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APPLYING PARTIAL ROOT DRYING DRIP IRRIGATION IN PRESENCE OF ORGANIC MULCHING. IS THAT THE BEST IRRIGATION PRACTICE FOR ARID REGIONS?: FIELD AND MODELLING STUDY USING SALTMED MODEL[†]

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ABSTRACT

This research aimed at investigating the impact of irrigation systems, deficit irrigation strategy and organic mulching using rice straw on maize water productivity under Egypt's arid condition. The field experiment included sixteen treatments during two seasons, 2015 and 2016. Irrigation systems were [drip irrigation system (DIS) and furrow irrigation system (FIS)] while the irrigation strategies were [100% full irrigation (FI), 75% FI, 50% FI and partial root drying (PRD)]. Organic mulching using rice straw (OMRS) was also investigated. The experimental results indicated that there was a positive impact of applying PRD strategy by drip irrigation in presence of organic mulching on the yield (12.6 t ha^{-1} for 2015 and 12 t ha^{-1} for 2016) and water productivity of maize (4.81 kg m^{-3} for 2015 and 4.58 kg m^{-3} for 2016) but under control treatment (FIS with 100% full irrigation and without organic mulching) were (7.22 t ha^{-1} for 2015 and 7.34 t ha^{-1} for 2016) and water productivity of maize (0.64 kg m^{-3} for 2015 and 0.62 kg m^{-3} for 2016). The SALTMED model simulated reasonably well the soil moisture and salinity distribution as well as maize dry matter, yield and water productivity for all treatments, with R^2 of 0.998, 0.997 and 0.996, respectively. The results support the use of partial root drying strategy by drip irrigation system

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[†] Application de l'irrigation goutte-à-goutte partielle en présence de paillis organique. Est-ce la meilleure pratique d'irrigation pour les régions arides ?: Etude de terrain et de modélisation à l'aide du modèle SALTMED

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accompanied by using organic mulch by rice straw instead of the commonly used furrow irrigation. The PRD would save more fresh water, achieve higher yields and water productivity. In addition, mulching would reduce the evaporation losses, retain soil moisture and increase the organic matter content.

KEY WORDS: deficit irrigation; drip irrigation; furrow irrigation; SALTMED modelling; soil moisture; PRD strategy; water productivity; maize; organic mulch using rice straw.

RÉSUMÉ

Cette recherche visait à étudier l'impact des systèmes d'irrigation, la stratégie d'irrigation déficitaire et le paillage organique en utilisant la paille de riz sur la productivité de l'eau du maïs dans les conditions arides de l'Egypte. L'expérience de terrain comprenait seize traitements pendant deux saisons, 2015 et 2016. Les systèmes d'irrigation étaient un système d'irrigation goutte à goutte (DIS) et un système d'irrigation par rigoles (FIS) alors que les stratégies d'irrigation étaient irrigation complète à 100 % (FI), 50 % de FI et séchage partiel des racines (PRD). Le paillage organique utilisant de la paille de riz (OMRS) a également été étudié. Les résultats expérimentaux ont montré qu'il y avait un impact positif de l'application de la stratégie PRD par goutte à goutte en présence de paillage organique sur le rendement (12,6 t ha^{-1} pour 2015 et 12 t ha^{-1} pour 2016) et la productivité de l'eau du maïs (4,81 kg m^{-3} pour 2015 et 4,58 kg m^{-3} pour 2016) mais sous contrôle (FIS avec 100 % d'irrigation totale et sans paillage organique) étaient (7,22 t ha^{-1} pour 2015 et 7,34 t ha^{-1} pour 2016) et la productivité de l'eau du maïs (0,64 kg m^{-3} pour 2015 et 0,62 kg m^{-3} pour 2016). Le modèle SALTMED a raisonnablement simulé la distribution de l'humidité et de la salinité du sol ainsi que la matière sèche du maïs, le rendement et la productivité de l'eau pour tous les traitements, avec R2 de 0,998, 0,997 et 0,996, respectivement. Les résultats appuient l'utilisation d'une stratégie de séchage partiel des racines par un système d'irrigation au goutte-à-goutte accompagné d'un paillis organique avec de la paille de riz au lieu de l'irrigation par sillon couramment utilisée. Le PRD permettrait d'économiser plus d'eau douce, d'atteindre des rendements plus élevés et la productivité de l'eau. En outre, le paillage réduirait les pertes par évaporation, retiendrait l'humidité du sol et augmenterait la teneur en matière organique.

MOTS CLÉS : irrigation déficitaire ; irrigation goutte à goutte ; irrigation à la raie ; Modélisation SALTMED ; humidité du sol ; Stratégie PRD ; la productivité de l'eau ; maïs ; paillis organique

en utilisant de la paille de riz.

INTRODUCTION

Agriculture consumes the largest amount of the available water in Egypt, with its share exceeding 85% of the total demand for fresh water. The agricultural sector in Egypt contributes about 20% to Gross Domestic Product (GDP) and provides about 40% of total employment. In view of the expected increase in demand by other sectors, such as municipal and industrial for more water supply, the development of Egypt's economy strongly depends on its ability to conserve and efficiently manage its limited water resources. Appling of micro-irrigation irrigation systems which have high efficiency is an important concept should be implement in Egypt for saving the irrigation water due to limitation of water resources (El-Habbasha, *et al*., 2014). There are several approaches and techniques that have the ability to conserve and efficiently use such limited water resources. For example, drip irrigation system, applying deficit irrigation especially Partial Root Drying strategy, PRD and also, covering the soil surface by crop residues following the harvest such as rice straw (organic mulch). Drip irrigation is one of the most efficient water-saving irrigation methods because it has precise control of irrigation quantity, targets the root zone only and hence increases irrigation water productivity (WP) by reducing evaporation and percolation losses (Camp, 1998). Deficit irrigation (DI) including partial root drying (PRD) are water-saving irrigation strategies (Kang and Zhang, 2004). PRD involves alternate watering to each side of the plant root system, by which it allows the plant to be subjected to mild stress inducing partial closure of stomata to reduce transpiration losses without significantly affecting the photosynthesis and yield. PRD has been found to be a promising strategy in several crops (Kang and Zhang, 2004). Davies and Hartung (2004) suggested that PRD could stimulate root growth whereas under DI, some of the roots may die if dry conditions are prolonged. Subsequently, it was decided to investigate if DI and PRD could be promising irrigation strategies to apply on maize grown in sandy soils of Egypt. Mulches are frequently used in vegetable production to reduce evaporation losses from the soil surface, to accelerate crop development in cool climates by increasing soil temperature, to reduce erosion, or to assist in weed control. Mulches may be composed of organic plant materials or they may be synthetic mulches consisting of plastic sheets. Organic mulches are often used with orchard production and with row crops under reduced tillage operations. Organic mulches may consist of in situ plant residues or external material imported to the field. The depth of the organic mulch and the fraction of the soil surface covered can vary widely. These two parameters will affect the amount of reduction in evaporation from the soil surface. The magnitude of the evaporation component (Ke ETo) as part of the dual crop coefficient, Kcb + Ke, should be reduced by about 5% for each 10% of soil surface covered by the organic mulch (FAO 56, Allen *et al.* 1998). These recommendations are only approximate and attempt to account for the effects of partial reflection of solar radiation from residue, micro-advection of heat from residue into the soil, lateral movement of soil water from below residue to exposed soil, and the insulating effect of the organic cover. As these parameters can vary widely, local observations and measurements are required if precise estimates are required. (Allen *et al*., 1998). The SALTMED model (Ragab, 2015) has been selected as it has more integrated approach to water, field, soil and crop management. It has been developed for generic applications and has proved its ability to simulate several crops under different field managements. The model accounts for different irrigation systems, irrigation strategies, different water qualities, different crops and soil types, N-fertilizer applications, fertigation, impact of a biotic stresses such as salinity, temperature, drought and the presence of shallow groundwater and a drainage system. SALTMED 2015 allows real-time simultaneous simulation of 20 fields, each of which would have different irrigation systems, irrigation strategies, crops, soils and N-fertilizers. The model simulates the evapotranspiration, crop water uptake, soil temperature, soil salinity and soil moisture profiles, dry matter, yield, salinity and N-leaching, soil nitrogen dynamics, groundwater level and its salinity, and drainage flow to open and tile drains. The model has been calibrated and validated with field data of drip irrigation on tomato and potato crops (Ragab *et al*., 2005b and 2015), on sugar cane using sprinkler irrigation (Golabi *et al*., 2009), on quinoa, sweet corn and chickpea using drip irrigation (Hirich *et al*., 2012) on vegetable crops (Montenegro *et al*., 2010), on quinoa using saline water (Pulvento *et al*., 2013), on amaranth using saline water (Pulvento *et al*., 2015), on rainfed and irrigated chickpea (Silva *et al*., 2013), on quinoa under deficit drip irrigation (Fghire *et al*., 2015), on sweet pepper in green houses (Rameshwaran et al., 2015), on potato using gated pipes (El-Shafie *et al*., 2016) on maize and potato using drip irrigation (Afzal *et al*., 2016). In all these studies the model proved its reliability and ability to predict the field measured yield, dry matter, soil moisture and salinity. The model was also used to predict the impact of climate change on the amaranth and corn water requirement, yield, sowing and harvest dates and the length of the growing season (Pulvento *et al*., 2015; Hirich *et al*., 2016). The aim of this study was to identify the best irrigation system, deficit irrigation strategy and evaluate the impact of organic mulch on yield production and water productivity of maize under arid conditions through field and modelling study using SALTMED model.

MATERIALS AND METHODS

Location and climate of experimental site

Field experiments were conducted during 2015 and 2016 at a farm in Biyala City in Kafr El-Sheikh governorate, Egypt, latitude 31° N, longitude 31° E, and evaluation is 20 m above sea level, Figure 1. The experimental area has an arid climate with cool winters and hot dry summers. The data of maximum and minimum temperature, relative humidity, and wind speed were obtained from nearest weather station to the Farm as shown in Figure 2.

