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IS THE PARTIAL ROOT DRYING IRRIGATION METHOD SUITABLE FOR SANDY SOILS?

FIELD EXPERIMENT AND MODELLING USING SALTMED MODEL[†]

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ABSTRACT

This study investigated the impact of Regulated Deficit Irrigation (RDI) and Partial Root Drying (PRD) on soil moisture, dry matter, and yield and water productivity of maize grown in sandy soil in Egypt. The experiment was conducted in 2013 and included eight treatments of RDI and PRD. Four RDI treatments [100%Full Irrigation requirement, FI, (control), 80% FI, 60% FI and 40% FI] and four PRD treatments [100% PRD, 80% PRD, 60% PRD and 40% PRD] were conducted. The experimental and simulated results using SALTMED model showed that maize yields obtained under RDI were higher than those obtained under PRD, this may be due to the fact that the soil is sandy soil and the PRD treatment received relatively less irrigation water. The latter perhaps have led to a smaller and narrower wetted soil volume within the root zone and possibly some of the water was partly lost below the root zone due to the high infiltration rate commonly associated with sandy soils. The correlation between the observed and simulated grain yield showed that the SALTMED model was able to simulate grain yield and water productivity for all treatments with high accuracy producing an average R^2 of 0.98 and 0.95, respectively.

KEY WORDS: regulated deficit irrigation; RDI; partial root drying; PRD; SALTMED modelling; soil moisture; irrigation; yield; water productivity; maize.

[†] La méthode d'irrigation par séchage partiel des racines est-elle adaptée aux sols sableux? Expérience sur le terrain et modélisation à l'aide du modèle SALTMED

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RÉSUMÉ

Cette étude a étudié l'impact de l'irrigation à déficit régulé (RDI) et du séchage partiel des racines (PRD) sur l'humidité du sol, la matière sèche et le rendement et la productivité de l'eau du maïs cultivé dans les sols sableux en Egypte. L'expérience a été menée en 2013 et comprenait huit traitements de RDI et de PRD. Quatre traitements RDI [100% irrigation requise, FI, (contrôle), 80% FI, 60% FI et 40% FI] et quatre traitements PRD [100% PRD, 80% PRD, 60% PRD et 40% PRD] étaient menés. Les résultats expérimentaux et simulés utilisant le modèle SALTMED ont montré que les rendements de maïs obtenus sous RDI étaient plus élevés que ceux obtenus sous PRD, ceci peut être dû au fait que le sol est un sol sableux et que le traitement PRD a reçu relativement moins d'eau d'irrigation. Ces derniers ont peut-être conduit à un volume de sol mouillé plus petit et plus étroit dans la zone racinaire et une partie de l'eau a été partiellement perdue en dessous de la zone racinaire en raison du taux d'infiltration élevé associé aux sols sableux. La corrélation entre le rendement en grains observé et simulé a montré que le modèle SALTMED était capable de simuler le rendement grainier et la productivité de l'eau pour tous les traitements avec une grande précision produisant un R2 moyen de 0,98 et 0,95, respectivement.

MOTS CLÉS: irrigation à déficit régulé; RDI; séchage partiel des racines; PRD; Modélisation SALTMED; humidité du sol; irrigation; rendement; productivité de l'eau; maïs.

INTRODUCTION

Food demand across the world has been significantly increased due to the increased food demand for the growing population. Irrigation water has the main share of the fresh water consumption. Around 280 million hectares of agricultural land is irrigated using freshwater that provides around 60% of total food production worldwide (Tilman *et al.*, 2002). 60% of the world’s food is produced on irrigated land and irrigation water accounts for over two thirds of the global water consumption (Letey *et al.*, 2011). The agricultural water consumption has increased fivefold since the 1940’s and now accounts for 70 to 80% of the world fresh water use (Ragab *et al.*, 2015). The availability of the water resources is not only under threat due to the increase in water demand for agriculture but also due to climate variability. Therefore, the gap between water supply and demand is expected to increase. In several parts of the world, climate variability is expected to reduce water availability for agriculture and subsequently for crop yield. Therefore, it is very important to double the food production as the world population is expected to reach 9 billion

(Ragab *et al*., 2015). Regions with limited for a sustainable agriculture (World Water Assessment Programme (WWAP), 2012).

Deficit irrigation (DI) including partial root drying (PRD) are considered good water-saving irrigation strategies (Kang and Zhang, 2004). 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). 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 RDI and PRD could be promising irrigation strategies to apply on maize grown in sandy soils of Egypt.

