irrigation water salinity (dS m^{-1})	pH	Cations and anions in water sample (meq L^{-1})							
		CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
2	8.25	0.50	1.69	15.00	7.44	3.95	7.75	12.76	0.17
6	7.73	-	2.95	51.00	15.57	6.10	17.25	45.83	0.34
10	7.61	-	3.00	90.00	25.97	8.70	27.60	82.20	0.47
14	7.73	-	3.50	130.50	35.68	11.35	38.50	119.14	0.69

The application efficiency (E_a) of all irrigation events (basin irrigation) was assumed as 70 percent (or 30% deep percolation). Therefore, the volume of water application for each main plot was calculated for a specific plot area as follows:

$$V_g = \frac{d_n}{E_a} \times P_a \quad (6)$$

where V_g is the volume of water application for each main plot and P_a is the specific plot area.

A soil core per each main plot was taken to a depth of 0.9 m (0-0.3, 0.3-0.6 and 0.6-0.9 m layers) four times during the growing seasons to determine electrical conductivity of soil saturation extract (EC_e) of each layer as described by Richards (1954). Electrical conductivity of soil saturation extract of the 0.0-0.9 m soil depth was calculated by taking the average of EC_e values of the soil layers in each soil core. Since SALTMED model generates electrical conductivity of soil water solution (EC_{sw}), the ECe was calculated as follows (Smedema and Rycroft, 1983):

$$\theta_s \times EC_e = EC_{sw} \times \theta_m \tag{7}$$

where θ_s and θ_m are volumetric soil water content at saturation and soil water content at which EC_{sw} derived.

During growing seasons, dry matter accumulation, leaf area index (LAI) and plant height of the plant were measured 5 times in both years. At harvest, 2 m^2 of each plot was harvested by cutting plants at ground level. Plants were oven dried at 80° C for 48 h and weighed.

Model evaluation

The model calibration process was carried out using both the measured and estimated crop, soil and climate parameters of 2012. Crop coefficients (K_c, K_{cb}, π_{50}) and fraction cover (F_c) used in the model were based on FAO no. 56 paper (Allen et al., 1998). Leaf area index, plant height, growth stage lengths, harvest index, grain and dry matter were measured in the field in both years. Photosynthetic efficiency was modified during the calibration. The soil saturated water content, soil water at field capacity and wilting point were measured in the laboratory using a pressure plate. Soil parameters such as pore size distribution index (lambda), residual water content, saturated hydraulic conductivity and bubbling pressure predicted with RETC software (van Genuchten et al., 1991). For this purpose, soil physical properties (i.e. particle size distribution, bulk density and water content at 33 kPa and 1500 kPa) were entered to the model and the parameters were predicted using "neural network prediction" module (Table 3).

Table 3. Soil properties of the field at 0-0.3, 0.3-0.6 and 0.6-0.9 m depths.

Soil properties	Depth (m)		
	0-0.3	0.3-0.6	0.6-0.9
Soil saturated moisture content (m^3 m^{-3})	0.393	0.403	0.398
Soil water content at field capacity (m^3 m^{-3})	0.216	0.217	0.217
Soil water content at wilting point (m^3 m^{-3})	0.071	0.054	0.054
pore size distribution index (Lambda)†	0.411	0.412	0.410
Residual soil water content (m^3 m^{-3})†	0.042	0.046	0.046
Saturated hydraulic conductivity (mm day^{-1})†	456.9	466.0	427.1
Bubbling pressure (cm)†	51.02	44.84	45.45

† Generated by RETC software.

To validate the model, the observed and simulated dry matter, grain yield, soil water content and soil salinity in 2013 were compared by F-test analysis to quantify the differences. For quantitative differences between observed and simulated data, results were also evaluated by Willmott index of agreement (*d*) and normalize root mean square error (N*RMSE*) as follows (Willmott et al., 1985):

$$d = 1 - \frac{\sum (O_i - S_i)^2}{\sum (\left|S_i - \overline{O}\right| + \left|O_i - \overline{O}\right|)^2} \qquad (8)$$

$$NRMSE = \frac{\sqrt{\frac{\sum (O_i - S_i)2}{n}}}{\overline{O}} \qquad (9)$$

where S_i is the stimulated value, O_i is the observed value, $\overline{O}$ is mean of observed value and *n* is the number of observations. Linear regression was done between the observed and simulated values of the soil water content, salinity and dry matter accumulation during the growing season. Since the intercept values were not significantly different from zero, they were omitted from the equations.