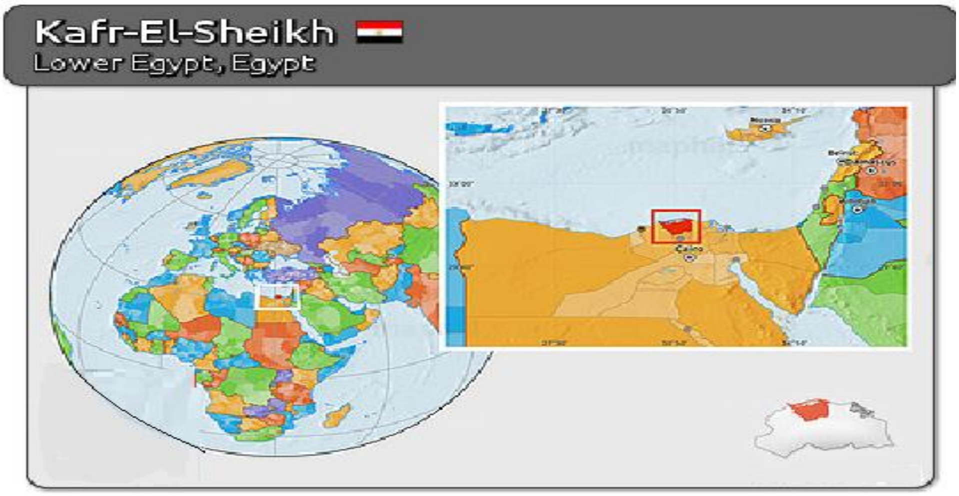


Figure 1. Locution of study site in Kafer El-Sheikh governorate in Egypt

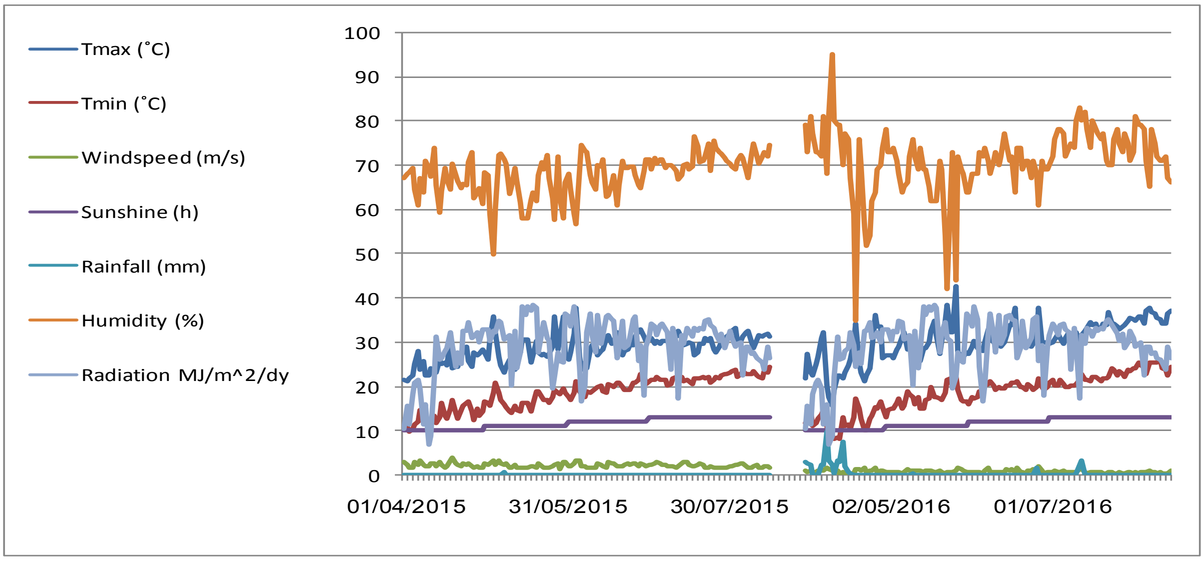


Figure 2. Meteorological data in the study site during maize growth seasons 2015 and 2016

Physical and chemical properties of the soil and irrigation water

Irrigation water was supplied by open irrigation canal cutting across the experimental area. The irrigation water had a pH of 7.4 and an electrical conductivity of 0.45 dS m^{-1}. The main physical and chemical properties of the soil were determined in situ and in the laboratory at the beginning of the field trial (Table I). The main physical, and chemical properties of irrigation water are reported in Table II.

Table I. Main physical and chemical characteristics of the soil of the experimental area

Physical parameters				
Soil layer (cm)	0–20	20-40	40-60	60-80
Texture	Clay	Clay	Clay	Clay
Sand (%)	1.56	1.67	1.71	2.14
Fine sand (%)	15.2	15.6	16.7	17.2
Silt (%)	20.1	18.7	18.6	17.9
Clay (%)	63.1	64.0	63.1	62.7
Bulk density (t m^{-3})	1.13	1.26	1.38	1.38
Chemical parameters				
EC$_{1:5}$ (dS m^{-1})	2.2	2.4	2.3	2.6
pH (1:2.5)	8.0	8.2	8.3	8.3

(Note: three significant figures imply already an accuracy of better than one promille, which you cannot achieve in practice. Please check the whole text and the Tables and Graphs for not more than three significant figures)

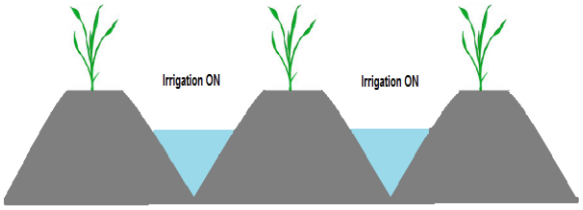
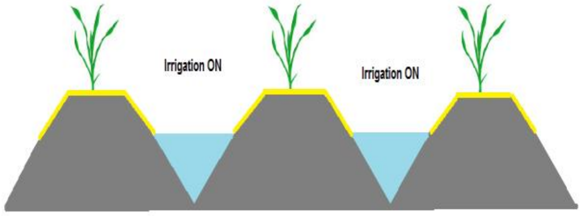
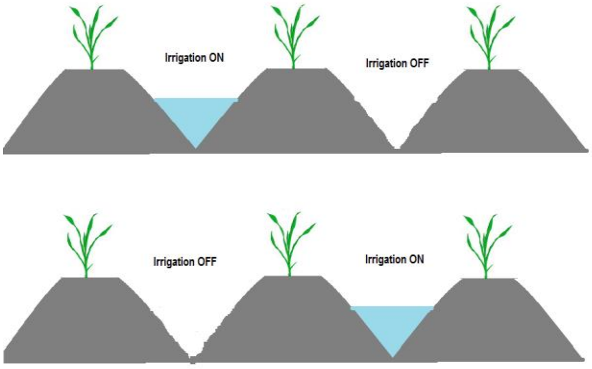
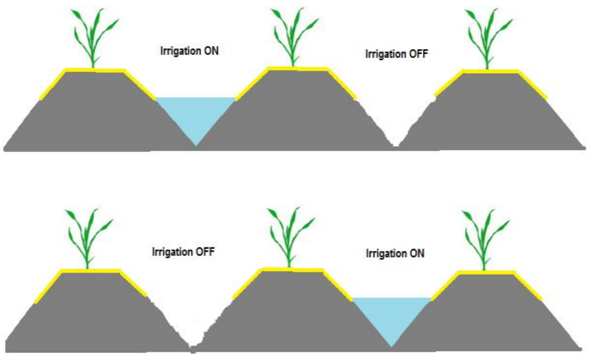
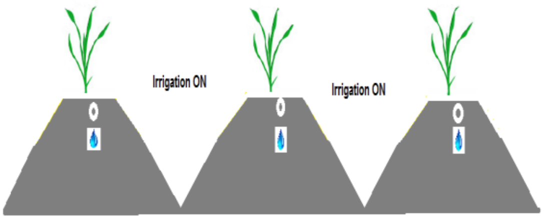
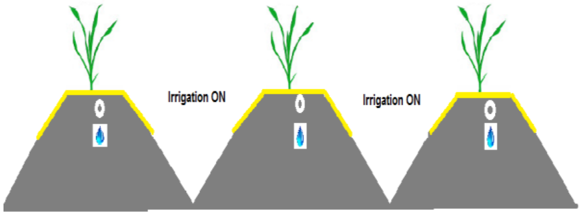
Table II. Main characteristics of irrigation water of the experimental area

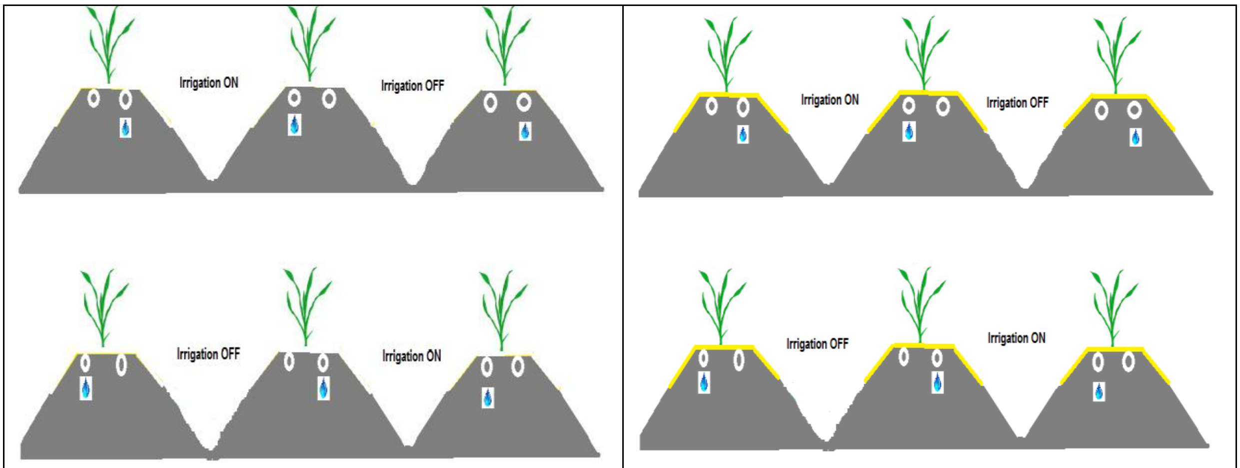
Item	Symbol	Irrigation water, IW
EC, dS m^{-1}		0.45
pH		7.41
Cations (mmol *l $^{-1}$)*	Ca^{+2}	1.10
	Mg^{+2}	0.40
	Na^{+}	2.50
	K^{+}	0.30
Anions (mmol *l $^{-1}$)*	CO_3^{-2}	0.00
	HCO_3^{-}	0.30
	Cl^{-}	2.60
	SO_4^{-2}	1.40

Experimental Design

The planting and harvesting dates for maize were 1th of April and 15th of August for both seasons 2015 and 2016, respectively. The growth period for maize was 137 days. The experimental design included sixteen treatments: Irrigation systems were [drip irrigation system

(DIS) and furrow irrigation system (FIS)] shared the main plot and irrigation strategy [100% from full irrigation (FI), 75% FI, 50% FI and partial root drying (PRD)] represented as sub main plot and organic mulch by rice straw (OMRS) represented as sub-sub main plot. The irrigation amount was calculated as crop evapotranspiration, ETc based on the modified Penman-Monteith equation according to Allen *et al*., 1998). One layer of rice straw mulch (3 cm deep) which equivalent 7.5 tons ha^{-1} was used (Eid *et al*., 2013). The total number of plots was 48 and each plot area was 236 m^{2}. The 48 plots were divided into three replicates of 16 plots each. The statistical design of this experiment was a split- split design. The soil moisture profile probe access tubes were placed in each plot to measure the soil moisture with depth as shown in Figure 2.

	
FIS with 100% FI, 75% FI and 50% FI	FIS with 100% FI, 75% FI and 50% FI with OM
	
FIS with PRD	FIS with PRD with OM
	
DIS with 100% FI, 75% FI and 50% FI	DIS with 100% FI, 75% FI and 50% FI with OM



DIS with PRD

DIS with PRD with OM

FIS: Furrow Irrigation System, DIS: Drip Irrigation, OM: Organic Mulch, FI: Full irrigation, PRD: Partial Root Drying

Figure 3. Schematic diagram showing the different treatments.

