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Modeling of corn growth and root zone salinity dynamics to improve irrigation and fertigation management under semi-arid conditions

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Abstract

Modeling is an advanced technique to study the effects of crop management practices as management scenarios simulations in a convenient and economical way. A multi seasonal study was conducted on corn, sown under drip irrigation, to assess its growth under three irrigation intervals (I_1: irrigation on daily basis, I_2: irrigation on 3rd day and I_3: irrigation on 5th day) and three fertigation levels [F_1:100% RFA (recommended fertigation applications), F_2:75% RFA and F_3:50% RFA)] of two types of fertilizers (M_1: Imported and M_2: Indigenous). The SALTMED model was calibrated and validated, using data collected from experiments, to develop different management scenarios of corn production. The accuracy of the validation process was examined by root mean square error (RMSE), percentage of difference (%D), coefficient of residual mass (CRM) and coefficient of determination (R^2). The results showed that corn produced significantly high plant height (183.7 cm), dry matter (16.9 t/ha) and grain yield (8.57 t/ha) under I_1 in comparison to that under other irrigation intervals. Similarly, M_1 and F_1 produced significantly high dry matter and grain yield as compared to M_2 and other fertigation levels, respectively. SALTMED simulated soil moisture and soil salinity accurately with the values of RMSE, R^2 and CRM, not exceeding 0.017, 0.833 and 0.027, respectively for soil moisture and 0.565, 0.836 and 0.249, respectively for soil salinity. The SALTMED simulations showed good results also for grain yield (RMSE= 0.475, R^2=0.873, CRM= -0.0013 and highest %D= 19.65%) and dry matter

(RMSE=0.596, R^2=0.909, CRM=-0.027 and highest %D= 9.22%). Based on these finding, it is recommended that corn should be irrigated on daily basis under drip irrigation and fertilized with 100% RFA. Moreover, SALTMED model proved to be a useful tool for simulations of different scenarios regarding corn growth and soil salinity under different management scenarios with reliable results under semi-arid conditions.

Key Words: Corn, fertigation level, irrigation interval, fertilizer type, SALTMED model

Introduction

The world's population is growing rapidly, posing challenges for agriculture sector to meet food demands. Water consumption by the agriculture sector has increased globally and reached 70-80% of the total world's water usage (Ragab, 2015). Under this current situation, on-farm water management has become an important subject for sustainability of agricultural systems. The drip irrigation, being an efficient irrigation system (Biswas et al., 2015; Dağdelen et al., 2006; Mansour et al., 2013; Tayel et al., 2008), can be used to apply irrigation and fertilizers with an application efficiency of 90% (Allen et al., 1998). To avoid excessive irrigation and use of fertilizers, there is need to adopt optimized operational scheme of drip irrigation regarding irrigation frequencies and fertigation levels. To check and compare multiple operational schemes, computers models such as SALTMED are widely used along with field studies. The SALTMED model was developed to account different management and climatic conditions and environments (Ragab, 2010; Ragab et al., 2005b, 2005a) for studying crop growth.

The SALTMED model (Ragab, 2002, 2009, 2010, 2013, 2015)) was calibrated and validated by researchers for different crops such as sugarcane (Golabi et al., 2009) and tomatoes (Flowers et al., 2005),. The recent version (SALTMED 2015) can run with up to twenty different fields or treatments at the same time, each of which could have different input parameters like irrigation system, irrigation and fertigation strategy, soil, crop and fertilizers management. Also, this version of the model accounts for deficit irrigation as partial root drying (PRD), subsurface irrigation, salinity dynamics in root zones, fertigation, nitrate leaching, soil nitrogen fertilizer application and plant nitrogen uptake, dry matter and grain yield production. These new version has been calibrated and validated successfully by researchers (Aly et al., 2015; J.N. Chauhdary et al., 2019; Daliakopoulos et al., 2016; El-Sadek, 2014; Fghire et al., 2015; Hassanli et al., 2016; Hirich et al., 2016; Kaoutar et al., 2017; Kaya et al., 2015; Rameshwaran et al., 2015). For improvement in performance and increase reliability of the new versions, the need of calibration exists for different conditions regarding irrigation and fertigation.

Therefore, this study was designed (i) to study corn response under different management schemes regarding irrigation and fertigation, (ii) to calibrate and validate the latest version of SALTMED model viz. 2015 for crop response and root zone salinity dynamics (iii) to perform scenario simulations of corn growth under different irrigation intervals and fertigation levels.

Material and methods

Study site and experiment description

A two year (2015 and 2016) field study was carried out on corn under drip irrigation at the Water Management Research Centre (WMRC), University of Agriculture, Faisalabad (UAF), Pakistan (31.38739 N, 73.01196 E; elevation 184 m m.s.l). The average annual rain fall of study area is 350 mm and temperature varies from 0^o (in winter) to 50^o C (in summer). The soil of the area is sandy loam with 1.52 g/cm^3 bulk density.

In this study, eighteen treatments comprised three irrigation intervals (I_1:irrigation on daily basis, I_2: irrigation on 3rd day and I_3: irrigation on 5th day) and three fertigation levels [F_1:100% (recommended fertigation applications (RFA), F_2:75% RFA and F_3:50% RFA)] of two types of fertilizers (M_1: Imported fertilizer and M_2: Indigenous fertilizer) were tested The corn was sown under drip irrigation with 90 cm row spacing and 23 cm plant spacing. The layout of experimental treatments replicated three times under RCBD, is shown in Figure 1.

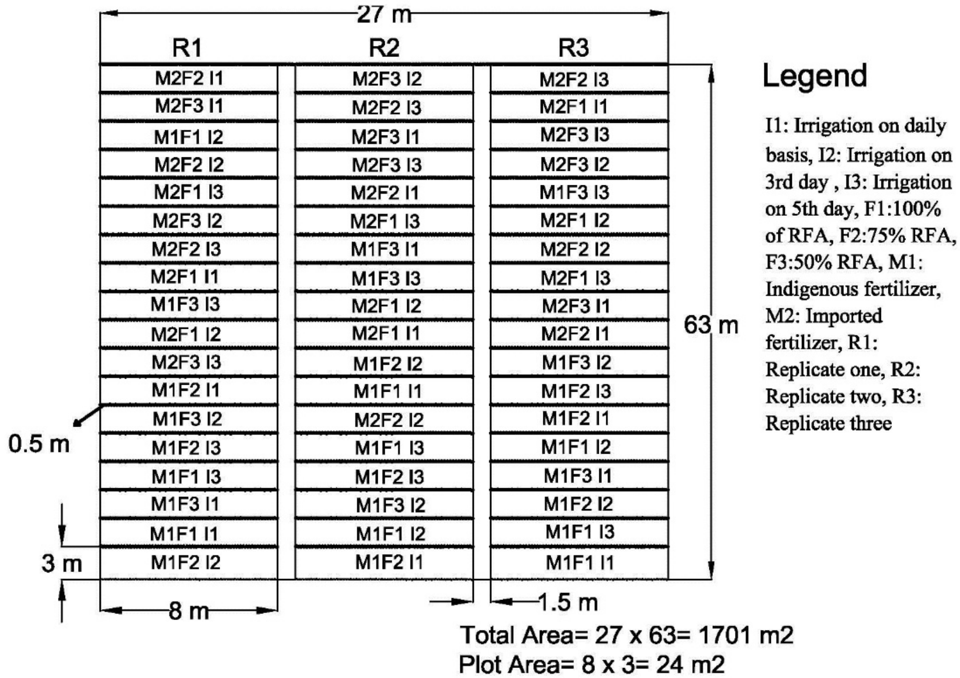


Figure 1: Layout of experiment

Irrigation and fertigation

Groundwater with salinity level, varied from 1.49 dS/m to 2.19 dS/m was used for irrigation of corn. Irrigation was applied according to the crop water requirement (CWR) for each irrigation interval. Under I_1, water was applied on daily basis according to daily CWR; whereas, under I_2 and I_3, the collective CWR of three days and five days was applied at every 3rd and 5th day, respectively. The total rainfall during the crop growing period was 130.90 mm in 2015 and 103.98 mm in 2016.