Results and Discussion

Model Calibration

Appropriate crop factors (K_c, K_{cb}, F_c, π_{50}, plant height and LAI) and crop growth parameters (photosynthesis efficiency and harvest index) were used to calibrate grain yield and dry matter in 2012. However, Photosynthesis efficiency is the only parameter which was estimated and adjusted during the calibration. The calibrated photosynthesis efficiency value of the 2 dS m^{-1} irrigation water salinity level was used in the calibration of the other treatments. There was a very good agreement between the measured and simulated sorghum dry matter and grain yield (Table 4). By gradually changing the input values of the model parameters (i.e. K_r, H_{50} and reference diffusion coefficient), soil water content and soil salinity for each irrigation water salinity level were also calibrated in order to make them equal or nearly equal to the observed values in 2012 (Table 4).

Table 4. Results of model calibration for dry matter, grain yield, electrical conductivity of soil saturation extract (EC_e) and soil water content at 0-0.3, 0.3-0.6 and 0.6-0.9 m depths in 2012.

Irrigation water salinity		Dry matter	Grain yield	EC_e			Soil water content		
				0-0.3	0.3-0.6	0.6-0.9	0-0.3	0.3-0.6	0.6-0.9
(dS m^{-1})		(Mg ha^{-1})		(dS m^{-1})			(m^3 m^{-3})		
2	Ob.†	13.56	4.6	2.45	5.73	4.94	0.07	0.09	0.10
	Si.	13.56	4.5	2.33	6.05	5.39	0.07	0.10	0.12
6	Ob.	10.15	0.36	6.94	8.74	7.51	0.10	0.13	0.14
	Si.	10.15	0.35	6.64	8.77	7.86	0.11	0.14	0.14
10	Ob.	6.00	0	7.94	9.38	7.77	0.12	0.13	0.14
	Si.	6.03	0	9.51	10.02	8.31	0.17	0.18	0.20
14	Ob.	4.20	0	9.29	10.63	9.64	0.14	0.15	0.15
	Si.	4.21	0	11.09	11.96	10.47	0.19	0.20	0.21

† Ob. and Si. are observed and simulated data.

Model validation

Sorghum dry matter and grain yield

Analysis of F-test showed significant differences between the observed and simulated sorghum dry matter at 2, 6, 10 and 14 dS m^{-1} salinity levels (Table 5). Sorghum dry matter was overestimated slightly in 10 dS m^{-1} water salinity level; however, model showed lower estimation of sorghum dry matter at 2, 6 and 14 dS m^{-1} (Table 5). Absolute mean differences between the observed and simulated SDM values for 2, 6, 10 and 14 dS m^{-1} were 0.45, 1.53, 0.04 and 1.07 Mgha^{-1}, respectively. Values of the observed dry matter were higher than the simulated dry matter at irrigation salinity levels of 2, 6 and 14 dS m^{-1} by 3%, 14% and 24%, respectively. Pulvento et al. (2013) in an experiment with quinoa (*Chenopodium quinoa* Willd) observed differences in general lower than 5.4% in different irrigation water salinity treatments between observed and simulated grain yield and dry matter.

Table 5. F-test results for differences between the observed and simulated sorghum dry matter and grain yield in 2013.