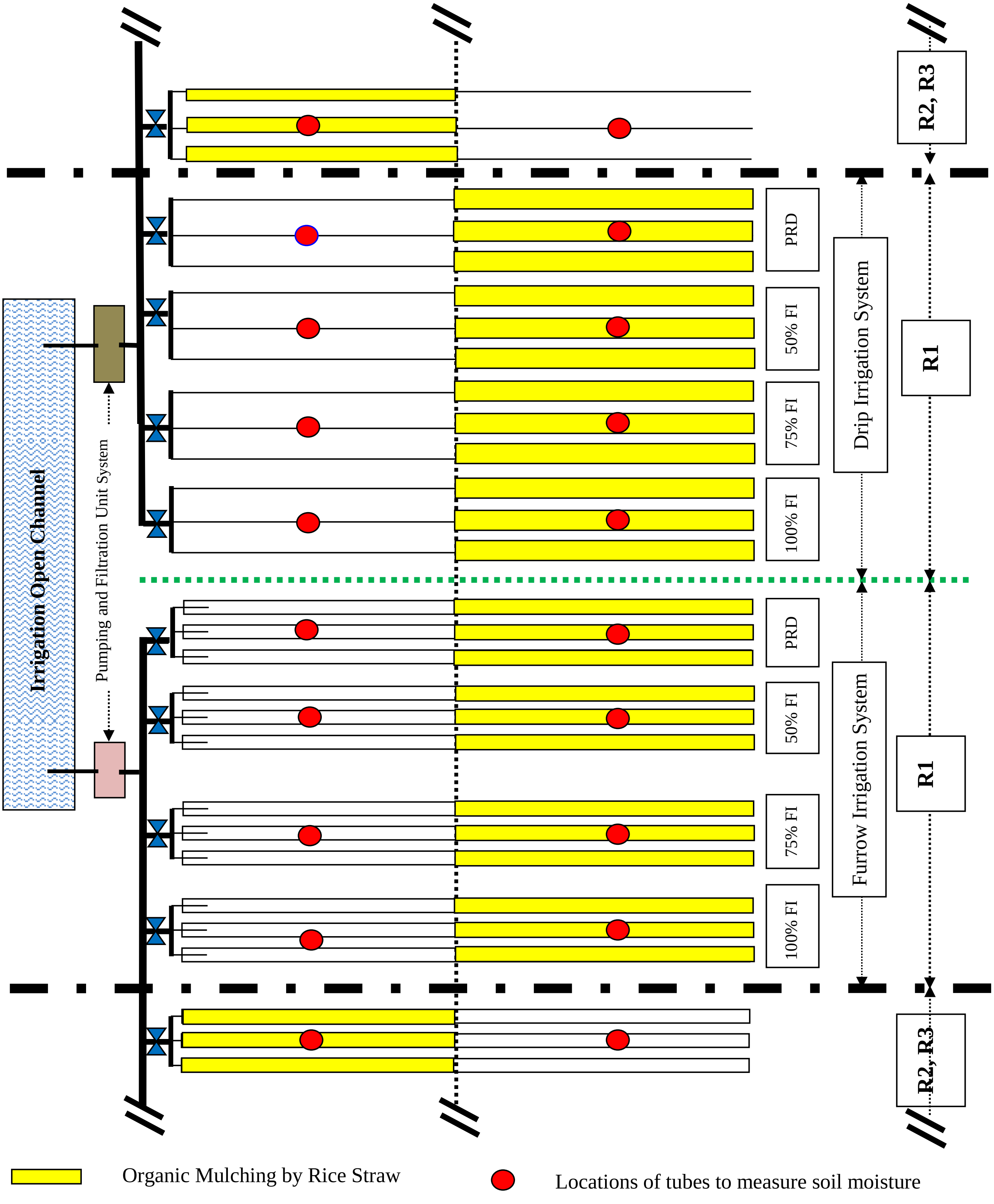


Figure 4. Layout of the experimental design

Irrigation requirements for maize

The daily irrigation water requirement was calculated using Penman Monteith equation and the crop coefficient, according to Allen *et al*. (1998). The seasonal irrigation water applied was 1129 mm season^{-1} and 1179 mm season^{-1} for furrow irrigation system for 2015 and 2016, respectively and 523 mm season^{-1} for drip irrigation system for both seasons 2015 and 2016. The efficiency of FIS was 50% and DIS was 90% and ETc was calculated based on ETo*Kc and ETo was calculated based on Penman-Monteith equation. Irrigation every 15 days under FIS and every 6 days under DIS. Irrigation requirements of maize for 2015 and 2016 with and without organic mulch per treatment per season as shown in Table III.

Table III. Irrigation requirements of maize for 2015 and 2016 with organic and without organic mulch

Irrigation systems	Deficit irrigation	Mulching	Irrigation frequency, days	Irrigation requirements 2015, mm	Irrigation requirements 2016, mm
Furrow Irrigation System, FIS	100% FI	WOM	15	1130	1180
		WM		1130	1180
	75% FI	WOM		847	884
		WM		847	884
	50% FI	WOM		565	590
		WM		565	590
	PRD	WOM		565	590
		WM		565	590
Drip Irrigation System, DIS	100% FI	WOM	6	523	523
		WM		523	523
	75% FI	WOM		392	392
		WM		392	392
	50% FI	WOM		262	262
		WM		262	262
	PRD	WOM		262	262
		WM		262	262

FI: Full irrigation, PRD: partial root drying, WOM: Without Organic Mulch, WM: With Mulch,

Acquiring the model parameters

The data required for the model calibration and validation were taken during each growth stage. The soil moisture was measured using the profile probes at four depths 0-20, 20-40, 40-60 and 60-80 cm. All the required climatic variable data were collected *in situ* from the site weather station. Climate data required as input to the model consisted of precipitation, maximum and minimum temperature, the relative humidity, wind speed, net and total radiation. In addition, dry matter and total leaf area, required to calculate the Leaf Area Index (LAI), were obtained at regular intervals. At harvest, a random plant sample (2 m^2) was taken from each plot to determine grain yield, which was then converted to yield in ton ha^{-1}. Other plant parameters, such as plant height, root depth, length of each growth stage and harvest index, were also based on field measurements. Water productivity of maize was calculated according to James (1988) as follows:

$$WP_{maize} = (Ey/Ir) \times 100 \tag{1}$$

Where: WP maize is the water productivity of maize (kg grains m^{-3}water), Ey is the economical yield (kg ha^{-1}) and Ir is the amount of applied irrigation water (m^3 water ha^{-1} $season^{-1}$).

SALTMED MODEL

The new version of SALTMED (Ragab, 2015) which accounts for surface and subsurface irrigation, partial root drying (PRD) or deficit irrigation, biomass and dry matter production was used in this study. A detailed description of the SALTMED model is provided in Ragab (2015), Ragab *et al*. (2005a), and Ragab *et al*. (2015). The SALTMED model is a free download from the Water4Crops EU funded project web site: http://www.water4crops.org/saltmed-2015-integrated-management-tool-water-crop-soil-n-fertilizers/ and from the International Commission on Irrigation and Drainage, ICID, web site: http://www.icid.org/res_tools.html#saltmed_2015.

Model calibration

During the calibration, fine tuning of the relevant SALTMED model parameters was carried out to obtain good agreement between the simulated and observed soil moisture, soil salinity, dry matter, and crop yield. For the calibration, furrow irrigation system with 100% full irrigation without organic mulch treatment and with organic mulch treatments were selected where evaporation (Ke ETo) was reduced according to the guidelines of FAO 56 (Allen *et al*., 1998) by 25% and this reduction was considered in irrigation requirements. [A general rule when applying Kc from Table 12 in FAO 56 is to reduce the amount of soil water evaporation by about 5% for each 10% of soil surface that is effectively covered by an organic mulch. For example, if 50% of the soil surface were covered by an organic crop residue mulch, then the soil evaporation would be reduced by about 25%], so, according this information new calibration has been carried out and the main parameters in this calibration were maximum depth for evaporation and saturated hydraulic conductivity where maximum depth for evaporation changed from 90 to 20 under organic covering and saturated hydraulic conductivity changed from 111 to 100 under organic mulching. Different soil parameters such as soil hydraulic properties including bubbling pressure, saturated hydraulic conductivity, saturated soil water content and pore distribution index, 'lambda' were fine-tuned until close matching between the simulated and observed soil moisture values has been achieved. In addition to the soil parameters, crop parameters such as the crop coefficient, Kc that is used to calculate the crop evapotranspiration (ETc), and basal crop coefficient, Kcb (represents the crop transpiration part of the Kc), were also slightly tuned to find the best fit of the soil moisture against the observed soil moisture for each soil layer (Tables IV and V). After achieving a good fit for the soil moisture, only fine tuning was needed for dry matter and crop yield. The key parameter that was required to be fine-tuned for the crop yield was photosynthetic efficiency. The goodness of fit expressions used were the root mean square error (RMSE), the coefficient of determination (R^2), and the coefficient of residual mass (CRM). The RMSE values, calculated using Equation 2, indicate by how much the simulations under or overestimate the measurements.

$$RMSE = \sqrt{\frac{\sum(y_o - y_s)^2}{N}} \tag{2}$$

Where: $\boldsymbol{y_o}$ = predicted value, $\boldsymbol{y_s}$ = observed value, $\boldsymbol{N}$= total number of observations.

The coefficient of determination, R^2 (Equation 3) demonstrates the ratio between the scatter of simulated values to the average value of measurements:

$$\mathrm{R}^2 = \left\{\frac{1}{\mathrm{N}}\frac{\sum(\mathrm{y_o} - \bar{\mathrm{y_o}})(\mathrm{y_s} - \bar{\mathrm{y_s}})}{\sigma \mathrm{y_o} - \sigma \mathrm{y_s}}\right\} \tag{3}$$

Where: $\boldsymbol{y_o^-}$ = averaged observed value, $\boldsymbol{y_s^-}$ = averaged simulated value, $\boldsymbol{\sigma y_o}$ = observed data standard deviation, $\boldsymbol{\sigma y_s}$ = simulated data standard deviation.

The coefficient of residual mass (CRM) is defined by Equation 4 as:

$$\mathrm{CRM} = \frac{(\sum \mathrm{y_o} - \sum \mathrm{y_s})}{\sum \mathrm{y_o}} \tag{4}$$

The CRM is a measure of the tendency of the model to over or underestimate the measurements. Negative values for CRM indicate that the model underestimates the measurements and positive values for CRM indicate a tendency to overestimate. For a perfect fit between observed and simulated data, values of RMSE, CRM and R^2 should equal 0.0, 0.0, and 1.0, respectively.

Table IV. Main calibrated and observed input parameters used in the study site without organic mulch and with organic mulch for maize, 2015, Egypt

Parameter	Developmental Stage	Without organic mulch		With organic mulch	
		Observed	Calibrated	Observed	Calibrated
Sowing (day)		1 April		1 April	
Emergence (day after		1		1	
Harvest (day after sowing)		137		137	
Growth stages duration in					
Initial		19		19	
Development		35		35	
Middle		45		45	
Late		37		37	
Crop inputs					
Crop coefficient, Kc	Initial		0.4		0.4
	Middle		1.2		1.2
	End		0.8		0.8
Transpiration crop	Initial		0.3		0.3
	Middle		0.7		0.7
	End		0.5		0.5
Fraction cover, FC	Initial	0.2		0.3	
	Middle	0.9		1	
	End	0.8		0.9	
Plant height (m), h	Initial	0.4		0.5	
	Middle	1.9		2	
	End	1.8		1.9	
Leaf area index, LAI	Initial	1		1	
	Middle	5.5		5.7	
	End	5		5.2	
Minimum root depth (m)		0		0	
Maximum root depth (m)		1		1	
Photosynthesis efficiency			2.5		2.5
Water uptake effect	Initial		0.75		0.75
	Middle		0.75		0.75
	End		0.75		0.75
Harvest index, HI		0.27		0.29	

Table V. Main calibrated and observed input parameters used in the study site without organic mulch and with organic mulch for clay soil

Parameter	Without organic mulch		With organic mulch	
	Observed	Calibrated	Observed	Calibrated
Saturated moisture content ($m^3 m^{-3}$)	0.58		0.48	
Field capacity ($m^3 m^{-3}$)	0.45		0.45	
Wilting point ($m^3 m^{-3}$)	0.15		0.15	
Lambda pore size		0.3		0.3
Residual water content ($m^3 m^{-3}$)		0.1		0.1
Root width factor	0.4		0.4	
Saturated hydraulic conductivity (mm day^{-1})	111		100	
Max. depth for evaporation, mm		90		20
Bubbling pressure, cm		70		70

RESULTS AND DISCUSSION

Soil moisture distribution

Soil moisture distribution (SMD) was affected by the irrigation system, irrigation strategies and mulching system. Initially the soil moisture was calibrated with FIS, 100% FI with and without organic mulch by rice straw for season 2015 and validated against all the other treatments for two seasons 2015 and 2016. The model calibration simulated the soil moisture for two layers (0-40 and 40-80 cm depth) as shown in Figures 5 and 6 without organic mulch and with organic mulch respectively for 2015 season and was validated for 2015 season (Figures 7 and 8).