Simulation models with the ability to simulate crop growth and yield under different irrigation managements are considered to be good tools to improve water use efficiency and productivity. These models can also simulate crop growth in regions where some crops have not been grown before or when the conditions for growing have changed. Sivakumar and Glinni (2002) briefly described a number of crop growth models, however, most of them were single crop models. Some of the models cannot be used for general application. The extension services usually need models that can assist them to take decisions such as what crop or even crop variety to use, best time to sow and harvest, when and how much to irrigate, and what yield is to expect under certain irrigation system or strategy when using a specific water quality. Therefore, it is preferable to have models with a more holistic approach that account for water, crop, climate, and soil and field management (Ragab, 2015) and be able to simulate different crops. The SALTMED model (Ragab, 2002; Ragab, 2010; Ragab, 2015; Ragab *et al*., 2005a, b) has been developed for such generic applications and has proved its ability to simulate several crops and agricultural situations. It accounts for different irrigation systems, irrigation strategies, different water qualities, different crop and soil types, N-fertilizer applications, fertigation, impact of abiotic stresses such as salinity, temperature, drought and the presence of shallow groundwater and a drainage system. The model allows simultaneous simulation of 20 fields each of which would have a different irrigation system, irrigation strategy, crop, soil, and N-fertilizer. The model simulates the dry matter production, crop yield, soil salinity and soil moisture profiles, salinity leaching requirements, soil nitrogen dynamics, nitrate leaching, soil temperature, water uptake, evapotranspiration, groundwater level and its salinity, and drainage flow. The model was calibrated and validated with field data Flowers *et al*. (2005), Ragab *et al*. (2005a, b), Ragab *et al*. (2015), Golabi *et al*. (2009), Hirich *et al*. (2012) and Montenegro *et al*. (2010).

Therefore, the objectives of this study were, to investigate the suitability of deficit irrigation strategies by regulated deficit irrigation (RDI) and partial root drying (PRD) for sandy soils, to study the impact of RDI and PRD on soil moisture, total dry matter and crop yield and water productivity of maize grown under arid Egyptian conditions through field experiments and modelling using SALTMED model.

MATERIALS AND METHODS

The experimental site

The field experiments were carried out during 2013. Maize crop was sown at the research farm of the National Research Centre (NRC) in Nubaryia Region, Al Buhayrah Governorate, Egypt (latitude 30° 30’ 1.4’’ N, longitude 30° 19’ 10.9’’ E, and 21 m, MSL (mean sea level)). The area has semi-arid climate with cool winters and hot dry summers. The data of maximum and minimum temperature, relative humidity, and wind speed were obtained from in situ local weather station (Figure 1).

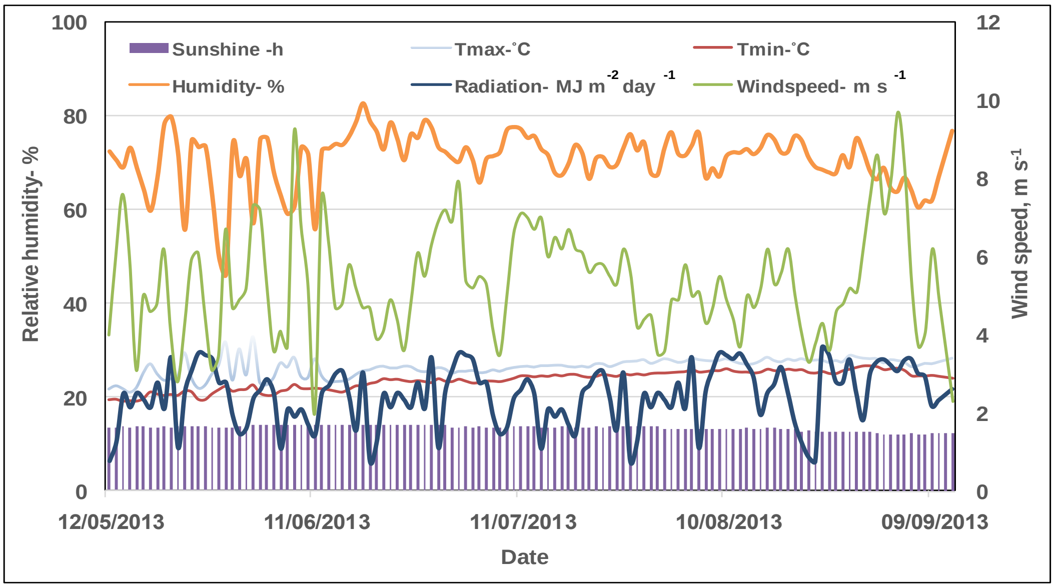


Figure1. Maximum and minimum temperature, relative humidity, Sunshine and wind speed obtained from the weather station in the research farm of National Research Centre (NRC) in Nubaryia region

Some physical and chemical properties of soil and irrigation water

Irrigation water that has been supplied by the irrigation canal had a pH of 7.35 and an average electrical conductivity of 0.41 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 experiment (Table I).