Irrigation water salinity (dS m^{-1})	Observed	Simulated	Means difference	SE	F_value	P>F
	Dry matter (Mg ha^{-1})					
2	14.09	13.64	0.45	1.10	18305.33	0.0001†
6	11.01	9.48	1.53	1.14	1279.92	0.001
10	4.53	4.57	-0.04	0.38	243.92	0.004
14	4.44	3.37	1.07	0.67	5824.00	0.0002
	Grain yield (Mg ha^{-1})					
2	4.90	4.52	0.38	0.15	283.00	0.004
6	0.33	0.32	0.01	0.01	1.71	0.368

† Values lower than 0.05 shows significant differences. SE: Standard error.

There was a relatively good agreement between the observed and simulated sorghum dry matter under different irrigation salinity levels during the growing season (Figure 1). Values of R^2 for correlation between the observed and simulated dry matter accumulation during the growing season for 2, 6, 10 and 14 dS m^{-1} water salinity levels were 98, 94, 94 and 90%, respectively. Hirich et al. (2012) predicted dry matter of quinoa grown in south Morocco with SALTMED model obtaining an R^2 of 0.98. Similarly, Silva et al. (2013) reported R^2 of 0.99 simulating biomass of chickpea in Portugal under wet and dry year conditions. Results from the SALTMED model are also comparable to dry matter (R^2=0.87) simulations carried out on seven different quinoa cultivars grown in the Bolivian Altiplano (Geerts et al., 2009) using the AquaCrop model. Similar results were also observed by Razzaghi et al. (2011b) for quinoa yield.

Figure 1 also showed a rapid decline in sorghum dry matter with increasing irrigation water salinity. In fact, increase in soil salinity decreased soil water potential, leading to disordered transplanting stream and ceased the plant growth and development (Munns and Tester, 2008). On the other hand, accumulation of salt in the cell of the crop (Munns and Tester, 2008), would gradually increase the osmotic gradient between the inside and outside of the cells. To achieve a thermodynamic equilibrium, water inside the cell would move outward into the intercellular spaces, leading to progressive cellular dehydration and eventually cell death (Volkmar et al., 1998).

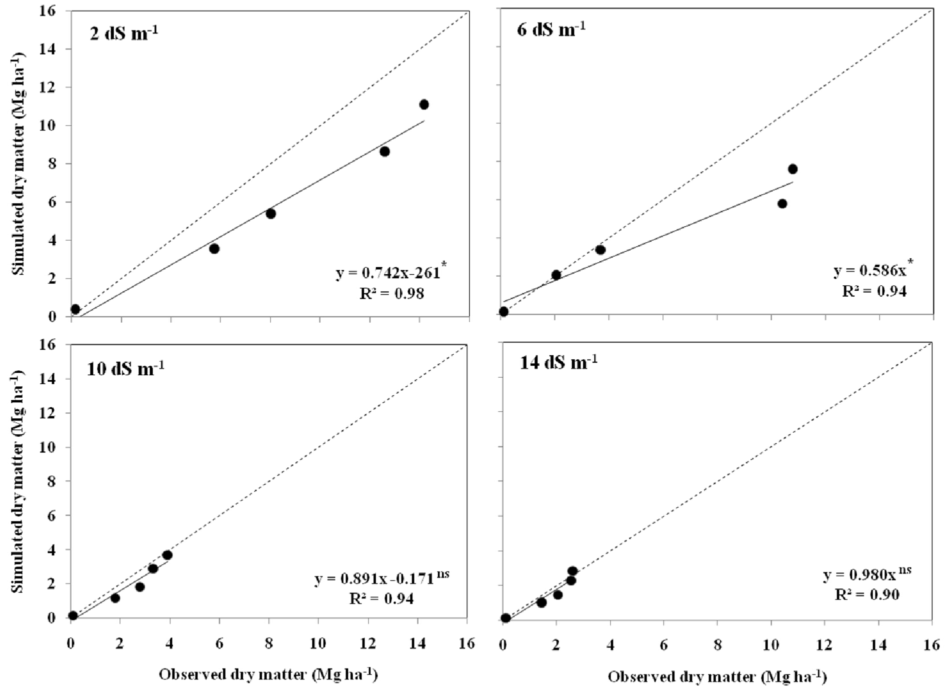

Figure 1. Correlation between the observed and simulated sorghum dry matter during the growing season of 2013 for different water salinity levels (* and *ns* show significant and non significant differences between slopes of the model line and 1:1 ratio dash line).