The soil moisture of under DIS, PRD with and without organic mulch were only shown here (Selected example from validation treatments, 2015) as shown as in Figures 9 and 10. Overall the model was able to simulate reasonably well the observed data both during the calibration and validation processes. These results are consistent with those obtained by Pulvento *et al*. (2013), Pulvento *et al*. (2015), Hirich *et al*. (2012), Silva *et al*. (2013) Ragab *et al*. (2015), Fghire *et al*. (2015) and Rameshwaren *et al*. (2015).

Good correlation between the simulated and observations were obtained for the 2016 season (not shown here).Table VI for 2015, the model showed slightly lower values for the R^2 for the top layer (0.90 to 0.98 for 0- 40 cm) in comparison to the subsurface layers and R^2 was increased by increasing the soil depth under all treatments (e.g. R^2 ranged from 0.91 to 0.99 for 40-80 cm layer) but that values increased with using organic mulch by rice straw. However, in general, the SALTMED model proved its high sensitivity to simulate the soil moisture changes caused by irrigation events. Overall the simulated and the observed soil moistures for all treatments combined showed a strong correlation for two seasons 2015 and 2016.

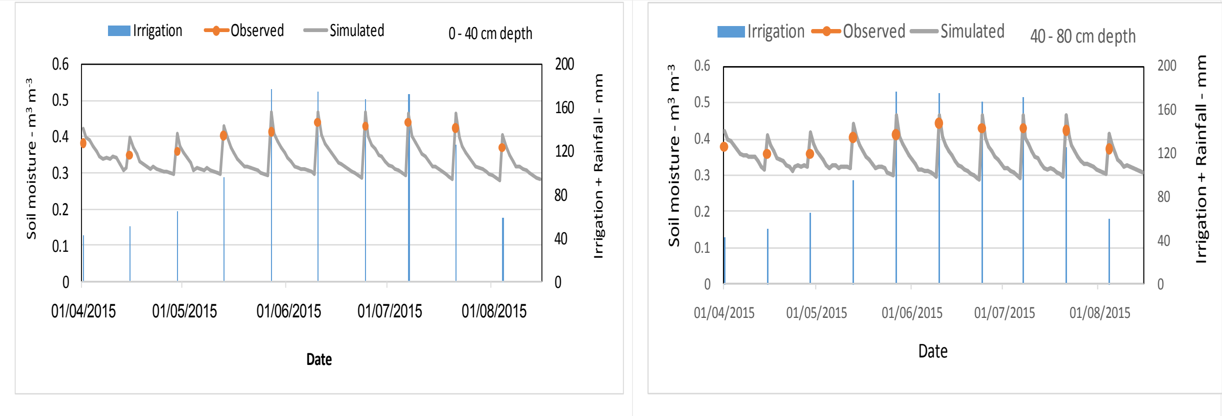


Figure 5. Observed and simulated soil moisture for 0-80 cm depth under FIS, 100% FI and without organic mulch (Calibration treatment), 2015

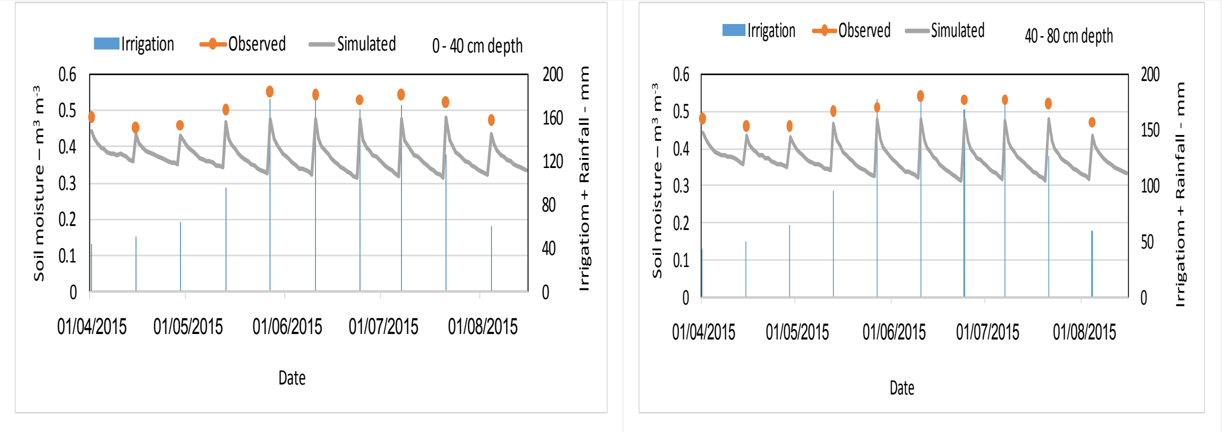


Figure 6. Observed and simulated soil moisture for 0-80 cm depth under FIS, 100% FI and with organic mulch by rice straw (Calibration treatment), 2015

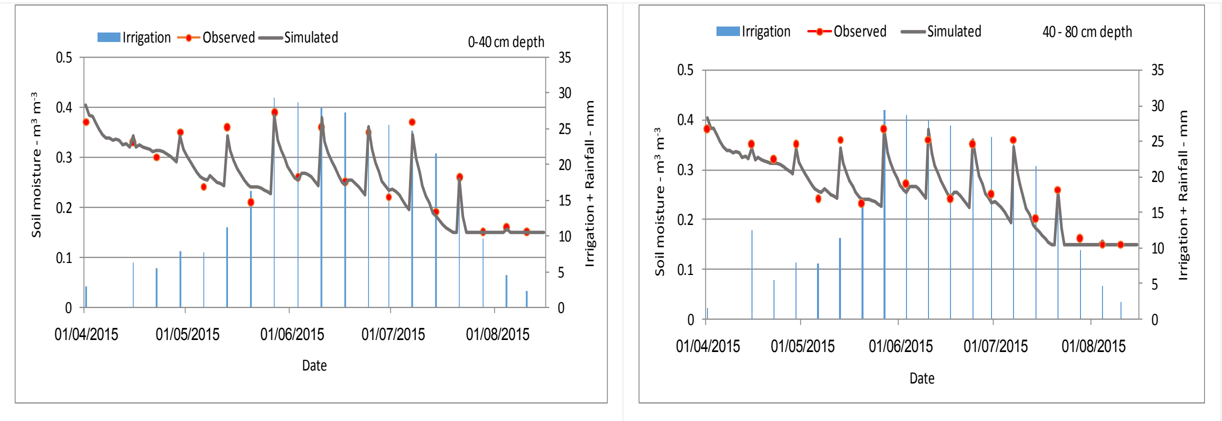


Figure 7. Observed and simulated soil moisture for 0-80 cm depth under DIS, PRD and without organic mulch (Selected example from validation treatments), 2015

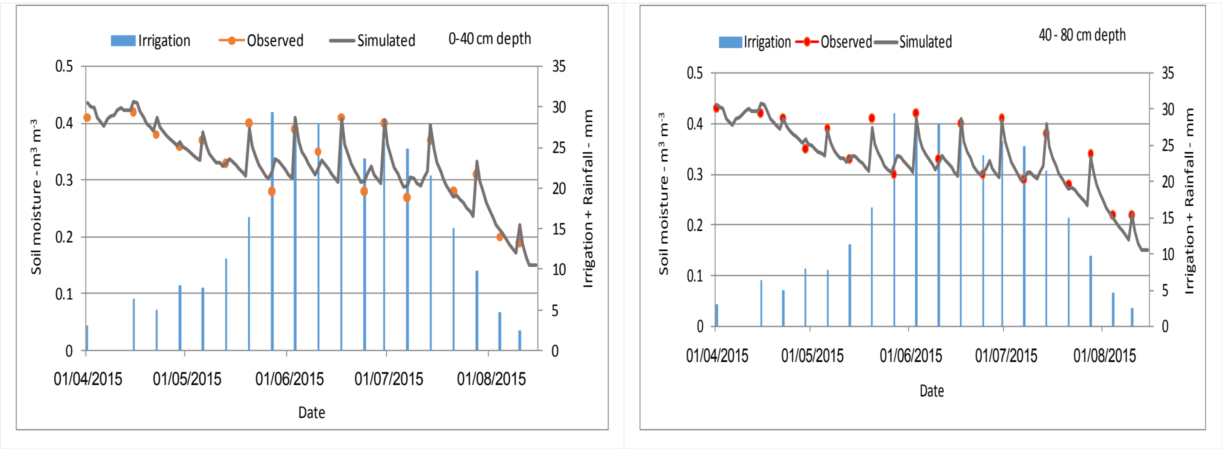


Figure 8. Observed and simulated soil moisture for 0-80 cm depth under DIS, PRD and with organic mulch by rice straw (Selected example from validation treatments), 2015

Table VI. The coefficient of determination, R^2, RMSE and CRM for soil moisture in the layers 0-80 cm, 2015

Mulching	Soil layer, cm	Correlation parameter	Treatment							
			Furrow Irrigation System				Drip Irrigation System			
			100%FI Calibration	75% FI	50% FI	PRD	100% FI	75% FI	50% FI	PRD
Without Organic Mulch Calibration1	0-40	R^2	0.900	0.930	0.900	0.980	0.970	0.950	0.930	0.960
		RMSE	0.039	0.018	0.013	0.010	0.014	0.010	0.018	0.015
		RCM	-0.095	-	0.022	-	-	0.016	0.024	-
	40-80	R^2	0.920	0.940	0.910	0.990	0.990	0.960	0.950	0.970
		RMSE	0.037	0.016	0.014	0.010	0.011	0.011	0.012	0.014
		RCM	-0.094	-	0.021	-	-	0.015	0.024	-
With Organic Mulch Calibration2	0-40	R^2	0.910	0.940	0.920	0.980	0.980	0.970	0.940	0.980
		RMSE	0.038	0.017	0.012	0.009	0.013	0.010	0.017	0.014
		RCM	-0.096	-	0.020	-	-	0.015	0.022	-
	40-80	R^2	0.910	0.950	0.920	0.990	0.990	0.980	0.950	0.990
		RMSE	0.035	0.015	0.013	0.010	0.010	0.011	0.011	0.013
		RCM	-0.091	-	0.018	-	-	0.014	0.021	-
	0-80	R^2	0.951							
		RMSE	0.016							
		RCM	-0.017							

FI: Full Irrigation, PRD: Partial Root Drying, RMSE: Root Mean Square Error, CRM: Coefficient of Residual Mass, R^2: Coefficient of determination/correlation coefficient

Table VII. The coefficient of determination, R^2, RMSE and CRM for soil moisture in the layers 0-80 cm, 2016