Table I. The main physical and chemical properties of the soil

Physical characteristics					
Soil layer depth (cm)	0–20	20-40	40-60	60-80	80-120
Texture	Sandy	Sandy	Sandy	Sandy	Sandy
Course sand (%)	47.8	56.7	36.8	35.8	33.4
Fine sand (%)	49.8	39.6	59.4	60.1	62.4
Silt+ clay (%)	2.49	3.72	3.84	4.12	4.32
Bulk density (t m^{-3})	1.69	1.68	1.67	1.69	1.65
Chemical characteristics					
$EC_{1:5}$ (dS m^{-1})	0.35	0.32	0.44	0.45	0.53
pH (1:2.5)	8.7	8.8	9.3	9.0	9.2
Total $CaCO_3$ (%)	7.02	2.34	4.68	5.01	5.20
Organic matter (%)	0.65	0.40	0.25	0.24	0.21

Experimental design

The planting and harvesting dates for maize were 12th of May 2013 and 12th of September 2013, respectively. The growth period for maize crop was 122 days. The experimental design included eight irrigation treatments: 100% full irrigation (FI) as control treatment and three DI treatments (80%FI, 60% FI and 40% FI), each combined with two irrigation application strategies (PRD and RDI)**.** For the RDI irrigation treatments, the driplines were placed next to the plants; whereas, for the PRD treatments double driplines were used with the plants placed in the mid-point between the two driplines. In total there were 24 plots, covering the 8 treatments with three replicate per treatment. The area of each plot was 84 $m^{2.}$. More details about RDI and PRD can be found in Afzal *et al*. (2016). The statistical design of this experiment was a split design. Profile probe access tubes were placed in each plot to measure the soil moisture. The experimental design is given in Figure 2.

Irrigation requirements of the maize

The irrigation requirements were based on the reference evapotranspiration equation of Penman-Monteith using daily data of the in situ weather station. Total water volumes for each treatment are reported in Table II.

Table II. Total water volumes for each treatment

Irrigation treatments		Irrigation no.	Irrigation intervals	Irrigation volumes	Rainfall
Treatment definition	Short definition	n	n	m^3 ha^{-1}	m^3 ha^{-1}
100% Fully Irrigated (FI)	100% FI	55	2	5060	0
100% FI in initial growth stage + 80% FI for whole season	80% FI	55	2	4080	0
100%FI in initial growth stage + 60% FI for whole season	60% FI	55	2	3090	0
100%FI in initial growth stage + 40% FI for whole season	40% FI	55	2	2110	0
100%FI in initial growth stage + PRD (50% FI for whole season)	PRD	55	2	2600	0
100%FI in initial growth stage + 80% PRD for whole season	80% PRD	55	2	2110	0
100%FI in initial growth stage + 60% PRD for whole season	60% PRD	55	2	1620	0
100%FI in initial growth stage + 40% PRD for whole season	40% PRD	55	2	1130	0