There were significant differences between the observed and simulated grain yield at 2 dS m^{-1}; however, this difference for 6 dS m^{-1} was not significant (Table 5). Grain yield in 6 dS m^{-1} was negligible and with 10 and 14 dS m^{-1} treatment no grain was produced. Igartua et al. (1995) concluded that salinity markedly reduced yield of sorghum. They indicated that sorghum yield was reduced by 50% at EC_e of 5.0 dS m^{-1}. Kafi et al. (2011) in a similar experiment with Sepideh cv. observed that reproductive phase did not occur in this cultivar irrigated with water salinity of 10.5 and 23.1 dS m^{-1} and dry matter accumulation was significantly decreased at all salinity levels. In their experiment, the reduction in dry matter in irrigation salinity level of 10.5 dS m^{-1} was 55% higher than that of 5.2 dS m^{-1}. It seems that Sepideh cv. a semi-dwarf sorghum cultivar, is much more sensitive to salinity than the commonly accepted old sorghum cultivars. Reductions in crop yield due to salinity were observed for maize (Azizian and Sepaskhah, 2014), quinoa (Razzaghi et al., 2011a), wheat (Ranjbar and Banakar, 2011; Francois et al., 1986; Steppuhn and Wall, 1997) and madder (Sepaskhah and Beirouti, 2009).

Soil water content

Results showed that differences between the simulated soil water content at 0.0-0.3, 0.3-0.6, 0.6-0.9 as well as 0.0-0.9 m soil depth were significant (Table 6). Absolute mean differences between the simulated and observed soil water content at 0.0-.3, 0.3-0.6, 0.6-0.9 and 0.0-0.9 m soil depths were 0.02, 0.04, 0.02 and 0.03 $m^3\ m^{-3}$, respectively (Table 6).

The highest amount for *d* was observed between predicted and observed soil water content at 0.0-0.3 m soil depth (Table 6). As soil depth was increased, *d* index decreased. The *NRSME* values were also approximately higher for predicted and observed values of soil moisture in deep soils. Since the higher values of *d* and lower values of *NRSME* indicated good agreement between the observed and simulated data, it is concluded that SALTMED model had a weak prediction of the soil water content at different soil depths in the present study.

Table 6. F-test results for differences between the observed and simulated soil water content ($m^3\ m^{-3}$) in 2013.

Soil depth (m)	Observed	Simulated	Means difference	SE	F_value	P>F	d	NRSME
0.0-0.3	0.11	0.13	-0.02	0.016	0.278	0.022†	0.73	0.39
0.3-0.6	0.13	0.16	-0.04	0.013	0.280	0.023	0.65	0.31
0.6-0.9	0.14	0.16	-0.02	0.012	0.091	0.002	0.45	0.29
0.0-0.9	0.12	0.15	-0.03	0.014	0.172	0.003	0.64	0.31
EC_{iw}‡ ($dS\ m^{-1}$)								
2	0.10	0.10	0	0.012	1.60	0.259†	0.95	0.11
6	0.12	0.13	-0.01	0.008	2.04	0.167	0.77	0.13
10	0.13	0.18	-0.05	0.005	3.04	0.068	0.24	0.34
14	0.14	0.20	-0.06	0.007	4.48	0.024	0.37	0.44

† Values lower than 0.05 shows significant differences, ‡ EC_{iw}: Electrical conductivity of irrigation water.

The values of R^2 for correlation between the simulated and observed soil water contents at different soil depths were shown in Figure 2. The highest and lowest R^2 values for correlation between the observed and simulated soil water content were at 0.0-0.9 m and 0.6-0.9 m soil depths, respectively. Values of R^2 for correlation between the observed and simulated soil water content at 0.0-0.3, 0.3-0.6, 0.6-0.9 and 0.0-0.9 m soil depths were 87, 71, 45 and 88%, respectively. By using field data of three growing seasons of quinoa (*Chenopodium quinoa* Willd.), chickpeas (*Cicer arietinum*) and sweet corn (*Zea mays* Saccharata) subjected to deficit and wastewater irrigation, Hirich et al. (2012) showed that the R^2 values for correlation between the simulated and observed soil water contents at 0.1, 0.3, 0.4 and 0.5 m soil depths were 81, 92, 69 and 84%, respectively.