For crop fertilization, two fertilizer compounds including M_1: Indigenous fertilizer (N:P:K= 19:19:19) and M_2: Imported fertilizer (N:P:K= 20:20:20) were used to calibrate model for variety of water soluble fertilizers. M_1 fertilizer was more acidic (pH=4.1) as compared to M_2 (pH=6.7). The recommended fertigation applications (RFA) for corn production was nitrogen (N)=250 kg/ha, phosphorus (P)= 125 kg/ha and potassium (K)= 125 kg/ha, recommended by Punjab Agricultural Department, Pakistan. Along with M_1 and M_2 applications, urea was applied to increase the quantity of N as compared to P and K fertilizer as per RFA for corn production. The quantity of M_1, M_2 and urea was calculated according to RFA for corn and are given in table 1.

Table 1: Details of irrigation regarding each interval and quantity of water soluble fertilizer and Urea for each level of fertigation.

Irrigation				
Interval	2015 Season		2016 Season	
	Irrigation events (Nos.)	Total irrigation depth (mm)	Irrigation events (Nos.)	Total irrigation depth (mm)
I_1	115	547	111	564
I_2	39		37	
I_3	23		22	
Fertigation				
Fertilizer type	**Fertilizer level**	**Water soluble fertilizer (kg/ha)**	**Urea (kg/ha)**	--
M_1	F_1	658	272	--
M_1	F_2	494	204	--
M_1	F_3	329	136	--
M_2	F_1	625	272	--
M_2	F_2	469	204	--
M_2	F_3	313	136	--

I_1: Irrigation on daily basis, I_2: irrigation on 3rd day, I_3: irrigation on 5th day, F_1:100% of RFA, F_2:75% of RFA, F_3:50% of RFA, M_1: Indigenous fertilizer, M_2: Imported fertilizer

Data collection and analysis

Soil samples were taken from each treatment at four depths of the root zone (0-15 cm, 16-30 cm, 31-45 cm and 46-60 cm) prior to irrigation to determination soil moisture and soil salinity. For calibration, soil samples were taken seven times [12th day after sowing (DAS), 25th DAS, 40th 58th DAS, 60th DAS 88th DAS, 115th DAS]; whereas, for validation, the samples were taken four times [25th DAS, 58th DAS, 88th DAS, 115th DAS]. Higher number of samples for calibration were taken to get more perfection in the calibration process.

Crop parameters including grain yield, dry matter weight and plant height were determined by taking plant samples, from pre-tagged plants, at the time of harvesting. Crop samples were taken from different locations in the plot and then the average of these samples was taken as single value for each replication of treatment. Plant height was measured using measuring tape. Crop samples from tagged plants were harvested and plant kernels were threshed manually to measure grain yield. For determination of dry matter weight, the harvested plants were chopped and oven dried for 48 hours at 70^{o}C (Chauhdary et al., 2017) and then weight of oven dried samples was measured.

Model input data and calibration

For calibration of the SALTMED model, data from treatment with daily irrigation (F_1), fertilized with Indigenous fertilizer (M_1) at 100% RFA (F_1) for the 2015 season was used. There is flexibility in the SALTMED model that more than one parameter can be used for its calibration. In the present study, the model was calibrated for four parameters including soil moisture, soil salinity, dry matter and grain yield to get more accurate results for model validation.

All calibration parameters are interlinked to each other in such a way that the parameters with final yield (e.g. dry matter and grain yield) depends on plant water uptake which relates to soil moisture and soil salinity. Thus, it was decided to start calibration with soil parameters and then focus on crop parameters to develop agreement between observed and simulated values. A similar approach was used and suggested by many researchers for calibration of the SALTMED model (Apostolakis et al., 2016; Arsalan et al., 2016; Chauhdary, 2018a; Pulvento et al., 2013; Silva et al., 2013). The input data used for model calibration are given in the subsequent steps:

1. The daily data of climatic parameters including maximum and minimum temperature (^{0}C), wind speed (m/s), sunshine hours (hrs), rainfall (mm), humidity (%) and radiations (MJ/m^2/d) were acquired from the metrological stations, installed at Main campus of University of Agriculture, Faisalabad. All these climatic parameters were imported into "Climate tab" of SALTMED.
2. The input data for "irrigation tab" was measured in the field for every irrigation. The data included duration of each irrigation and fertigation (minutes), drip emitter flow rate (L/h), water salinity (ds/m), nitrogen (ppm) and urea (ppm).
3. Soil physical properties including porosity, field capacity and permanent wilting point were determined in the laboratory using field samples and used for model input. Pore size distribution, saturated hydraulic conductivity, bubbling pressure, soil evaporation depth and residual water content were taken from the model database for sandy loam soil. Initial soil moisture and soil salinity were determined from the soil samples taken from the field prior to application of treatments.
4. The crop parameters including sowing and harvesting date, plant height and leaf area index were measured in field. The length of each growth stage, unstressed grain yield and root depth data were taken from literature (Anjum, 2013). The values Kc, Kcb, and Fc were taken from the model database, based on FAO Paper No. 56 (Allen et al., 1998) and π50 (Osmotic potential

at which potential water uptake is reduced to 50%) was taken from the experiments conducted by Ragab (2002) in a greenhouse under controlled conditions.

5. The harvest index was calculated from field data and used in the model run as a crop growth parameter. The other crop growth parameters were taken from model database.
6. The model domain was divided into 14 cells and 50 cells in the horizontal and vertical direction, respectively. The minimum and maximum time steps for model runs were taken as 25s and 300s, respectively.

The process of calibration was performed in two steps. In the first step, the model run was performed by using the initially measured/estimated values of soil, crop and crop growth parameters. In the second step, these parameters were changed gradually, one at a time, until the calibrated values of soil moisture, soil salinity, grain yield and dry matter weight were closer to the observed data.

Model validation and evaluation

In validation process, the model run was performed for the remaining treatments of 2015 season, except treatment used for calibration, and all treatments for 2016 season by using the same calibrated values for soil and crop parameters except length of crop period, as it was slightly different for both seasons.

Five statistical indicators were used to check accuracy of the model validation process as suggested by (Bakhsh et al., 2004; Loague and Green, 1991; Vinten et al., 1991). These indicators included (1) Root mean square error (RMSE), (2) Percentage of difference (%D), (3) Coefficient of residual mass (CRM) and (4) Coefficient of determination (R^2).