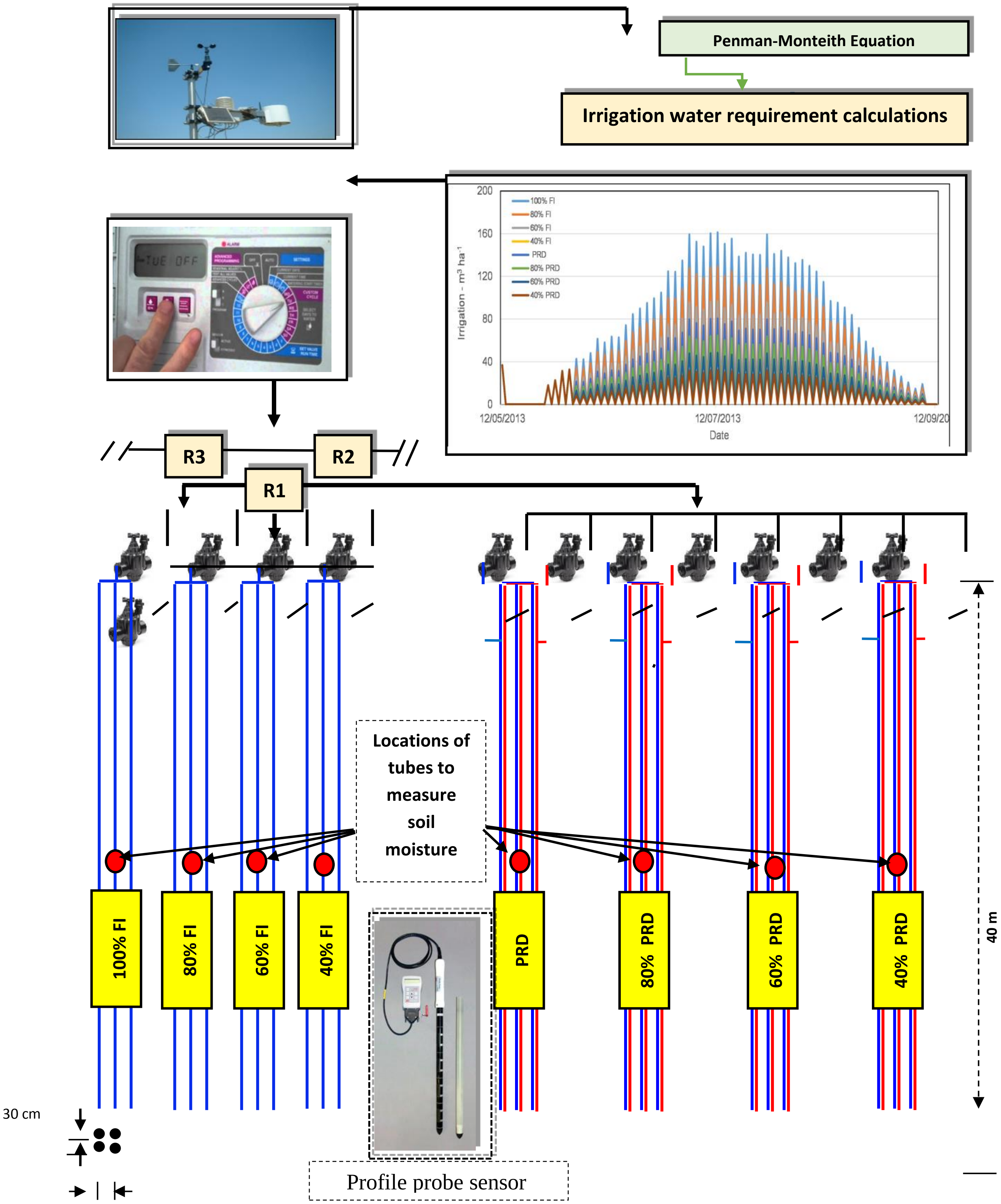


Figure 2. Layout of the experimental design

Model parameters

All the required data for the model calibration and validation were collected during each phase over the crop growing seasons. The soil moisture was measured by the profile probe at five depths: 0-20, 20 – 40, 40 – 60, and 60 - 80 and 80-120 cm depth. All the required climatic data were collected on site from the automatic weather station. The meteorological data required by the model consisted of precipitation, maximum temperature and minimum temperature, the relative humidity, wind speed and net and total radiation. The irrigation system was drip. Dry matter and total leaf area, were obtained at regular intervals. At harvest, a random sample was taken from each plot to determine grain yield. 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 'WP_{maize}' was calculated according to Equation (1), (James, 1988) as follows:

$$WP_{maize} = Ey/Ir \tag{1}$$

Where: WP_{maize} is the water productivity of maize ($kg_{\ maize}\ m^{-3}{}_{water}$), Ey is the economical yield ($kg\ ha^{-1}$); Ir is the amount of applied irrigation water ($m^{3}{}_{water}\ ha^{-1} season^{-1}$).

SALTMED MODEL

SALTMED model was used in this study. A detailed description of the SALTMED model is provided in Ragab (2002), Ragab *et al*. (2005a), Ragab (2015), 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 process

During the calibration, fine tuning of the relevant SALTMED model parameters was carried out against the observed data for the soil moisture, dry matter, and crop yield. In this analysis, 100% FI was selected for the calibration process. For the soil moisture calibration, 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 values was achieved. In addition to the soil parameters, other crop parameters such as the crop coefficient, Kc, which is used to calculate crop evapotranspiration (ETc) and basal crop coefficient, Kcb, that 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 layer as shown in Tables III and IV. After achieving a good fit for the soil moisture, only fine tuning of the photosynthetic efficiency was needed for dry matter and crop yield. During the process of model calibration and validation, three statistical measures for goodness of fit, were used.

The goodness of fit expressions were the root mean square error (RMSE), the coefficient of determination (R^2), and the coefficient of residual mass (CRM). The RMSE values indicate by how much the simulations under or overestimate the measurements.

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

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

The R^2 statistics demonstrate the ratio between the scatter of simulated values to the average value of measurements:

$$\boldsymbol{R^2} = \left\{\frac{\mathbf{1}}{\boldsymbol{N}} \frac{\Sigma(\boldsymbol{y_o} - \boldsymbol{y_{\bar{o}}})(\boldsymbol{y_s} - \boldsymbol{y_{\bar{s}}})}{\boldsymbol{\sigma y_o} - \boldsymbol{\sigma y_s}}\right\} \tag{3}$$

Where: $\boldsymbol{y_{\bar{o}}}$= averaged observed value, $\boldsymbol{y_{\bar{s}}}$ = 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:

$$\boldsymbol{CRM} = \frac{(\Sigma \boldsymbol{y_o} - \Sigma \boldsymbol{y_s})}{\Sigma \boldsymbol{y_o}} \tag{4}$$

The CRM is a measure of the inclination 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 III. Main calibrated and observed input parameters used in the study for maize