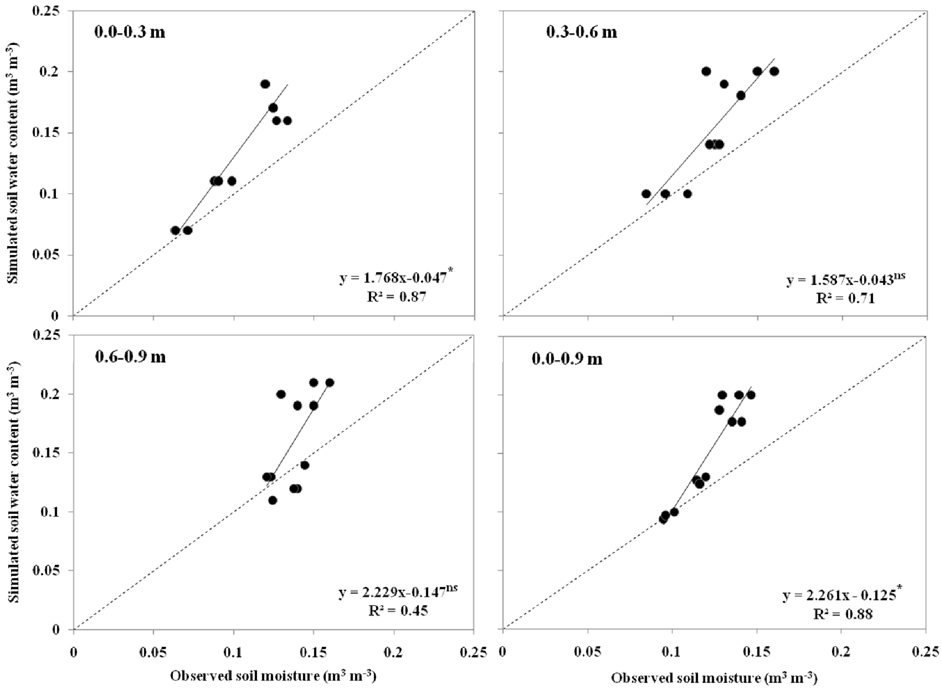

Figure 2. Correlation between the observed and simulated soil water content at different soil depths in 2013 (* and *ns* show significant and non significant differences between slopes of the model line and 1:1 ratio dash line).

There were no significant differences between the observed and simulated soil water content at 2, 6 and 10 dS m^{-1} salinity levels (Table 6). The simulated soil water content at 14 dS m^{-1} salinity level was significantly different from the observed values ($P<0.05$). Mean differences between the observed and simulated soil water content at 2, 6, 10 and 14 dS m^{-1} salinity levels were 0, 0.01, 0.05 and 0.07 m^3 m^{-3}, respectively (Table 6). Increase in *NRSME* and decrease in *d* values with increase in irrigation water salinity levels (Table 6), indicated that the accuracy of SALTMED model to predict the soil water content was decreased as irrigation water salinity increased. As salinity increased the mean differences between these values were markedly increased (Figure 3). The maximum difference between the observed and simulated soil water was obtained at 14 dS m^{-1}. SALTMED model also overestimated the soil water content at 6, 10 and 14 dS m^{-1} irrigation water salinity levels. In addition, SALTMED model predicted the soil water content at 2 and 6 dS m^{-1} reasonably well compared to 10 and 14 dS m^{-1} water salinity levels. It seems that good agreement between the simulated and observed soil water content at 2 and 6 dS m^{-1} was due to more plant water uptake in lower salinity conditions (Rhoades et al., 1992).