RMSE is used to measure cumulative difference between observed and predicted values. The value of RMSE, closer to zero, indicates best predictions by a model. The equation 1 was used for determination of RMSE.

$$RMSE = \left[\frac{\sum_{i=1}^{n}(S_i - O_i)^2}{n}\right]^{0.5} \qquad (1)$$

%D helps to compute the difference between observed and simulated data. Equation 2 was used to calculate %D.

$$\%D = \frac{(S_i - O_i)}{O_i} * 100 \quad (2)$$

The overestimation or underestimation by model simulations was checked by an indicator, named "coefficient of residual mass (CRM)". Model overestimation was represented by negative value of CRM and model underestimation was observed by vice versa. The CRM was calculated using equation 3.

$$CRM = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} O_i} \quad (3)$$

The R^2 (equation 4) is the proportion of variation in observed values that are predictable by simulated values. Its value, closer to one, indicates best agreement between measured and predicted values.

$$R^2 = \frac{[\sum_{i=1}^{n}(O_i - O_{ave}) - (S_i - S_{ave})]^2}{\sum_{i=1}^{n}(O_i - O_{ave})^2 - \sum_{i=1}^{n}(S_i - S_{ave})^2} \quad (4)$$

Scenario simulations

After successful validation and performance analysis, the model run was performed to simulate different scenarios for identification of corn response under variety of management practices, comprising combinations of different irrigation intervals and fertigation levels. These scenarios were as follows:

- Scenario 1: Corn response under M_1 fertilizer at fertigation level of 100% RFA and different irrigation intervals including irrigation on 2nd day (alternate day), irrigation on 4th day, irrigation on 6th day, irrigation on 7th day, irrigation on 8th day, irrigation on 9th day and irrigation on 10th day.
- Scenario 2: Corn response under daily irrigation and M_1 fertilizer at different fertigation levels including No-fertigation, 25% RFA, 125% RFA, 150% RFA, 175% RFA and 200% RFA.

Results and Discussion

Effects of treatments on crop parameters

The effects of experimental treatments were observed on crop parameters including plant height, dry matter weight and grain yield. It was observed that I_1 (daily irrigation) produced the greater plant height (183.7 cm), dry matter (16.9 t/ha) and grain yield (8.57 t/ha), followed by I_3 (irrigation on 5th day) and I_2 (irrigation on 3rd day), respectively. Better crop performance under I_1 was due to the daily irrigation applications that provided sufficient moisture for proper plant growth in comparison to that under I_2 and I_3. Sufficient moisture probably provided enough water to support plant water uptake regardless of higher salts content in root zone. Under I_3, heavy irrigation applications leached down the excessive salts from the root zone that created favorable environment for plant growth. But on the other hand, higher irrigation interval caused water stress (due to low moisture content in root zone between two successive irrigations) that resulted in less water uptake; therefore, the crop response was poor under I_3 as compared to that under I_1 but better as compared to that under I_2. Under I_2, the moisture content was higher due to small interval as compare to that under I_3 but salts remained in root zone, due to lighter irrigation as compare to that under I_3 that possibly restricted plant water uptake (may be due to higher osmotic potential). Higher salts concentration create unfavorable environment for plant water uptake despite the higher moisture in the root zone as compared to that under I_3. The study on different irrigation frequencies was also conducted by many researchers (Anjum et al., 2014; Chauhdary et al., 2017; Junaid Nawaz Chauhdary et al., 2019; Dağdelen et al., 2006; El-Hendawy and Schmidhalter, 2010; Jiotode et al., 2002) and they reported similar trend of crop response.

The M_1 (indigenous fertilizer) performed significantly better in terms of crop growth as plant height (182.8 cm), dry matter (16.7 t/ha) and grain yield (8.19 t/ha) in comparison to these parameters (plant height: 178 cm, dry matter weight: 16 t/ha and grain yield: 7.83 t/ha) produced under corresponding levels of M_2 (Imported fertilizer). This can be due to acidic nature of M_1 that affected the nutrient uptake by plant and ultimately increased grain yield. These results are in accordance with the work of Khaled and Fawy (2011) and Muhammad (2013).

Higher levels of fertigation up to recommended fertigation dose produced better yield. The highest crop parameters were observed under F_1 (100% RFA), which were significantly higher than that under F_2 (75% RFA) and F_3 (50% RFA), respectively. The highest plant height (190.2 cm), dry matter weight (17.8 t/ha) and grain yield (9.26 t/ha) were produced under F_1; whereas, these variables were produced significantly less under F_2 (180.1 cm, 16.3 t/ha and 8.25 t/ha respectively) and significantly least under F_3 (170.8 cm, 15.1 t/ha and 6.535 t/ha respectively). Similar trend of crop growth under varying fertigation levels were reported by other researchers (Abayomi et al., 2006; Al-Kaisi and Kwaw-Mensah, 2007; Arif, 2011; Hammad et al., 2011; Inamullah et al., 2011; Jena et al., 2015; Maqsood et al., 2001).

Table 2: Corn data under different treatments

Treatments	Plant height (cm)	Dry matter (t/ha)	Grain Yield (t/ha)
Irrigation interval			
I_1: Irrigation on daily basis	183.7a	16.9a	8.57a
I_2: Irrigation on 3rd day	177.4c	15.8c	7.44c
I_3: Irrigation on 5th day	180.1b	16.5b	8.03b
LSD	2.63	0.36	0.21
Fertilizer type			
M_1: Indigenous fertilizer	182.8a	16.7a	8.19a
M_2: Imported fertilizer	178b	16.0b	7.83b
LSD	2.15	0.29	0.17
Fertigation level			
F_1: 100% RFA	190.2a	17.8a	9.26a
F_2: 75% RFA	180.1b	16.3b	8.25b
F_3: 50% RFA	170.8c	15.1c	6.53c
LSD	2.63	0.37	0.21

RFA=Recommended fertigation applications
Treatment means with different letters are significantly different ($p \leq 0.05$)

Model calibration

First, model simulation results for soil parameter (soil moisture and soil salinity) were compared with observed corresponding results, then the simulations regarding crop parameters (dry matter and grain yield) were evaluated. During first model run, the default values of input parameters and the data, collected from field measurement, were used then, the model was calibrated by fine tuning the values of those parameters, which were taken only from literature while the measured parameters were kept unchanged. This process was continued until the simulated results became closer to the measured results. The initial and calibrated or measured values of soil and crop parameters are given in Table 3 and Table 4.

Table 3: Calibrated soil parameters

Sr. No.	Soil parameters	Units	Initial value	Measured/Calibrated value
1	Porosity/ saturated soil moisture	m^3/m^3	--	0.407
2	Residual water content	m^3/m^3	0.01	0.02
3	Wilting point	m^3/m^3	--	0.07

4	Field capacity	m^3/m^3	--	0.185
5	Lambda pore size distribution index	--	0.49	0.302
6	Root width factor	--	0.5	0.6
7	Maximum evaporation depth	mm	120	120
8	Saturated hydraulic conductivity	mm/day	96.9	135
9	Bubbling pressure	cm	10	13.52

Table 4: Calibrated crop parameters

Sr. No.	Parameter		Units	Initial/ Default value	Measured/ Calibrated value
1	Crop coefficient (Kc)	Initial stage	--	0.7	0.4
		Mid stage	--	1.15	1.10
		End stage	--	1.05	0.72
2	Basal crop coefficient (Kcb)	Initial stage	--	0.16	0.1
		Mid stage	--	1.1	1.0
		End stage	--	1	0.55
3	Fraction cover (Fc)	Initial stage	--	0.5	0.17
		Mid stage	--	0.85	0.92
		End stage	--	1	0.8
4	Plant height	Initial stage	m	0.2	0.1
		Mid stage	m	1	2.23
		End stage	m	1.5	1.95
5	Leaf area index (LAI)	Initial stage	--	1	0.39
		Mid stage	--	8	7.37
		End stage	--	7	5.01
6	π50 (Osmotic potential at which yield reduces to 50%)	Initial stage	--	5	11
		Mid stage	--	5.9	15
		End stage	--	5.9	17
7	Radiation interception effect	Photosynthesis efficiency	g of DM/MJ	2.0	2.09
		Extinction coefficient	--	0.6	0.65
		Photosyntheticall y active radiation (PAR) Ratio	--	0.5	0.6
		Harvest Index	--	0.6	0.58

The correlation between observed and simulated values of soil moisture and soil salinity are shown in Figure 2 and Figure 3, respectively. The values of R^2 of calibration process for soil moisture were 0.812, 0.844, 0.916 and 0.937 for 0-15 cm, 16-30 cm, 31-45 cm and 46-60 cm soil layer, respectively. The R^2 values of upper soil layers were slightly less when compared to deeper soil layers. This was due to higher soil moisture variations in upper soil layers due to direct evaporation and plant water uptake from top soil layers as compared to deeper layers. This trend of soil moisture variation was explained by Silva et al. (2013). The values of R^2 of calibration process for soil salinity were 0.915, 0.909, 0.933 and 0.948 for 0-15 cm, 16-30 cm, 31-45 cm and 46-60 cm soil layer, respectively. The accuracy of calibration process regarding soil salinity can be assessed by higher values of R^2 and correlation between observed and simulated data. The model calibration for crop parameters (dry matter and grain yield) showed good aggreement between measured and simulated data. The values of %D for dry matter weight and grain yield were -0.16 and -2.11, respectively. The negative values of %D means that model slightly underestimated crop parameters.