Parameter	Developmental stage	Observed	Calibrated
Cultivation dates			
Sowing (date)		12 May	
Harvest (days after sowing)		122	
Growth stage duration, days			
Initial		19	
Development		32	
Middle		40	
Late		30	
Crop inputs			
Crop coefficient, Kc	Initial		0.4
	Middle		1.1
	End		0.8
Transpiration crop coefficient, Kcb	Initial		0.3
	Middle		0.7
	End		0.6
Fraction cover, Fc	Initial	0.1	
	Middle	0.7	
	End	0.5	
Plant height, h (m)	Initial	0.3	
	Middle	1.8	
	End	1.7	
Leaf area index, LAI	Initial	1	
	Middle	5	
	End	4	
Minimum root depth (m)		0	
Maximum root depth (m)		1	
Unstressed crop yield (t h^{-1})		8.54	
Photosynthesis efficiency (g MJ^{-1})			2
Water uptake threshold, %	Initial		0.75
	Middle		0.75
	End		0.75
Harvest index		0.65	

Table IV. Main calibrated and observed input parameters used in the study for sandy soil

Parameter	Observed	Calibrated
Saturated moisture content (m^3m^{-3})	0.30	
Field capacity (m^3 m^{-3})	0.14	
Wilting point (m^3 m^{-3})	0.03	
Lambda pore size index		0.3
Residual water content (m^3 m^{-3})		0.0
Root width/length factor	0.15	
Saturated hydraulic conductivity (mm day^{-1})	3000	
Max. depth for evaporation (mm)		60
Bubbling pressure (cm)		10

RESULTS AND DISCUSSION

Soil moisture

Initially the soil moisture was calibrated with the 100% FI treatment and validated against all the other treatments, 80% FI, 60% FI, and 40% FI, PRD, 80% PRD, 60% PRD and 40%PRD. The model has shown a good fit for all layers 0-20, 20-40, 40-60, and 60-80 and 80-120 cm depth of the simulated soil moisture when compared with the observed soil moisture for RDI and PRD treatments as shown in Figures 3, 4, 5, 6, 7, 8, 9 and 10, respectively. The simulated soil moisture content was slightly lower in the initial and middle period and slightly higher in the late period in comparison to the observed soil moisture. This is mainly due to the high water uptake by the plants in the beginning and during the peak of the growth season. Figures 3, 4, 5, 6, 7, 8, 9 and10 show that, both simulated and observed soil moisture have the same trend through the maize season. Overall the model predicted well the observed data both during the calibration and validation stages. These result 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).

Overall the simulated and the observed soil moistures for all treatments showed strong correlation between the observed the simulated soil moisture with good R^2 values as shown in Table V with an overall average R^2 of 0.87. In general, SALTMED proved its ability to simulate the soil moisture changes under different irrigation treatments.