Overestimation of soil water content as compared to the observed values was also obtained in the highest salinity level reported by Razzaghi et al. (2011b) especially at the later growth stages. The remarkably higher soil water content in the higher salinity levels revealed that crop could not uptake water from the soil. Due to positive correlation between the water uptake and crop production (van Halsema and Vincent, 2012), some reduction in crop yield in higher salinity levels therefore could be resulted from the reduction in water uptake. It seems that overestimation of the soil water content by the model could be probably due to soil infiltration properties, higher evaporation in the arid region and type and rate of solute in the soil and water.

Soil salinity

Analysis of F-test showed that there were no significant differences between the observed and simulated EC_e values at 0-0.3, 0.3-0.6, 0.6-0.9 and 0-0.9 m soil depths (Table 7). Based on the mean differences, SALTMED model overestimated EC_e at different soil depths. Mean differences between the observed and simulated EC_e at 0-0.3, 0.3-0.6, 0.6-0.9 and 0-0.9 m soil depths were 0.93, 1.82, 1.01 and 1.26 dS m^{-1}. Table 7 shows that the *d* value of the observed and simulated EC_e at different soil depths were between 0.92 to 0.96. These values for *NRMSE* were between 0.18 to 0.23. Since values of *d* and *NRMSE* are approximately close to one and zero, respectively (Table 7), SALTMED model showed a relatively good prediction of EC_e at different soil depths.

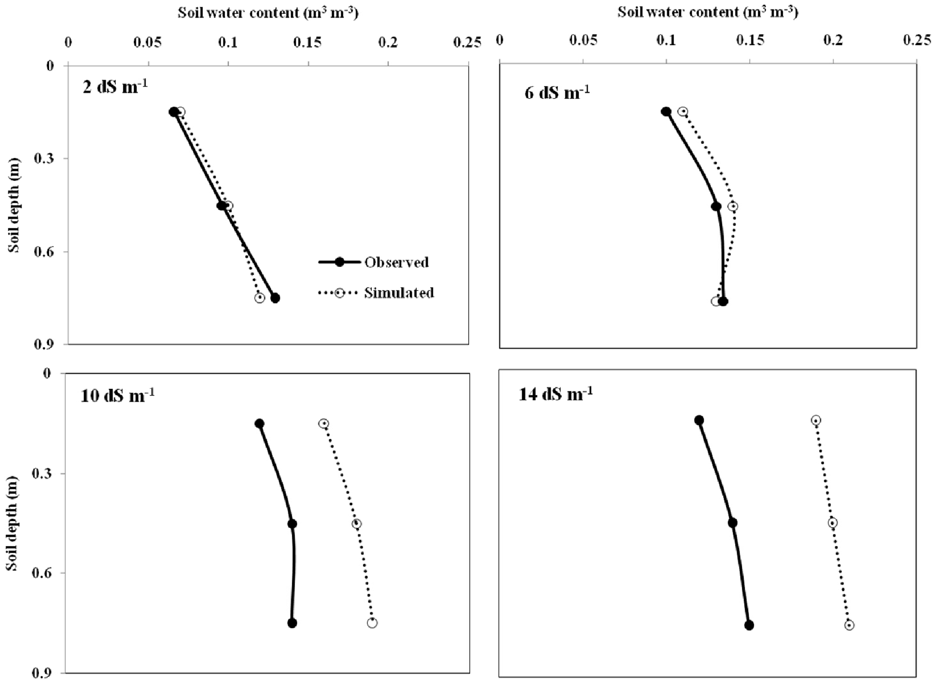

Figure 3. Comparison of the observed and simulated soil water content at different soil depths under different water salinity levels.

Table 7. F-test results for differences between the observed and simulated electrical conductivity of soil saturated extract (EC_e, dS m^{-1}) in 2013.