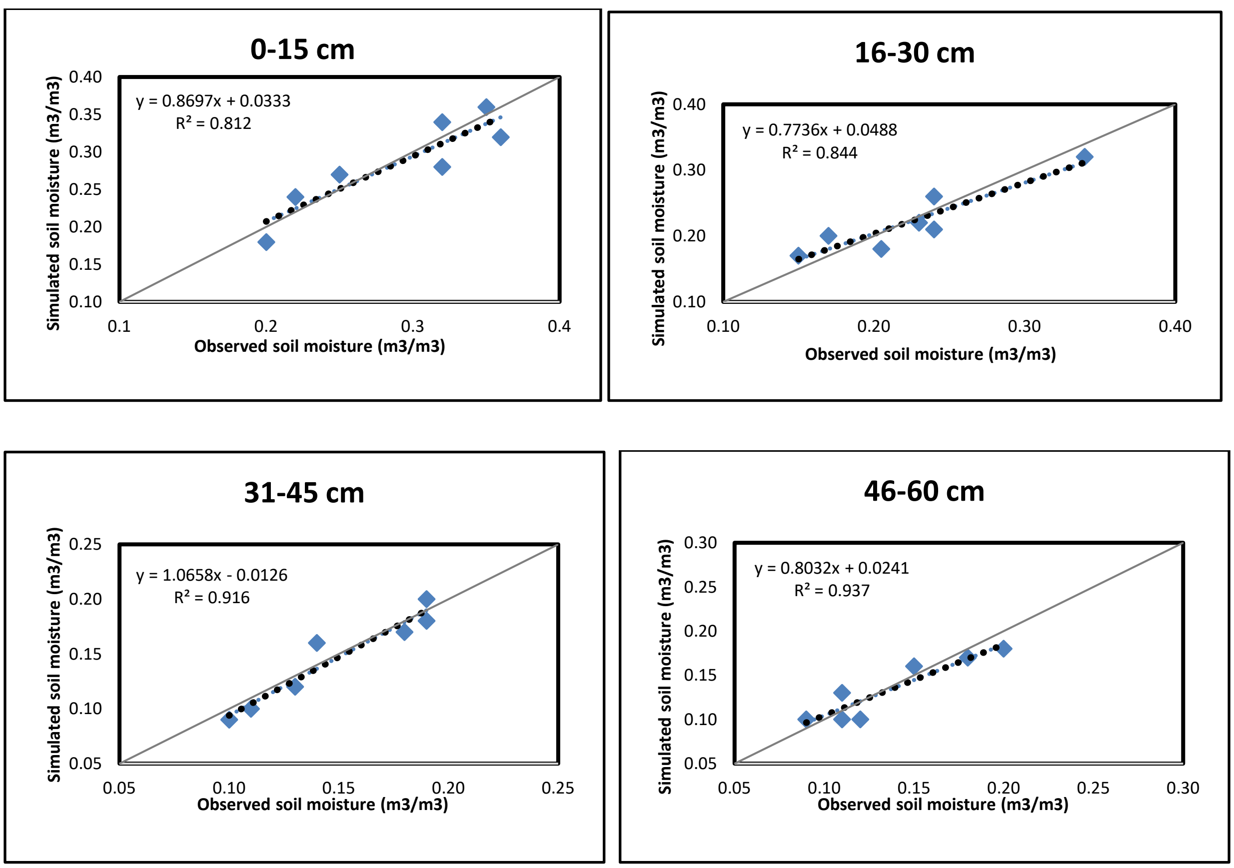


Figure 2: Calibration curves of soil moisture for different soil layers

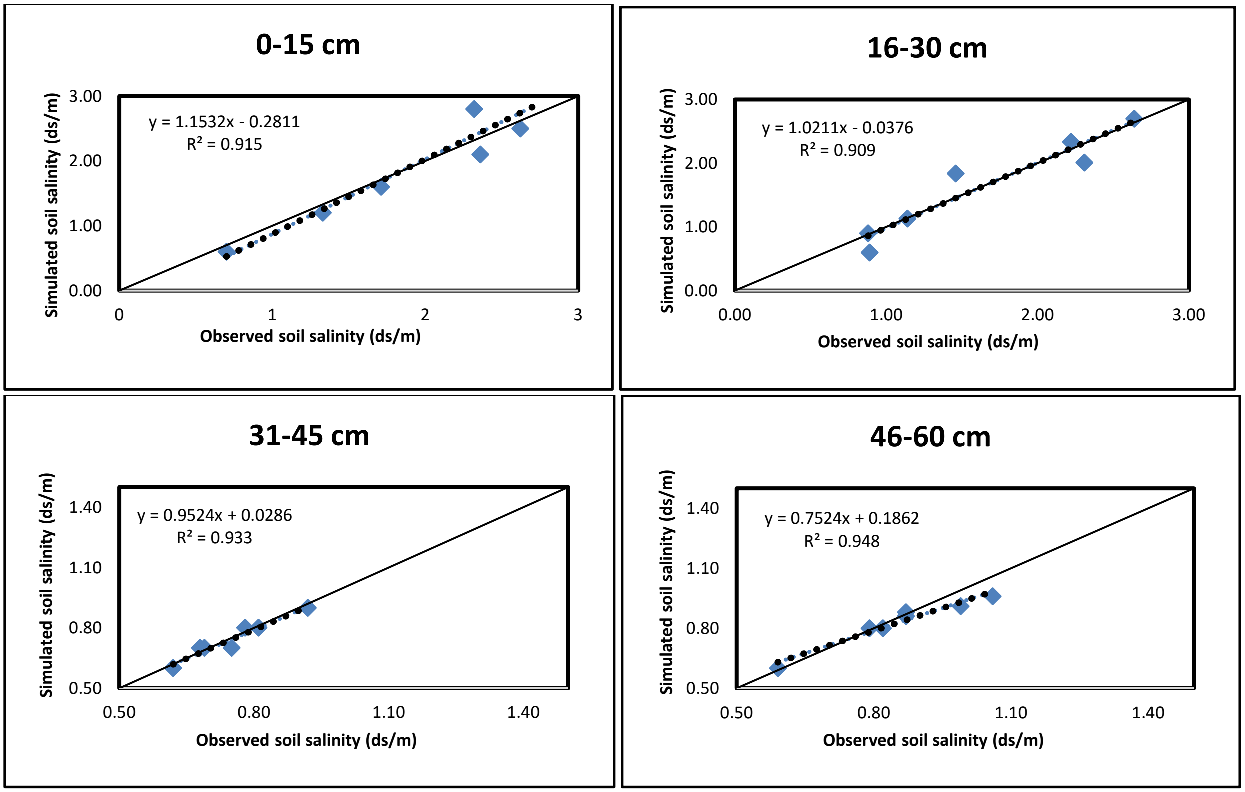


Figure 3: Calibration curves of soil salinity for different soil layers

Model validation and performance evaluation

SALTMED model (v.2015) can handle twenty different field or treatment at a time during model run. After successful calibration process, model run was performed for all the remaining treatments of the study. The average simulated soil moisture and soil salinity under different irrigation frequencies is shown in Figure 4 and Figure 6, respectively for different soil layers. The agreement between model simulated data and corresponding observed data of soil moisture and soil salinity is shown in Figure 5 and Figure 7. The RMSE for soil moisture varied from 0.009 to 0.017 among different soil layers. The results showed that R^2 for soil moisture was 0.906, 0.807, 0.833 and 0.853 for 0-15 cm, 16-30 cm, 31-45 cm and 46-60 cm soil layer, respectively. The results regarding CRM for soil moisture were consistent with values of 0.027 for 0-15 cm layer, -0.026 for 16-30cm layer, -0.001 for 31-45 cm layer and -0.007 for 46-60 cm soil layer. The results of soil salinity indicated that RMSE was 0.565, 0.415, 0.484 and 0.453 for 0-15 cm, 16-30 cm, 31-45 cm and 46-60 cm soil layers, respectively. The highest CRM for soil salinity was obtained for 0-15 cm layer (CRM=0.249), followed by 31-45 cm layer (CRM=0.130), 16-30 cm layer (CRM=0.079) and 46-60 cm layer (CRM=0.061), respectively. In case of soil salinity, positive values of CRM indicated that model slightly overestimated soil salinity in the root zone; whereas, in case of soil moisture, model underestimated values for all soil layers (16-30 cm, 31-45 cm and 46-60 cm) except 0-15 cm soil layer that was overestimated with positive value of CRM. The values of performance indicators for soil moisture and soil salinity are given in Table 5.