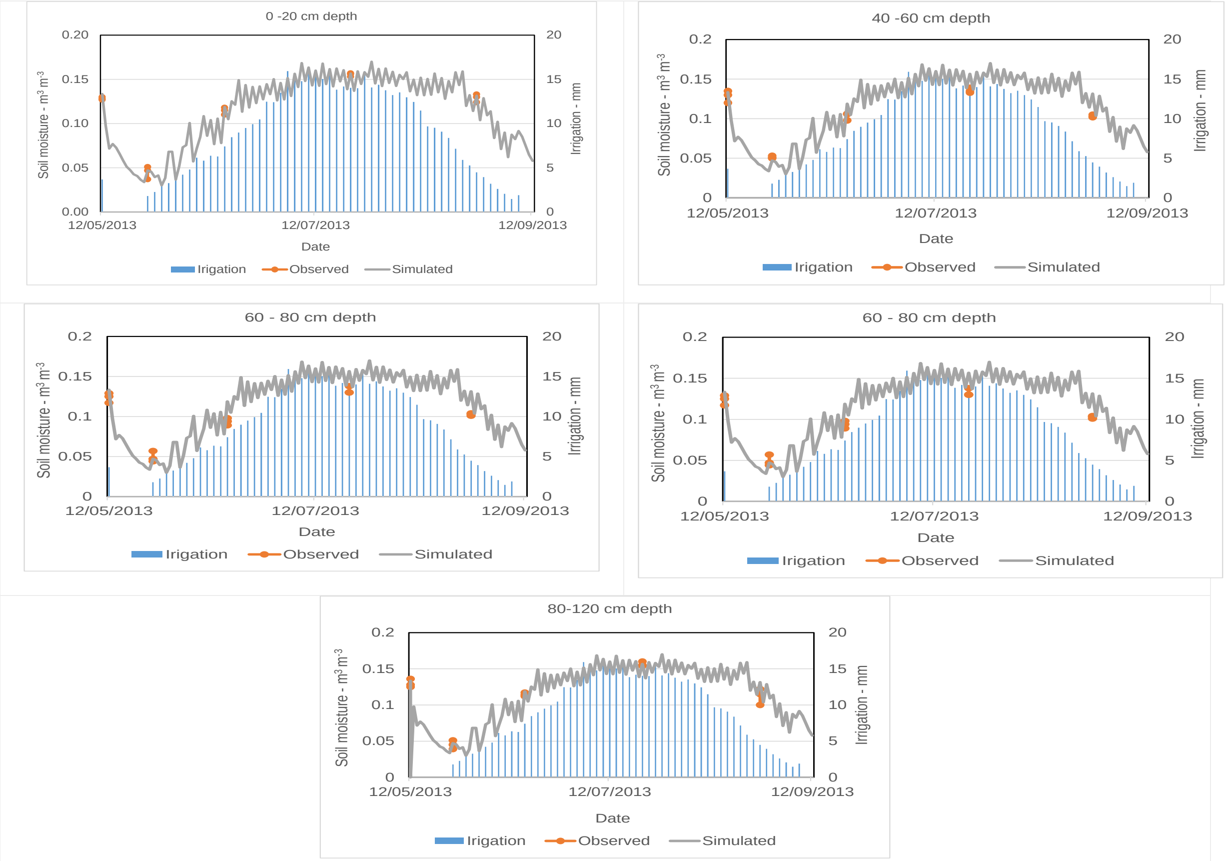
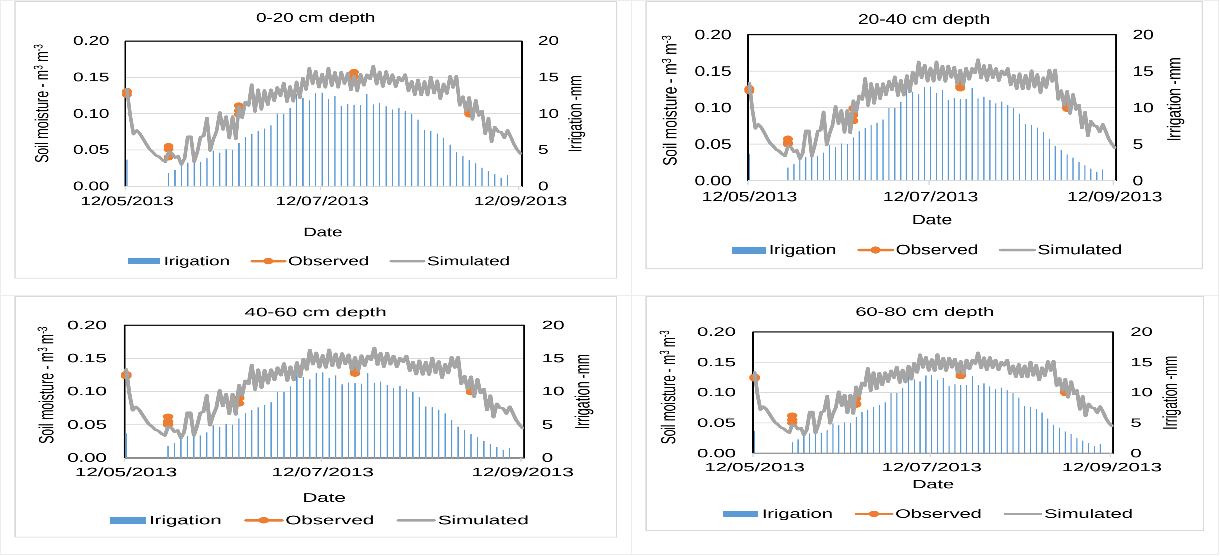


Figure 3.Observed and simulated soil moisture for 0-120 cm depth under 100% Full irrigation



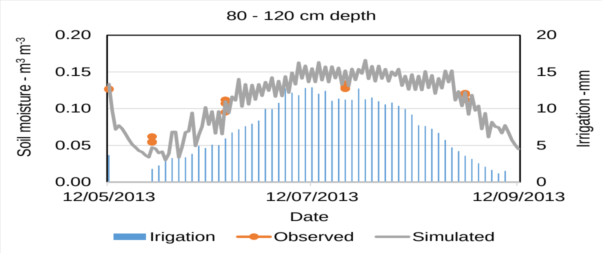


Figure 4. Observed and simulated soil moisture for 0-120 cm depth under 80% Full irrigation