Soil depth (m)	Observed	Simulated	Means difference	SE	F_value	P>F	d	NRSME
0.0-0.3	7.59	8.52	-0.93	1.55	0.670	0.259*	0.96	0.18
0.3-0.6	8.84	10.66	-1.82	1.44	0.737	0.311	0.92	0.23
0.6-0.9	7.58	8.59	-1.01	1.22	0.639	0.235	0.93	0.19
0.0-0.9	8.00	9.26	-1.26	1.39	0.682	0.268	0.95	0.19
EC_{iw}† (dS m^{-1})								
2	3.82‡	4.23	-0.41	0.54	0.362	0.086*	0.85	0.20
6	6.94	7.80	-0.86	0.48	0.190	0.051	0.61	0.18
10	10.18	11.53	-1.36	0.58	0.992	0.496	0.70	0.14
14	11.12	13.48	-2.35	0.55	1.62	0.256	0.47	0.23

* Values lower than 0.05 shows significant differences, † EC_{iw}: Electrical conductivity of irrigation water, ‡ Means of three depths.

As shown in Figure 4, the R^2 values for correlation between the observed and simulated EC_e at 0-0.3, 0.3-0.6, 0.6-0.9 and 0-0.9 m of depth were 0.95, 0.95, 0.91 and 96, respectively, indicating a good agreement between the model predictions and observed EC_e. However, based on the differences between slopes of the model line and 1:1 ratio line, this agreement in 0.3-0.6 and 0.6-0.9 m soil depth was better than that of 0.0-0.3 m soil depth. A part of this disagreement could be due to more dynamic and faster processes operating such as infiltration, evaporation and plant water uptake that generally exist at the soil surface compared with the rest of the profiles (Hirich et al., 2012; Silva et al., 2013).

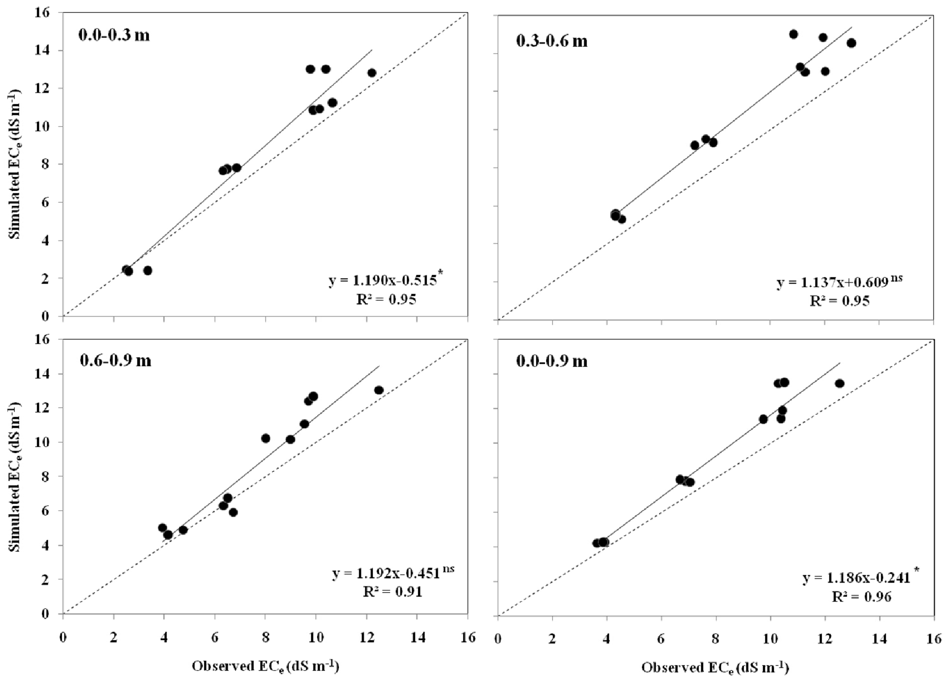

Figure 4. Correlation between the observed and simulated electrical conductivity of soil saturation extract (EC_e) at different soil depth in 2013 (* and *ns* show significant and non significant differences between slopes of the model line and 1:1 ratio dash line).