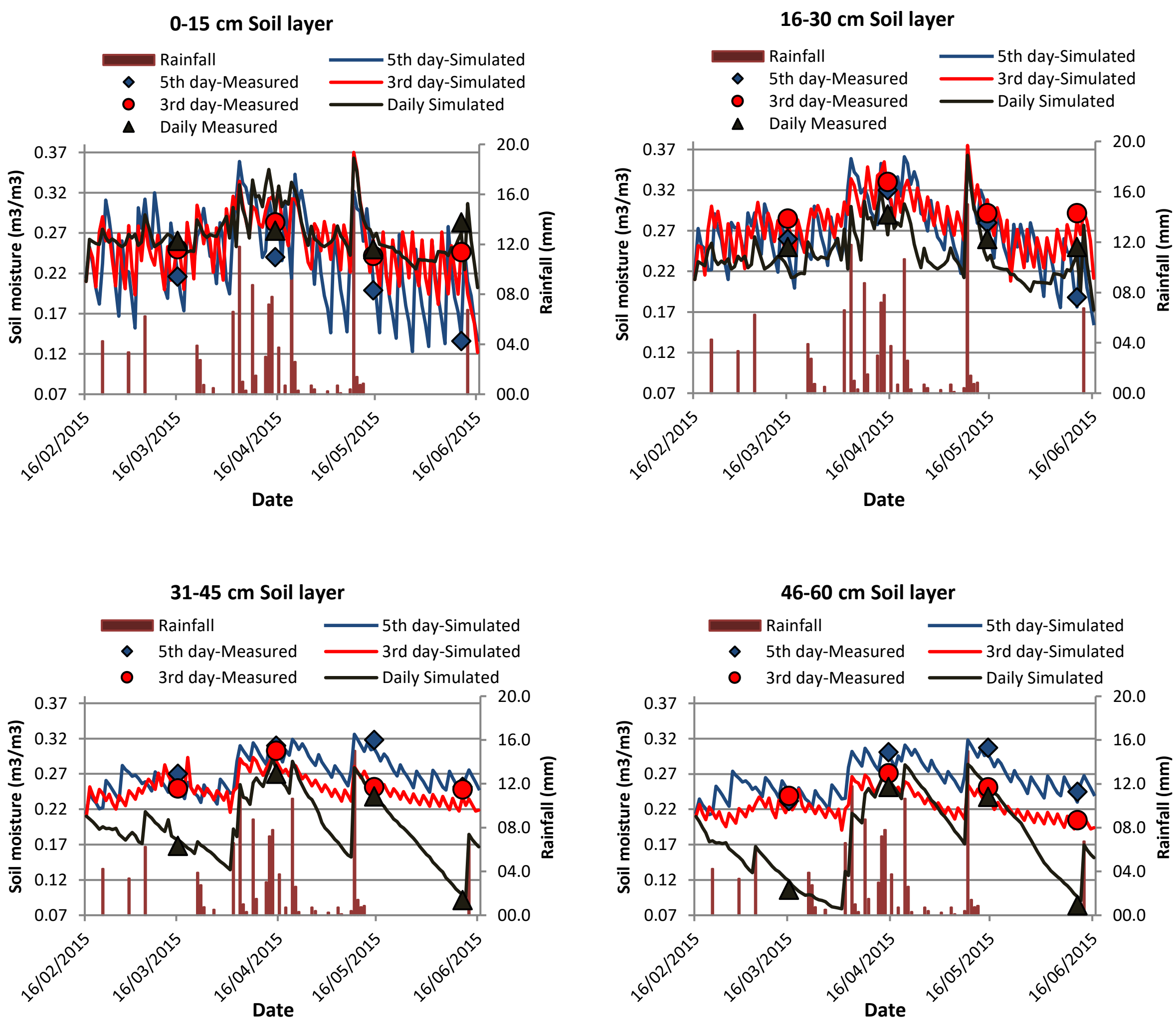


Figure 4: Average simulated soil moisture under different irrigation frequencies

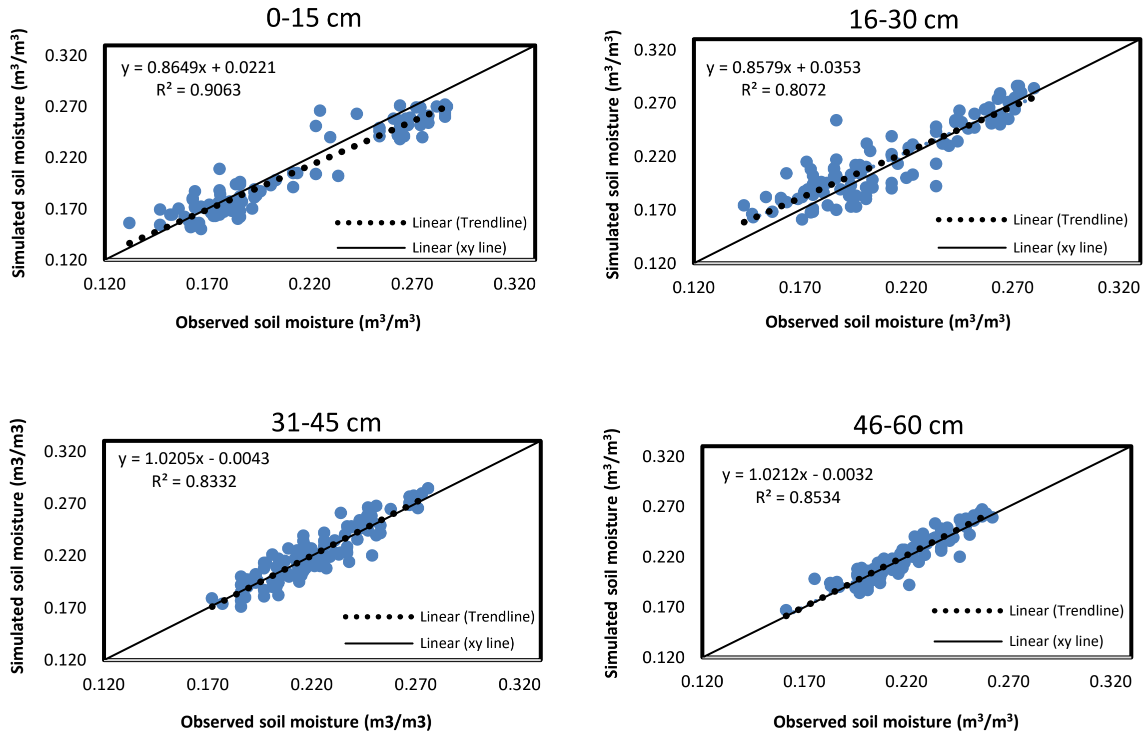
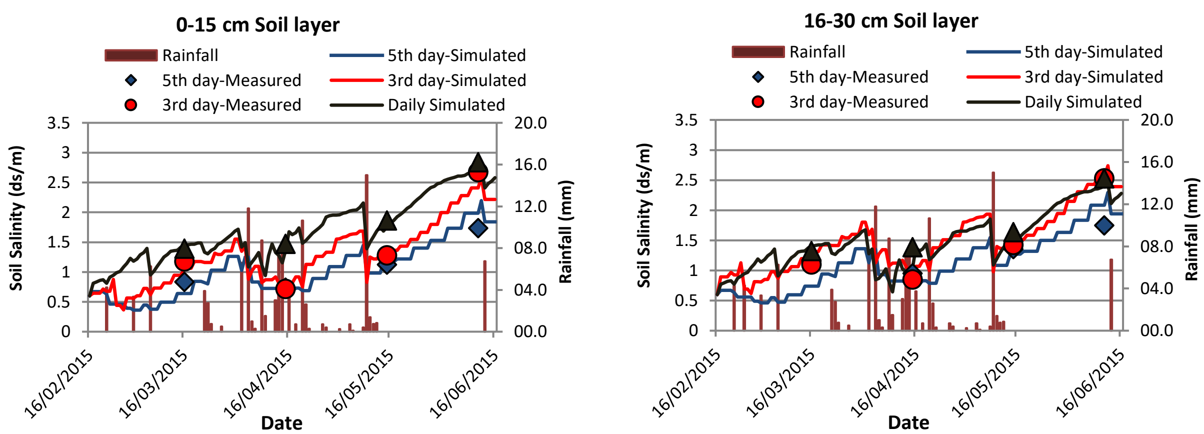


Figure 5: Validation curves of soil moisture for different soil layers



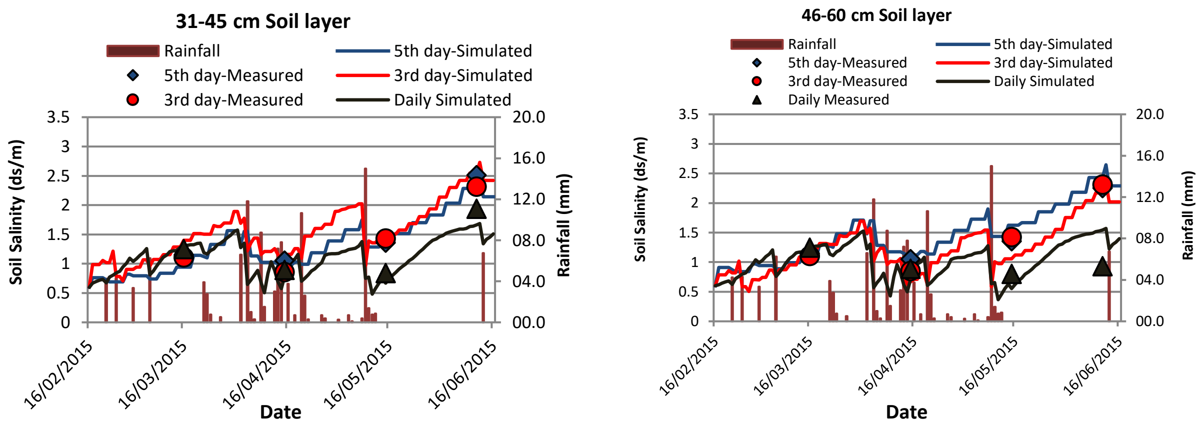


Figure 6: Average simulated soil salinity under different irrigation frequencies

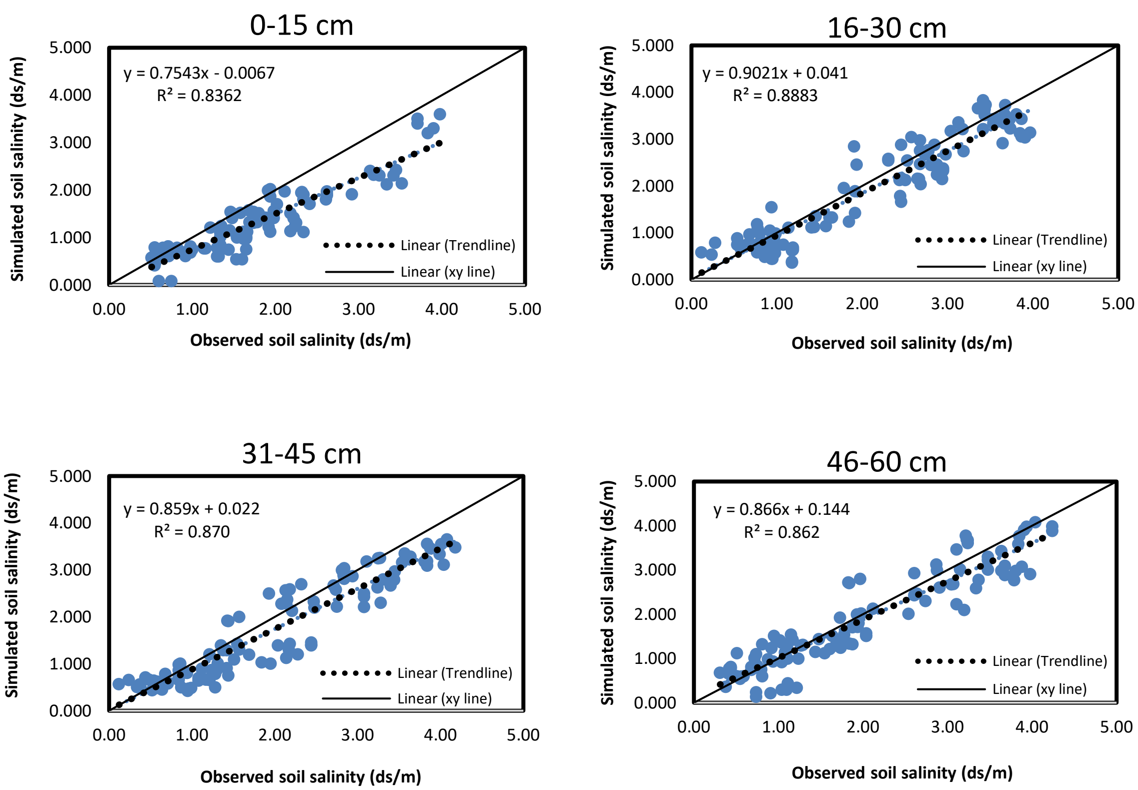


Figure 7: Validation curves of soil salinity for different soil layers

Table 5: Results of performance evaluation of model validation for soil and crop parameters

Soil Parameters					
Parameter	**Indicators**	**Soil depth (cm)**			
		0-15	**16-30**	**31-45**	**46-60**
Soil Moisture	**RMSE**	0.015	0.017	0.011	0.009
	R^2	0.906	0.807	0.833	0.853
	CRM	0.027	-0.026	-0.001	-0.007
Soil Salinity	**RMSE**	0.565	0.415	0.484	0.453
	R^2	0.836	0.888	0.870	0.862
	CRM	0.249	0.079	0.130	0.061
Crop Parameters					
Indicators		**Grain yield**		**Dry matter weight**	
RMSE		0.475		0.596	
R^2		0.873		0.909	
CRM		-0.001		-0.027	