Mulching	Soil layer, cm	Correlation parameter	Treatment							
			Furrow Irrigation System				Drip Irrigation System			
			100%FI	75%FI	50%FI	PRD	100%FI	75%FI	50%FI	PRD
Without Organic Mulch	0-40	R^2	0.890	0.920	0.900	0.970	0.960	0.940	0.920	0.950
		RMSE	0.038	0.019	0.012	0.011	0.014	0.009	0.017	0.014
		RCM	-0.093	-0.038	0.023	-	-0.033	0.015	0.023	-
	40-80	R^2	0.920	0.920	0.900	0.980	0.970	0.950	0.950	0.960
		RMSE	0.036	0.016	0.013	0.011	0.012	0.012	0.011	0.013
		RCM	-0.094	-0.038	0.021	-	-0.032	0.015	0.024	-
With Organic Mulch	0-40	R^2	0.910	0.940	0.920	0.980	0.980	0.970	0.940	0.970
		RMSE	0.035	0.017	0.012	0.010	0.013	0.010	0.018	0.014
		RCM	-0.095	-0.040	0.020	-	-0.034	0.015	0.022	-
	40-80	R^2	0.911	0.960	0.910	0.990	0.990	0.980	0.950	0.980
		RMSE	0.035	0.015	0.013	0.010	0.010	0.011	0.011	0.013
		RCM	-0.092	-0.036	0.018	-	-0.035	0.015	0.021	-
	0-80	R^2	0.94							
		RMSE	0.015							
		RCM	-0.016							

FI: Full Irrigation, PRD: Partial Root Drying, RMSE: Root Mean Square Error, CRM: Coefficient of Residual Mass, R^2: Coefficient of determination/correlation coefficient

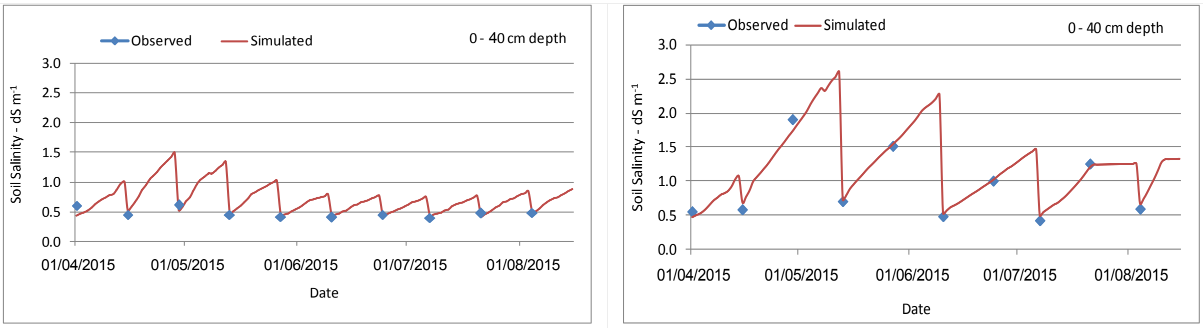
Soil salinity distribution

The soil salinity was also simulated for all irrigation systems FIS and DIS with deficit irrigation techniques 100% FI, 75% FI, 50% FI and PRD with and without organic mulch. Calibration treatment was 100% FI with and without organic mulch.

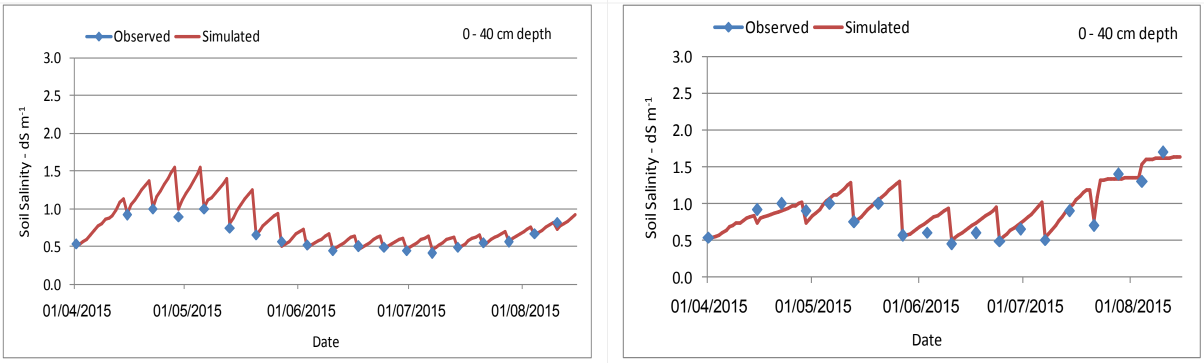
In this study the simulated soil salinity was compared with the observed soil salinity measured in the field with suction cups and sensors. The suction cups were used in calibrating the soil salinity sensors. The simulated results for both calibration and validation were close to the observed soil salinity (Figures 9 and 10).

The observed and simulated soil salinity was lower for the treatments with 100% FI, 75% FI and 50% FI under FIS and DIS systems than PRD strategy this may be due to increasing of salt leaching frequency under no PRD strategy as shown as in Figures 9 and 10.

The observed and simulated soil salinity was lower for the treatments with organic mulch than the treatments without organic mulch this may be due to the role of organic mulch layer in reducing evaporation rate hence, decreasing in salt accumulation in the root zone. (Figures 9 and 10) and also figures 11 and 12 show the importance of covering the soil surface by organic mulching in reducing of salt accumulation. Overall the observed and simulated soil salinity values are showing good fit for all treatments.

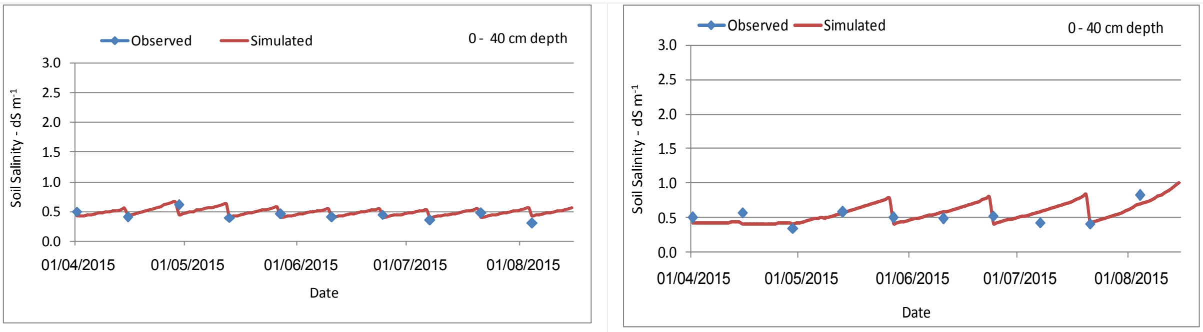


FIS, 100% FI (Calibration treatment) FIS, PRD



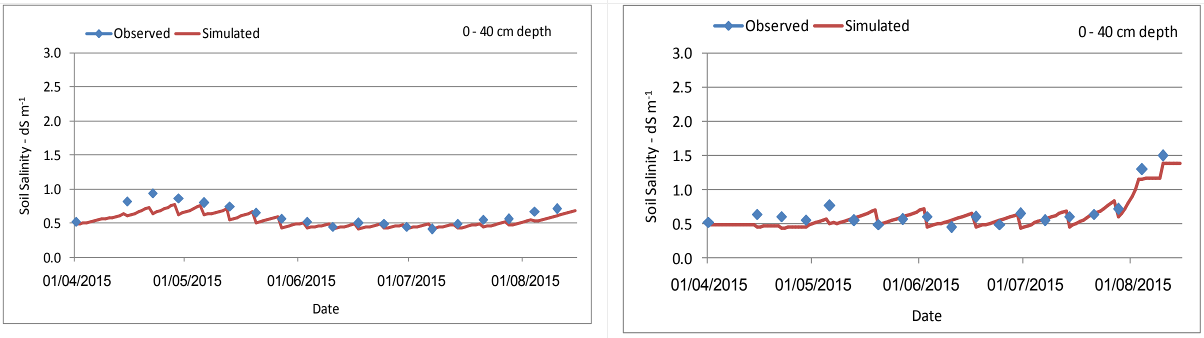
DIS, 100% FI DIS, PRD

Figure 9. Observed and simulated soil salinity for different treatments without organic mulch (0 – 40 cm soil depth), 2015



FIS, 100% FI (Calibration treatment)

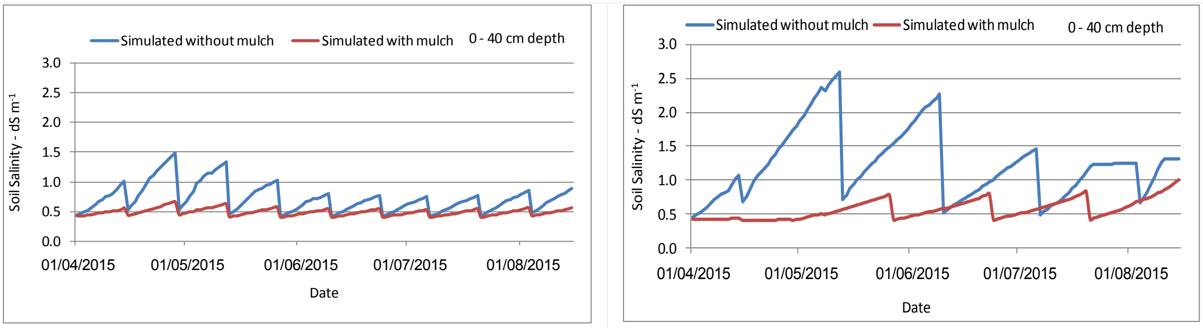
FIS, PRD



DIS, 100% FI

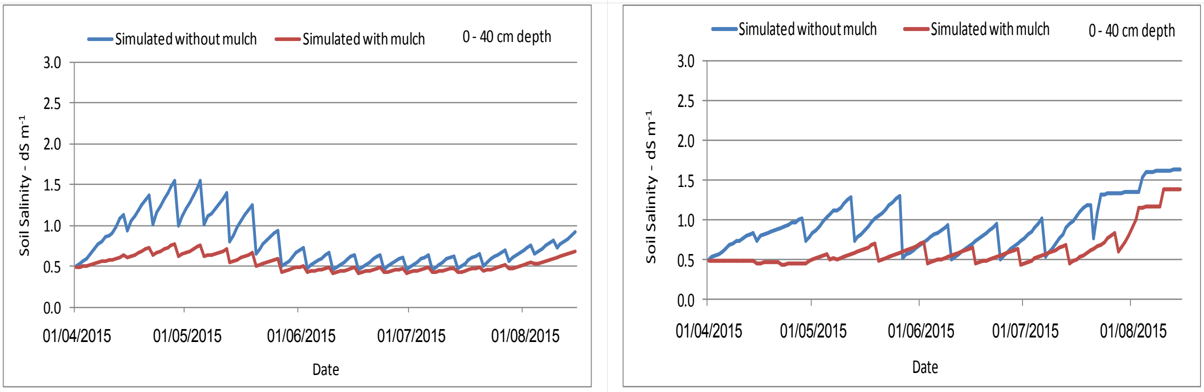
DIS, PRD

Figure 10. Observed and simulated soil salinity for different treatments with organic mulch (0 – 40 cm soil depth), 2015