Values of R^2 and differences between slopes of the model line and 1:1 ratio line, confirmed the ability of the model to predict EC_e with good accuracy. Razzaghi et al. (2011b) in a field experiment with drip irrigation showed that the simulated electrical conductivity of soil solution followed the same pattern as observed values; however, it was initially lower than the observed values in the depth of 0.5-0.6 m.

There were no significant differences between the observed and simulated EC_e of each water salinity level (Table 7). As irrigation water salinity increased, the differences between the observed and simulated soil salinity increased. The values of simulated EC_e obtained at 2, 6, 10 and 14 dS m^{-1} were 0.41, 0.86, 1.36 and 2.35 dS m^{-1} higher than the observed values (Table 7). In fact, the model overestimated the values of soil salinity for each water salinity level (Figure 5). Values of *d* also showed that SALTMED model predicted EC_e reasonably well at 2 dS m^{-1} compared with the other irrigation water salinity levels (Table 7); however, values of NRSME did not show a reliable accuracy for differences between the observed and simulated EC_e values. In addition, there was a good agreement between the observed and simulated EC_e at different water salinity levels. Similar results were reported by Haj Najib et al. (2007) who compared the observed and simulated values of soil salinity for the different irrigation methods.

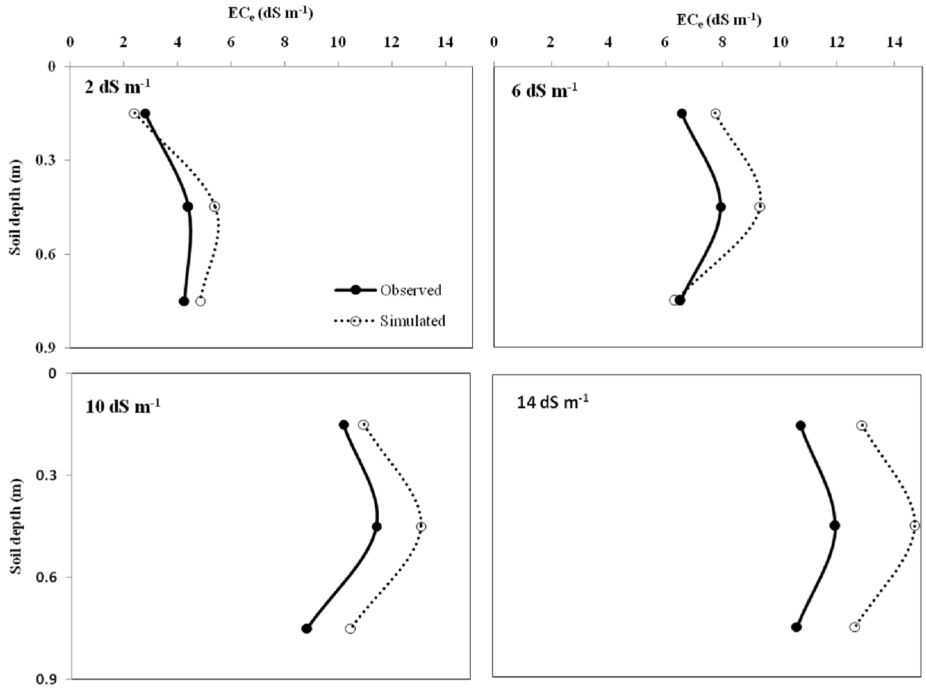

Figure 5. Comparison of the observed and simulated electrical conductivity of soil saturation extract (EC_e) at different soil depths under different water salinity levels.

Conclusions

Results of the current study clearly showed that saline water could have a negative impact on the sorghum grain yield and dry matter production in the arid region; however, acceptable crop yield could be obtained by use of non saline water in these conditions. It is also concluded that following successful calibration, the SALTMED model could predict dry matter and grain yield with fair accuracy at different water salinity levels. The model also had a reasonably good estimation of soil water content and salinity at different water salinity levels; however, the accuracy of the model at salinity levels of 2 and 6 dS m^{-1} was higher than those at the higher salinities. SALTMED model predicted soil salinity at different soil depth very good; however, there was a weak agreement between the observed and simulated soil water content at different soil depths.

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