The model was validated for dry matter weight after its successful calibration for soil parameters. The correlation of model and field data for dry matter is shown in Figure 8. The accuracy of model validation for dry matter weight was examined using statistical indicators, given in Table 5. The value of R^2 and RMSE were 0.908 and 0.596 for dry matter, respectively. The model slightly overestimated the dry matter with CRM= -0.027. The highest dry matter was obtained under treatment with I_1: daily irrigation, fertilized with M_1: indigenous fertilizer at F_1: 100% RFA in 2016 season (18.33 tons/ha). Detail comparison between observed and simulated data of dry matter is given in Table 6. The %D between observed and simulated values of dry matter weight was calculated for each treatment and it varied from 9.22% to -2.74% for 2015 season and 7.58% to 0.49% for 2016 season. The R^2 for grain yield (Figure 8) was 0.873, whereas, the value of RMSE was 0.596 (Table 5) that indicate the accuracy of model predictions regarding grain yield. It was observed that the maximum %D for grain yield was 11.32 % for 2015 season and 19.65 % for 2016 season. The maximum values of %D were within acceptable limit (Mahmood,(2004). CRM (-0.001) analysis showed that model slightly overestimated grain yield. The reason for overestimation of crop parameters was that the model was calibrated for the data of 2015 season, which was slightly higher than that of 2016 season. The detail comparison between observed and simulated grain yield is given in Table 7.

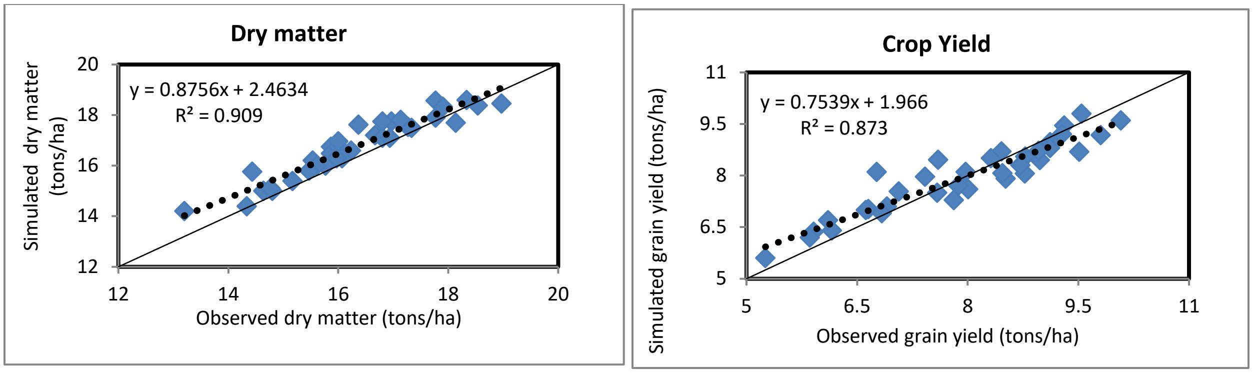


Figure 8: Validation curve for dry matter and grain yield

Table 6: Observed and simulated dry matter of corn under different treatments

Treatment	2015			2016		
	Observed (tons/ha)	Simulated (tons/ha)	%D (%)	Observed (tons/ha)	Simulated (tons/ha)	%D (%)
$I_1*F_1*M_1$	19.23	19.20	-0.16	18.33	18.60	1.47
$I_1*F_2*M_1$	17.77	18.57	4.50	16.23	16.60	2.28
$I_1*F_3*M_1$	16.37	17.62	7.64	15.17	15.40	1.52
$I_1*F_1*M_2$	18.53	18.38	-0.81	17.33	17.50	0.98
$I_1*F_2*M_2$	16.97	17.76	4.66	15.77	16.00	1.46
$I_1*F_3*M_2$	15.87	16.74	5.48	14.63	15.00	2.53
$I_2*F_1*M_1$	17.90	18.34	2.46	16.80	17.10	1.79
$I_2*F_2*M_1$	16.80	17.75	5.65	15.60	16.00	2.56
$I_2*F_3*M_1$	15.87	16.48	3.84	14.63	15.00	2.53
$I_2*F_1*M_2$	17.27	17.53	1.51	16.07	16.30	1.43
$I_2*F_2*M_2$	16.00	16.75	4.69	14.80	15.00	1.35
$I_2*F_3*M_2$	14.43	15.76	9.22	13.20	14.20	7.58
$I_3*F_1*M_1$	18.97	18.45	-2.74	17.77	17.90	0.73

$I_3*F_2*M_1$	17.13	17.82	4.03	15.97	16.30	2.07
$I_3*F_3*M_1$	16.00	16.97	6.06	14.77	15.10	2.23
$I_3*F_1*M_2$	18.13	17.70	-2.37	16.93	17.10	1.00
$I_3*F_2*M_2$	16.67	17.20	3.18	15.47	15.80	2.13
$I_3*F_3*M_2$	15.53	16.21	4.38	14.33	14.40	0.49

Table 7: Observed and simulated grain yields of corn under different treatments

Treatment	**2015**			**2016**		
	Observed (tons/ha)	Simulated (tons/ha)	%D (%)	Observed (tons/ha)	Simulated (tons/ha)	%D (%)
$I_1*F_1*M_1$	10.41	10.19	-2.11	9.54	9.79	2.62
$I_1*F_2*M_1$	9.31	9.46	1.61	8.46	8.70	2.84
$I_1*F_3*M_1$	7.60	8.46	11.32	6.77	8.10	19.65
$I_1*F_1*M_2$	10.08	9.60	-4.76	9.28	9.20	-0.86
$I_1*F_2*M_2$	9.12	8.97	-1.64	8.32	8.50	2.16
$I_1*F_3*M_2$	7.42	7.97	7.41	6.62	7.00	5.74
$I_2*F_1*M_1$	8.98	8.45	-5.90	9.12	8.80	-3.51
$I_2*F_2*M_1$	8.52	7.91	-7.16	7.59	7.50	-1.19
$I_2*F_3*M_1$	6.65	7.03	5.71	5.86	6.20	5.80
$I_2*F_1*M_2$	8.77	8.06	-8.10	8.01	7.60	-5.12
$I_2*F_2*M_2$	7.81	7.29	-6.66	6.84	6.90	0.88
$I_2*F_3*M_2$	5.91	6.37	7.78	5.26	5.60	6.46

$I_3*F_1*M_1$	9.80	9.18	-6.33	9.36	9.12	-0.03
$I_3*F_2*M_1$	8.78	8.55	-2.62	7.97	8.10	1.63
$I_3*F_3*M_1$	7.07	7.54	6.65	6.16	6.40	3.90
$I_3*F_1*M_2$	9.51	8.69	-8.62	8.71	8.30	-4.71
$I_3*F_2*M_2$	8.47	8.07	-4.72	7.87	7.70	-2.16
$I_3*F_3*M_2$	6.91	7.10	2.75	6.11	6.70	9.66