FIS, 100% FI

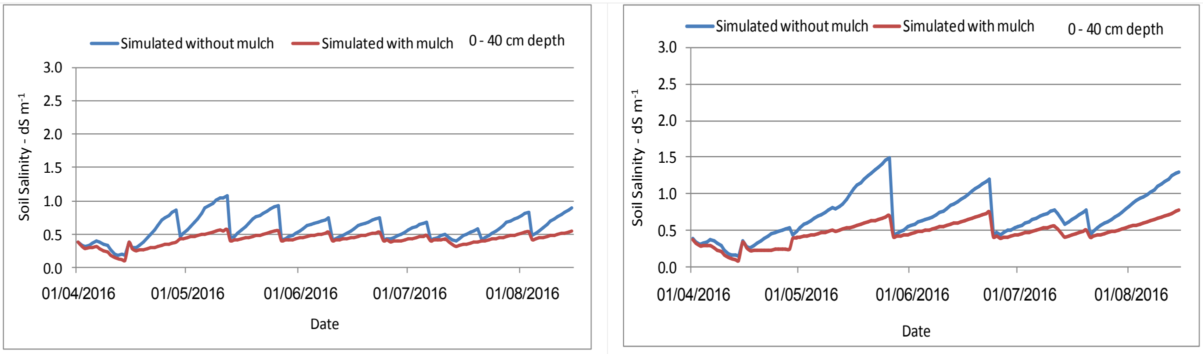
FIS, PRD



DIS, 100% FI

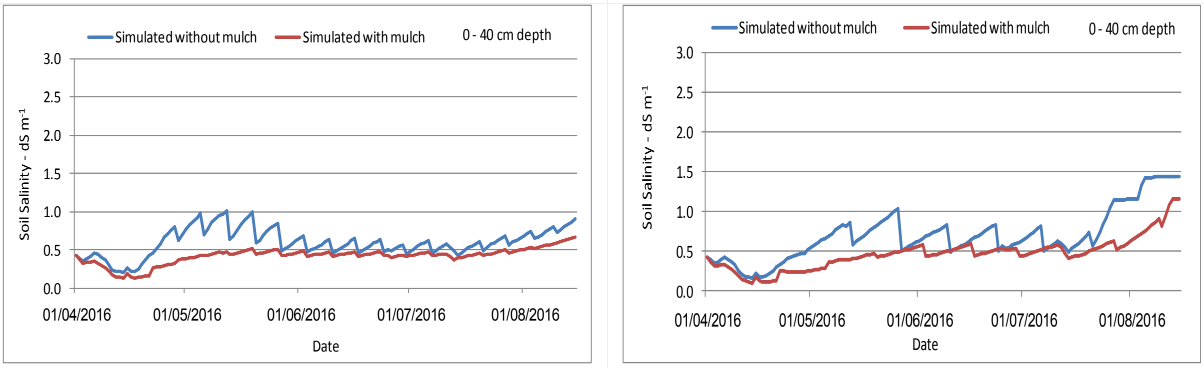
DIS, PRD

Figure 11. Simulated soil salinity for different treatments with (bottom) and without (top) organic mulch (0 -40 cm soil depth 2015



FIS, 100% FI

FIS, PRD

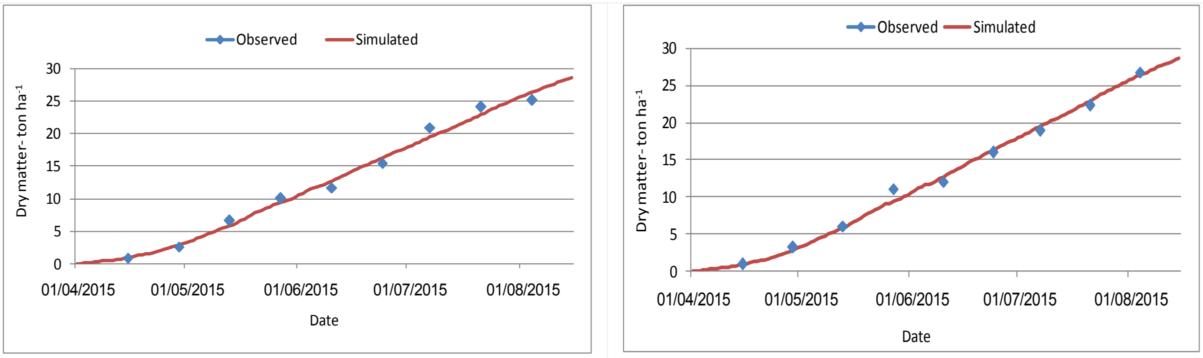


DIS, 100% FI	DIS, PRD

Figure 12. Simulated soil salinity for different treatments with (bottom) and without (top) organic mulch (0 -40 cm soil depth, 2016

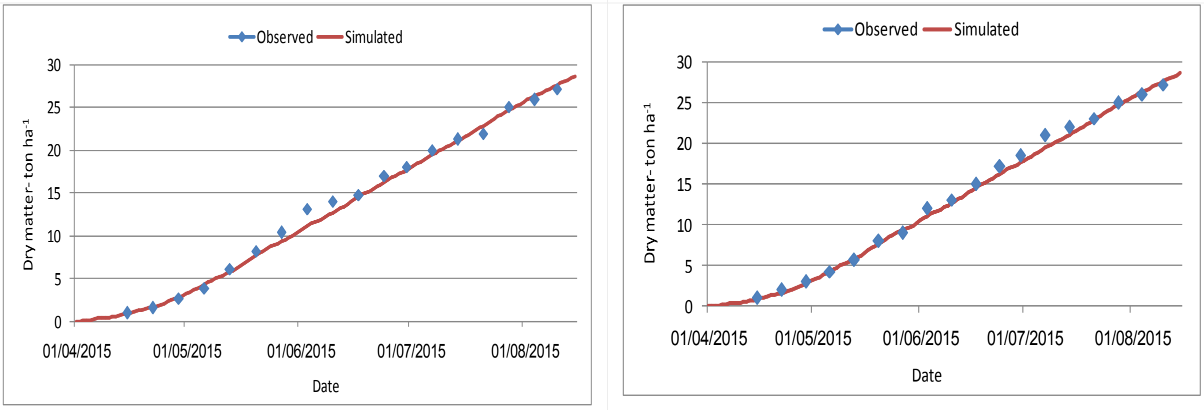
Dry matter

The time series of observed and simulated dry matter under different treatments for the maize were simulated, 100% FI (Calibration treatment) and PRD were tested under FIS and DIS for 2015 and 2016 season. Observed and simulated dry matter for different treatments without organic mulch for 2015 are shown as examples in Figures 13 and Observed and simulated dry matter for different treatments with organic mulch for 2016 are shown as examples in Figures 14. There were no significant differences between dry matter values under all treatments during the two seasons, 2015 and 2016, but there were significant differences between harvest index values under all treatments during the two seasons 2015 and 2016 (Tables VII and VIII). The observed and the simulated dry matters were in good agreement at all stages for all treatments. The correlation analysis between the observed and the simulated dry matter shows that the model was able to simulate the total dry matter with R^2 of 0.99 for all treatments during the two seasons 2015 and 2016.



FIS, 100% FI (Calibration treatment)

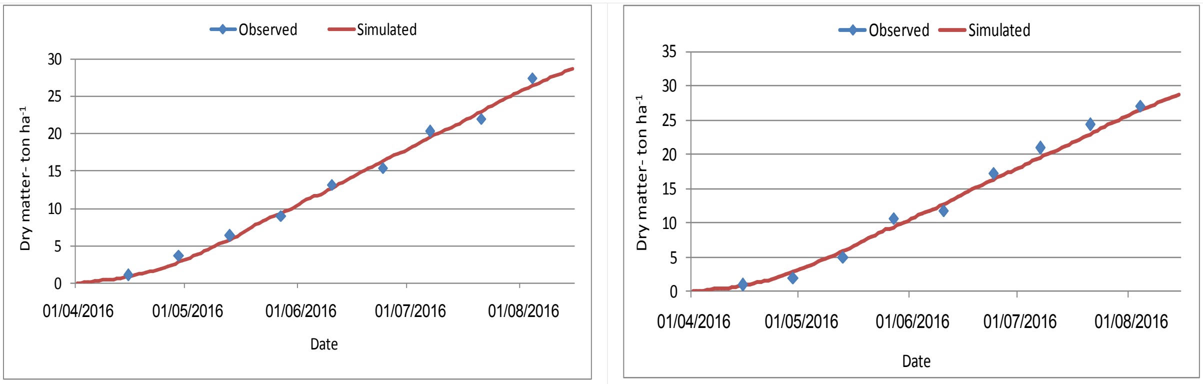
FIS, PRD



DIS, 100% FI

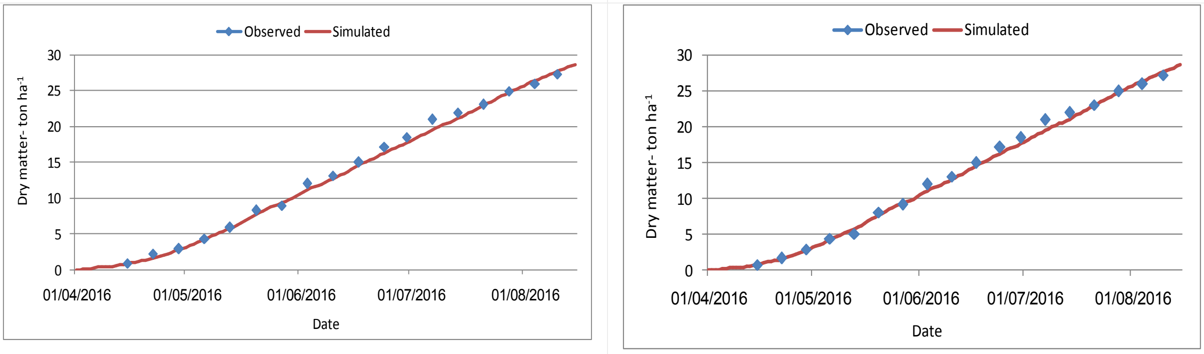
DIS, PRD

Figure 13. Observed and simulated dry matter for different treatments without organic mulch, 2015



FIS, 100% FI (Calibration treatment)

FIS, PRD



DIS, 100% FI

DIS, PRD

Figure 14. Observed and simulated dry matter for different treatments with organic mulch, 2016

Crop yield

The main goal from this study was to identify the best irrigation system, irrigation strategy and the impact of applying organic mulch on maize yield production.

Table VII and Figure 15 show the impact of irrigation systems, deficit irrigation and organic mulching on the yield of maize during 2015 and Table VIII and figure 16 show the yield of maize during 2016.

There was a negative impact on the yield by reducing the amount of irrigation water under FIS and DIS under both with and without organic mulch treatments in both seasons 2015 and 2016 but there was a positive impact with PRD strategy under FIS and DIS specially with using organic mulching.

The negative impact on the yield by reducing the amount of irrigation water under the deficit irrigation while observing a positive impact of PRD under organic mulch, is perhaps due to two reasons, first of all, the beneficial impact of PRD strategy [(PRD involves alternate watering to each side of the plant root system, this strategy induces a mild water stress to the plant leading to partial closure of stomata and reduction in transpiration losses without significantly affecting the photosynthesis and yield. PRD has been found to be a promising strategy in several crops (Kang and Zhang, 2004)] and the second reason was the importance of organic mulching in reducing of evaporation rate, hence, increasing water availability in the root zone and decreasing the salt concentration in the root zone.

In general, the statistical analysis indicated that there were significant differences between crop yield values under all treatments during the two seasons 2015 and 2016 and the highest value of yield was under (Drip, PRD with mulching).

The observed and the simulated yields were in good agreement at all stages for all treatments. The correlation analysis between the observed and the simulated yield shows that the model was able to simulate the yield with R^2 of 0.996 for all treatments during the two seasons 2015 and 2016 as shown in figure 17.