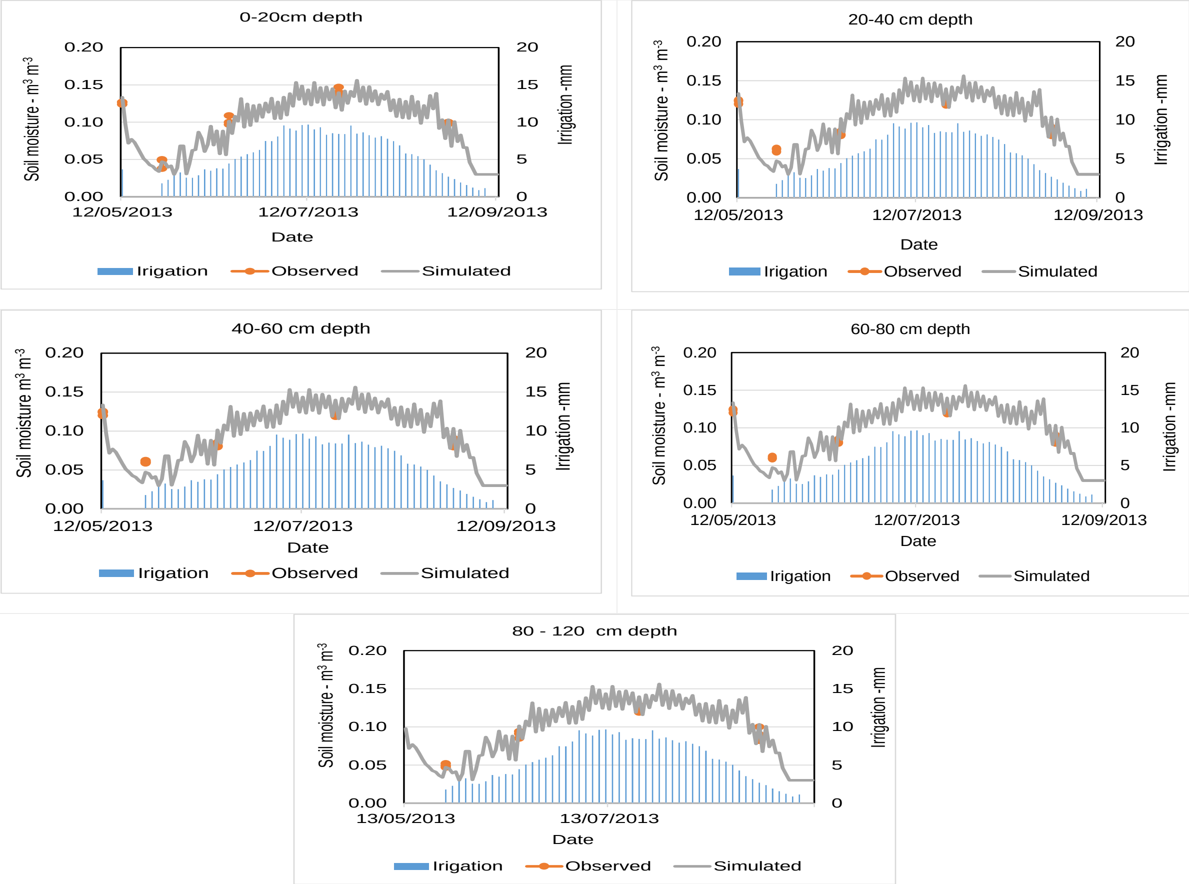
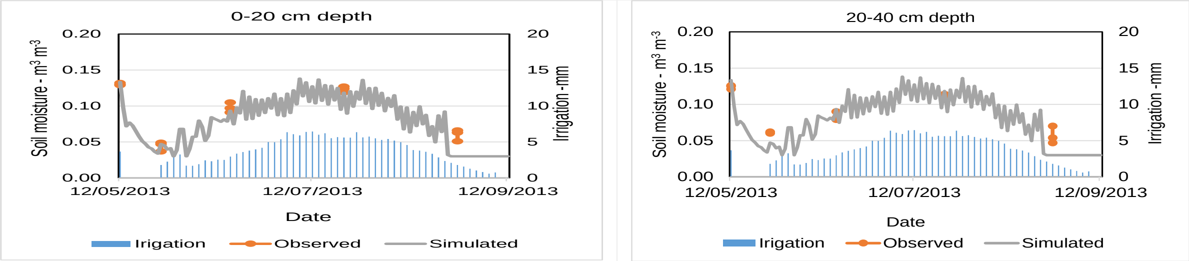


Figure 5. Observed and simulated soil moisture for 0-120cm depth under 60% Full irrigation