Scenarios simulations

Under first scenario, model run was performed for M_1 fertilizer type and F_1 fertigation level against different irrigation frequencies. Model simulations showed that the highest crop parameters (dry matter and grain yields) were produced under daily irrigation. The crop parameters started to be affected when irrigation moved from daily irrigation to 3rd day irrigation, then showed improvement when irrigation moved from 3rd day to 5th day. After that the crop parameters again started to decrease along with moving irrigation interval beyond 5th day irrigation towards irrigation on 10th day. Probably, the pattern of crop response against increasing irrigation frequencies was due to changing water and osmotic potential in crop root zone due to varying soil moisture and salts contents.. Under daily irrigation, due to the frequent irrigation applications, water potential was adequate in root zone to support plant water uptake regardless of higher salts contents in root zone. When irrigation interval moved towards 3rd day irrigation, salts remained in root zone that possibly increased osmotic potential in root zone and two days gap between consecutive irrigations created a deficit in water availability. The higher osmotic potential and lower water potential reduced plant water uptake and ultimately decreased crop yield. When irrigation interval moved from 3rd day irrigation to 5th day irrigation, heavy irrigation applications leached down the excessive salts from root zone that reduced osmotic potential in root zone to support water uptake. Water potential under 5th day irrigation was also low but due to less osmotic potential the water uptake was higher as compared to that under 3rd day irrigation. That's the reason that the crop response was better under 5th day irrigation as compared to that under 3rd day irrigation. Beyond 5th day irrigation, the salts contents were low (similar to that under 5th day irrigation due to heavy irrigation) but low moisture content affected badly the plant growth by reducing water uptake by plant. The crop yield started to continuously decrease with increase in irrigation frequency. Same phenomenon has been studied by Amin et al. (2015) and Chauhdary et al. (2019) and they reported similar results with similar reasons. The results of scenario simulations for different irrigation frequencies are shown in Figure 9 and Table 8.

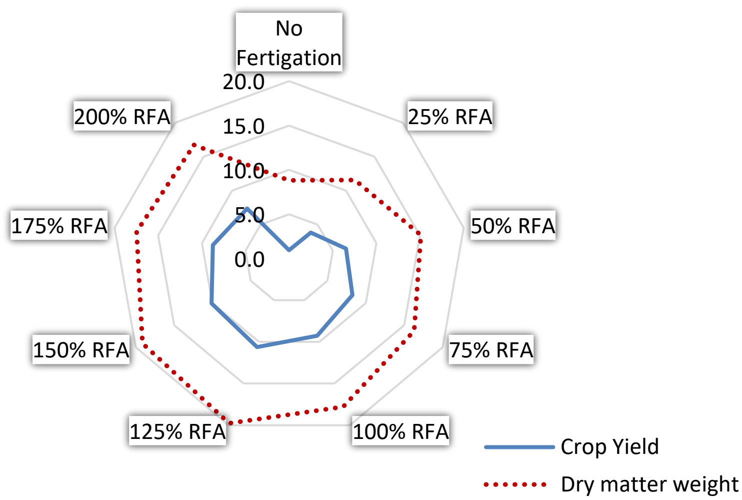


Figure 9: Response of crop parameters under different irrigation intervals (Scenario 1)

Table 8: Response of crop parameters under different irrigation intervals (Scenario 1)

Irrigation Interval	Dry matter weight (t/ha)	Grain Yield (t/ha)
Daily Irrigation	18.6	9.79
Irrigation on 2nd day	18.1	9.1
Irrigation on 3rd day	17.1	8.8
Irrigation on 4th day	17.3	8.9
Irrigation on 5th day	17.9	9.12
Irrigation on 6th day	17.4	8.92
Irrigation on 7th day	16.1	7.91
Irrigation on 8th day	14.9	7.1
Irrigation on 9th day	13.3	6.4
Irrigation on 10th day	11.8	5.14

Under second scenario, model run was performed for M_1 fertilizer type and I_1 irrigation interval against different fertigation levels. The lowest grain yield (0.9 t/ha) and dry matter (8.79 t/ha) were produced without use of fertilizer. In this condition, the plants absorbed nutrients from soil nutrient deposits for their growth, but the growth observed was very low due to small quantity of nutrients, present in soil. The crop parameters were increased gradually with increase the level of fertigation but after 125% RFA, the crop parameters started to decrease with increase in fertigation level. The dry matter weight and grain yield decreased 3.2% and 4.8%, respectively, when fertigation level increased from 125%RFA to 150% RFA. The drop in corn yield beyond opimum fertigation level has also been reported by Ju et al (2009). After 150% RFA, the crop parameters continuously decreased with increase in fertigation level up to 200% RFA. The excessive use of fertilizers probably created hazardous environment in root zone that effected plant water uptake and its growth and reduced final crop yield. Chauhdary (2018b) conducted research on maize under different fertigation levels and reported the reduction in yield with use of excessive fertilizers above optimal limit. The results of scenario for different fertigation levels are shown in Figure 10 and Table 9.

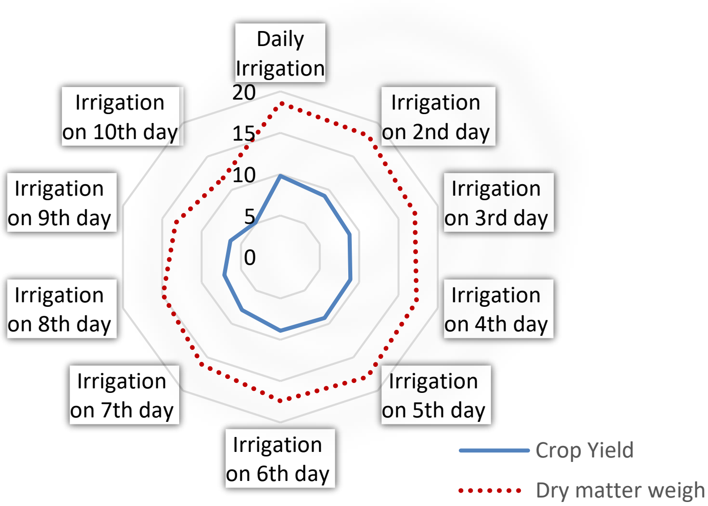


Figure 10: Response of crop parameters under different fertigation levels (Scenario 2)

Table 9: Response of crop parameters under different fertigation levels (Scenario 2)

Irrigation level (RFA)	Dry matter weight (t/ha)	Grain Yield (t/ha)
No Fertigation	8.79	0.9
25% RFA	11.54	3.8
50% RFA	15.1	6.53
75% RFA	16.3	8.25
100% RFA	17.8	9.26
125% RFA	19.76	10.62
150% RFA	19.12	10.11
175% RFA	17.48	8.7
200% RFA	16.72	7.4

Conclusions

Based on experimental results, it was concluded that the highest crop growth in terms of plant height, dry matter and grain yield were observed under daily irrigation applications. The Indigenous (acidic) fertilizer performed better as compared to Imported (less acidic) and fertigation level equal to RFA: recommended fertigation applications, produced the highest crop yield and crop growth parameters. Therefore, it was recommended that corn should be irrigated on daily basis under drip irrigation and fertilized with 100% RFA. The potential of SALTMED model to simulate corn growth was acceptable with the values of RMSE, R^2 and CRM, not exceeded from 0.017, 0.833 and 0.027, respectively for soil moisture and 0.565, 0.836 and 0.249, respectively for soil salinity. The SALTMED validation showed promising results also for grain yield (RMSE= 0.475, R^2=0.873, CRM= -0.0013 and highest %D= 19.65%) and dry matter weight

(RMSE=0.596, R^2=0.909, CRM=-0.027 and highest %D= 9.22%). The scenario simulations revealed that best response of corn was obtained under daily irrigation through drip irrigation with available groundwater. Similarly, the scenario simulation regarding fertigation levels showed that crop yield increased with increase in fertigation level up to 125% RFA, after that the crop growth started to decrease. Hence, the study proved the potential of the SALTMED model for simulation of soil moisture, soil salinity and corn growth under different irrigation frequencies and fertigation levels. SALTMED model proved to be an efficient tool for simulation of corn growth under different management scenarios with reliable results.

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