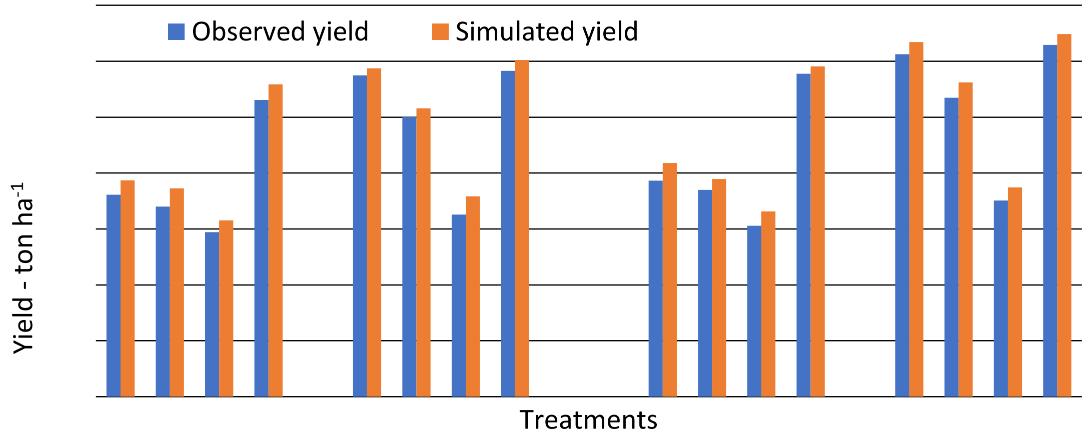


Figure 15. Observed and simulated yield for all treatments for seasons 2015 where WOM: without mulch and WM: with mulch

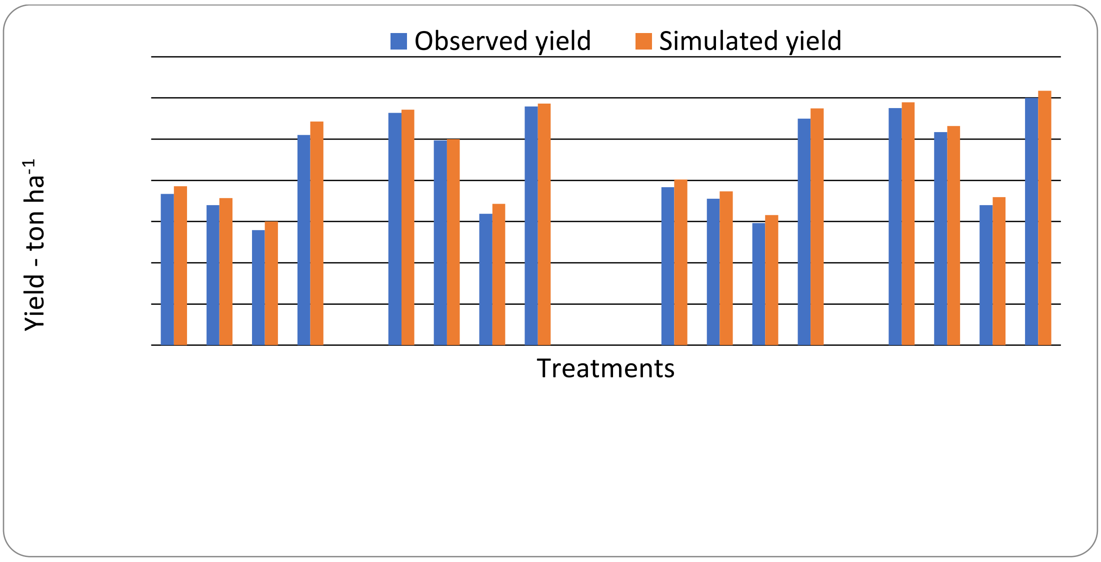


Figure 16. Observed and simulated yield for all treatments for seasons 2016 where WOM: without mulch and WM: with mulch

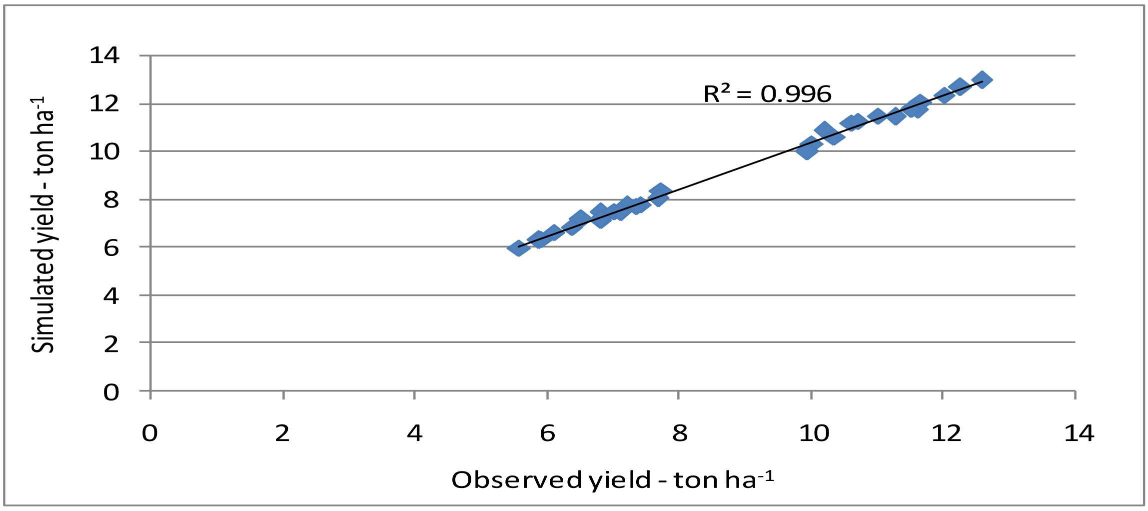


Figure 17. Observed versus simulated yield for all treatments for seasons 2015 and 2016

Water productivity

Water productivity is one of the goals for this study. The water productivity was calculated as the amount of grain yield produced in kg per cubic meter of irrigation water applied. Total water volume (Irrigation and Rainfall) was 1130 mm season^{-1} and 1180 mm season^{-1} for furrow irrigation system for 2015 and 2016, respectively and 523 mm season^{-1} for drip irrigation system for both seasons 2015 and 2016. WP was affected by the same trend of yield values as shown in figure 18 and 19. The highest values of WP occurred under DIS by PRD strategy using organic mulch.

The correlation analysis between the observed and the simulated water productivity showed a good agreement with R2 of 0.998 for all treatments during the two seasons (Figure 20).

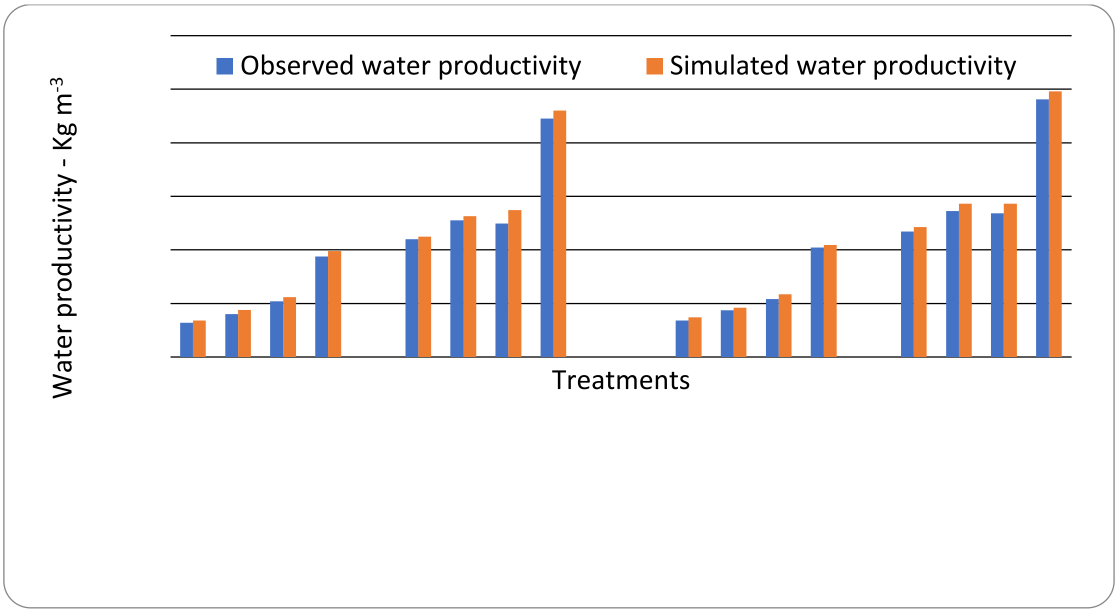


Figure 18. Observed and simulated water productivity for all treatments for seasons 2015 where WOM: without mulch and WM: with mulch

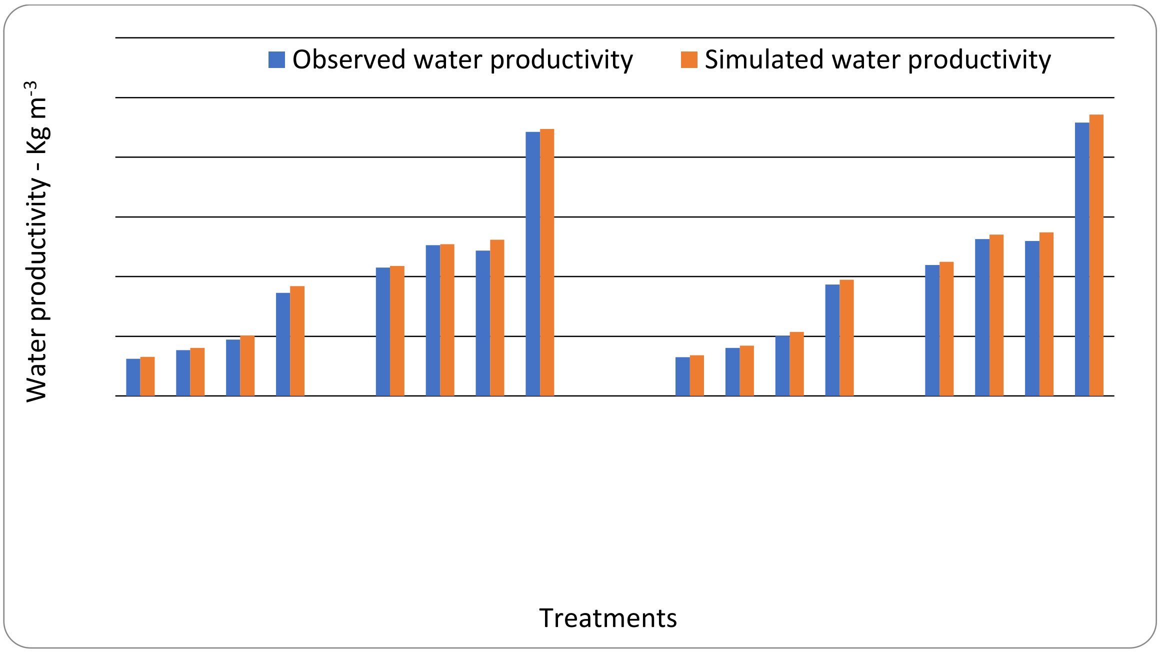


Figure 19. Observed and simulated water productivity for all treatments for seasons 2016 where WOM: without mulch and WM: with mulch

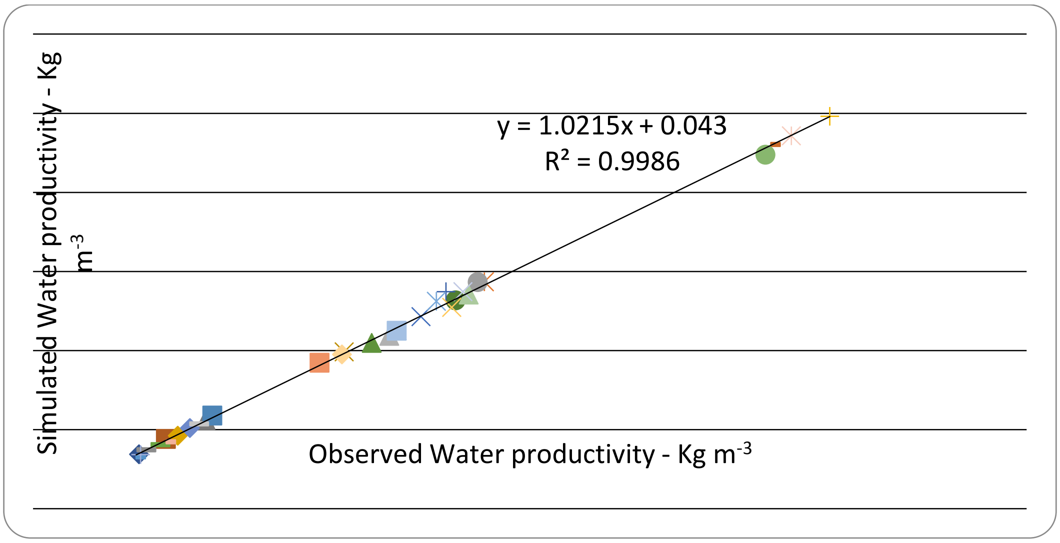


Figure 20. Observed vs simulated water productivity for all treatments for seasons 2015 and 2016

Table VIII. Impact of irrigation systems, irrigation strategy and organic mulching on Harvest Index, yield and water productivity of maize during 2015

Irrigation systems	Deficit irrigation	Mulching	HI	Observed yield, t ha^{-1}	Simulated yield, t ha^{-1}	% Relative error	Irrigation + Rainfall, m^3	Observed water productivity, kg m^{-3}	Simulated water productivity, kg m^{-3}
Furrow Irrigation System	100% FI	WOM	0.27	7.22 i	7.74	-7.2	1130	0.64	0.69
		WM	0.29	7.73 g	8.36	-8.2	1130	0.68	0.74
	75% FI	WOM	0.26	6.80 k	7.45	-9.6	847	0.80	0.88
		WM	0.27	7.40 h	7.78	-5.1	847	0.87	0.92
	50% FI	WOM	0.22	5.88 n	6.31	-7.3	565	1.04	1.12
		WM	0.23	6.11 m	6.63	-8.5	565	1.08	1.17
	PRD	WOM	0.39	10.6 e	11.18	-5.4	565	1.88	1.98
		WM	0.41	11.6 d	11.82	-2.3	565	2.05	2.09
Drip Irrigation System	100% FI	WOM	0.41	11.5 d	11.75	-2.2	523	2.20	2.25
		WM	0.44	12.3 b	12.68	-3.5	523	2.34	2.42
	75% FI	WOM	0.36	10.0 f	10.32	-3.1	392	2.55	2.63
		WM	0.39	10.7 e	11.24	-5.1	392	2.73	2.87
	50% FI	WOM	0.25	6.52 l	7.17	-10.0	262	2.49	2.74
		WM	0.26	7.02 j	7.49	-6.7	262	2.68	2.86
	PRD	WOM	0.24	11.7 c	12.04	-3.3	262	4.46	4.60
		WM	0.45	12.6 a	12.97	-3.1	262	4.81	4.96
LSD $_{\text{at 5\%}}$				0.095					

FI: full irrigation, PRD: partial root drying, WOM: without organic mulch, WM: with mulch, HI: harvest index, Means followed by the same letter in a column are not statistically different, means with different letters under the columns yield are statistically different at 5% level of significance.

Table IX. Impact of irrigation systems, deficit irrigation and organic mulching by rice straw on Harvest Index, yield and water productivity of maize during 2016

Irrigation systems	Deficit irrigation	Mulching	HI	Observed yield, t ha^{-1}	Simulated yield, t ha^{-1}	% Relative error	Irrigation + Rainfall, m^3	Observed water productivity, kg m^{-3}	Simulated water productivity, kg m^{-3}
Furrow Irrigation System	100% FI	WOM	0.27	7.34 i	7.72	-5.2	1180	0.62	0.65
		WM	0.28	7.67 g	8.04	-4.8	1180	0.65	0.68
	75% FI	WOM	0.25	6.80 k	7.14	-5.0	884	0.77	0.81
		WM	0.26	7.11 h	7.47	-5.1	884	0.80	0.84
	50% FI	WOM	0.21	5.58 n	6.00	-7.5	590	0.95	1.02
		WM	0.22	5.92 m	6.32	-6.8	590	1.00	1.07
	PRD	WOM	0.38	10.2 e	10.9	-6.5	590	1.73	1.84
		WM	0.40	11.0 d	11.5	-4.5	590	1.87	1.95
Drip Irrigation System	100% FI	WOM	0.40	11.3 d	11.4	-1.4	524	2.15	2.18
		WM	0.41	11.5 b	11.8	-2.3	524	2.20	2.25
	75% FI	WOM	0.35	9.94 f	10.0	-0.6	393	2.53	2.54
		WM	0.37	10.3 e	10.6	-2.8	393	2.63	2.70
	50% FI	WOM	0.24	6.38 l	6.86	-7.5	262	2.44	2.62
		WM	0.25	6.80 j	7.18	-5.6	262	2.60	2.74
	PRD	WOM	0.41	11.6 c	11.7	-1.1	262	4.42	4.47
		WM	0.43	12.0 a	12.4	-2.9	262	4.58	4.71

LSD at 5%		0.092					

FI: full irrigation, PRD: partial root drying, WOM: Without Organic Mulch, WM: With Mulch, HI: Harvest Index, Means followed by the same letter in a column are not statistically different, means with different letters under the columns yield are statistically different at 5% level of significance.

CONCLUSION

This study aimed at investigating the most suitable irrigation system, irrigation strategy and the impact of organic mulching on maize through field and modelling study using SALTMED model.

There were differences between harvest index values under all treatments during the two seasons and that led to significant differences in yields. The observed and the simulated dry matters were in good agreement at all stages for all treatments. The correlation analysis between the observed and the simulated dry matter shows that the model was able to simulate the total dry matter with R^2 of 0.99 for all treatments during the two seasons 2015 and 2016.

In general, the statistical analysis indicated that there were significant differences between crop yield values under all treatments during the two seasons 2015 and 2016 and the highest value of yield of maize was under drip irrigation with PRD as strategy and using the organic mulching. The observed and the simulated yield were in good agreement at all stages for all treatments. The correlation analysis between the observed and the simulated yield shows that the model was able to simulate the yield with R^2 of 0.996 for all treatments during the two seasons 2015 and 2016

Water productivity, WP of maize followed the same trend of yield values. The highest values of WP occurred under drip irrigation with PRD as strategy and using the organic mulching. The correlation analysis between the observed and the simulated water productivity showed a good agreement with R^2 of 0.998 for all treatments during the two seasons.

In summary, the field and modelling results, indicated that this study recommends the use of PRD technique by drip irrigation system and using organic mulch as a good management practice for irrigation to save fresh water and reduce the salt concentration in the root zone.

ACKNOWLEDGMENT

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REFERENCES

Afzal M, Battilani A, Solimando D, Ragab R. 2016. Improving water resources management using different irrigation strategies and water qualities: Field and modelling study. *Agricultural Water Management* 176: 40–54.

Allen RG., Pereira LS., Raes D., Smith M. 1998. *Guidelines for computing crop water requirements, Crop Evapotranspiration*, FAO Irrigation and Drainage Paper No. 56. Rome, Italy.

Camp CR. 1998. Subsurface drip irrigation: A review. *Trans. ASAE* 41, 1353–1367.

Davies WJ, Hartung W. 2004. Has extrapolation from biochemistry to crop functioning worked to sustain plant production under water scarcity? In: *Proc. Fourth Intl. Crop Sci. Congr*. p. 1–14.

Eid AR, Bakry AB, Taha MH. 2013. Effect of pulse drip irrigation and mulching systems on yield, quality traits and irrigation water use efficiency of soybean under sandy soil conditions. *Agricultural Sciences*, Vol.4, No.5, 249-261.

El-Habbasha SF, Okasha EM, Aabdelraouf RE, Mohammed ASH. 2014. Effect of Pressured Irrigation Systems, Deficit Irrigation and Fertigation Rates on Yield, Quality and Water use Efficiency of Groundnut. *Int.J. ChemTech Res.* 2014-15, 07(01),pp 475-487.

El-Shafie AF, Osama MA, Hussein MM, El-Gindy AM, Ragab R. 2016. Predicting soil moisture distribution, dry matter, water productivity and potato yield under a modified gated pipe irrigation system: SALTMED model application using field experimental data. *Agricultural Water Management*. doi: http://dx.doi.org/10.1016/j.agwat.2016.02.002.

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

Food and Agriculture Organization of the United Nations (FAO). 1998. *FAO 56* http://www.fao.org/docrep/X0490E/X0490E00.htm.

Golabi M, Naseri AA, Kashkuli HA. 2009. Evaluation of SALTMED model performance in irrigation and drainage of sugarcane farms in Khuzestan province of Iran. *J Food Agric Environ* 7, 874–880.

Hirich A, Fatnassi H, Ragab R, Choukr-Allah R. 2016. Prediction of Climate Change Impact on Corn Grown in the South of Morocco Using the Saltmed Model. *Irrigation and Drainage* **65**(1), 9-18. doi: 10.1002/ird.2002.

Hirich A., Choukr-Allah R, Ragab R, Jacobsen SE, El Youssfi L, Elomari H. 2012. The SALTMED model calibration and validation using field data from Morocco. J Mater Environ Sci3 (2):342–359 in South Italy. *Irrigation and Drainage,* 64, 59-68.

James LG. 1988. *Principles of farm irrigation system design*. John Willey & sons. Inc., Washington State University. 73, Washington, USA. 152-153, 350-351.

Kang SZ, Zhang JH. 2004. Controlled alternate partial root-zone irrigation: its physiological consequences and impact on water use efficiency ,*J. Exp. Bot.* 55: 2437–2446.

Montenegro SG, Montenegro A, Ragab R. 2010. Improving agricultural water management in the semi-arid region of Brazil: experimental and modelling study. Irrig Sci 28, 301–316.

Pulvento C, Ariccardi M, Lavini A, D'Andria R, Ragab R. 2015. Parameterization and field validation of SALTMED Model for grain amaranth tested in South Italy. *Irrigation and Drainage* 64,59-68.

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. *Irrigation and Drainage*, 62, 229-238.

Ragab R. 2015. Integrated water management tool for water, crop, soil and N-fertilizers: The SALTMED model. Irrigation and drainage, 64, 1-12.

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. *Irrigation and Drainage* 64, 13-28.

Ragab R, Malash N, Abdel Gawad G, 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. *Agric Water Manage* 78, 67–88.

Ragab R, Malash N, Abdel Gawad G, 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. *Agric 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. *Irrigation and Drainage* 64, 41-49.

Silva L, Ragab R, Duarte I, Lourenç E, Simões N, Chaves MM., 2013. Calibration and validation of SALTMED model under dry and wet year conditions using chickpea field data from Southern Portugal. Irrig Sci. DOI 10.1007/s00271-012-0341-5. *Irrigation Science*, 31(4), 651-659.