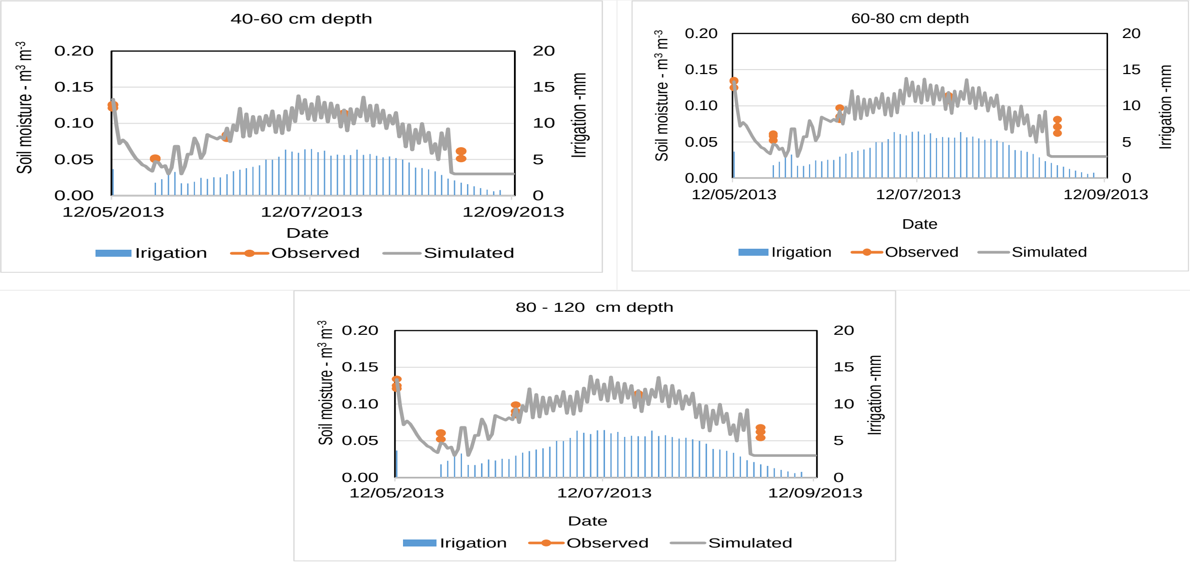


Figure 6. Observed and simulated soil moisture for 0-120 cm depth under 40% Full irrigation

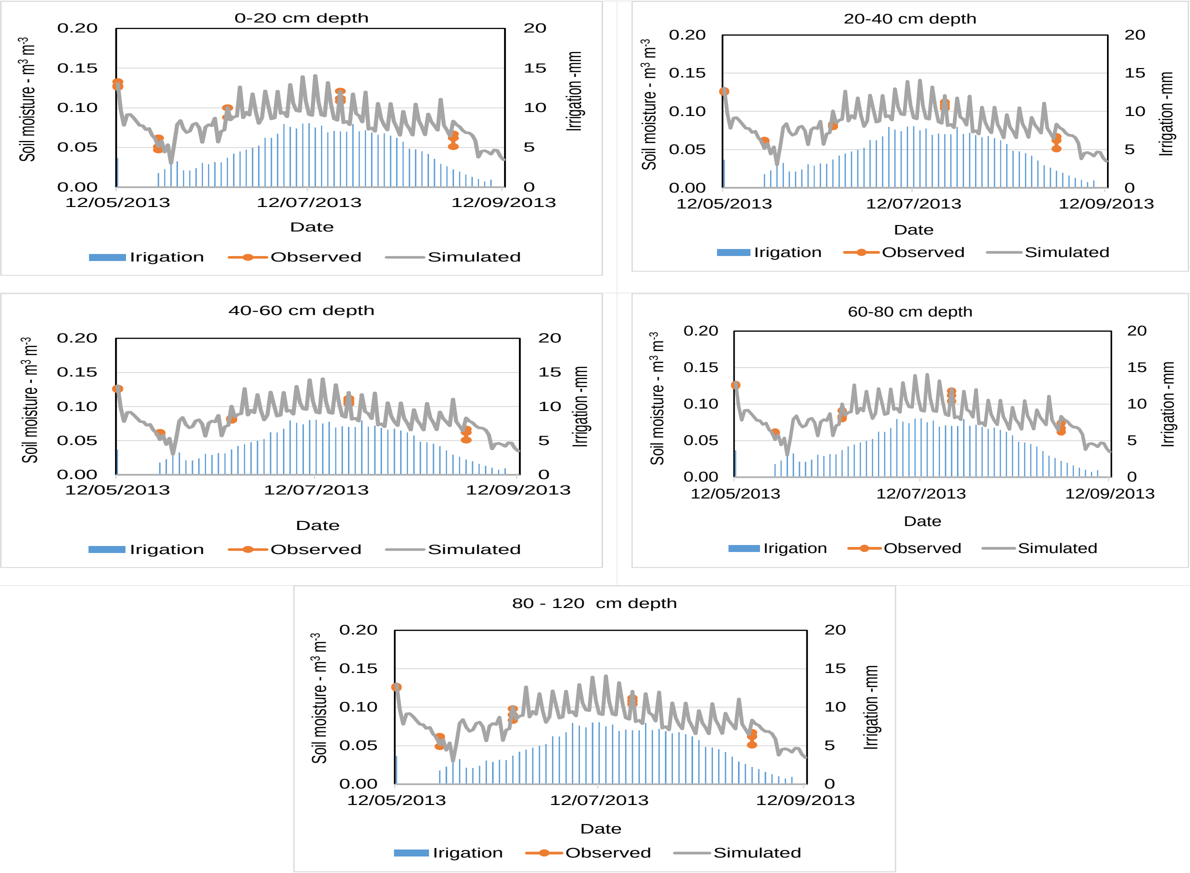


Figure7. Observed and simulated soil moisture for 0-20 cm depth under PRD

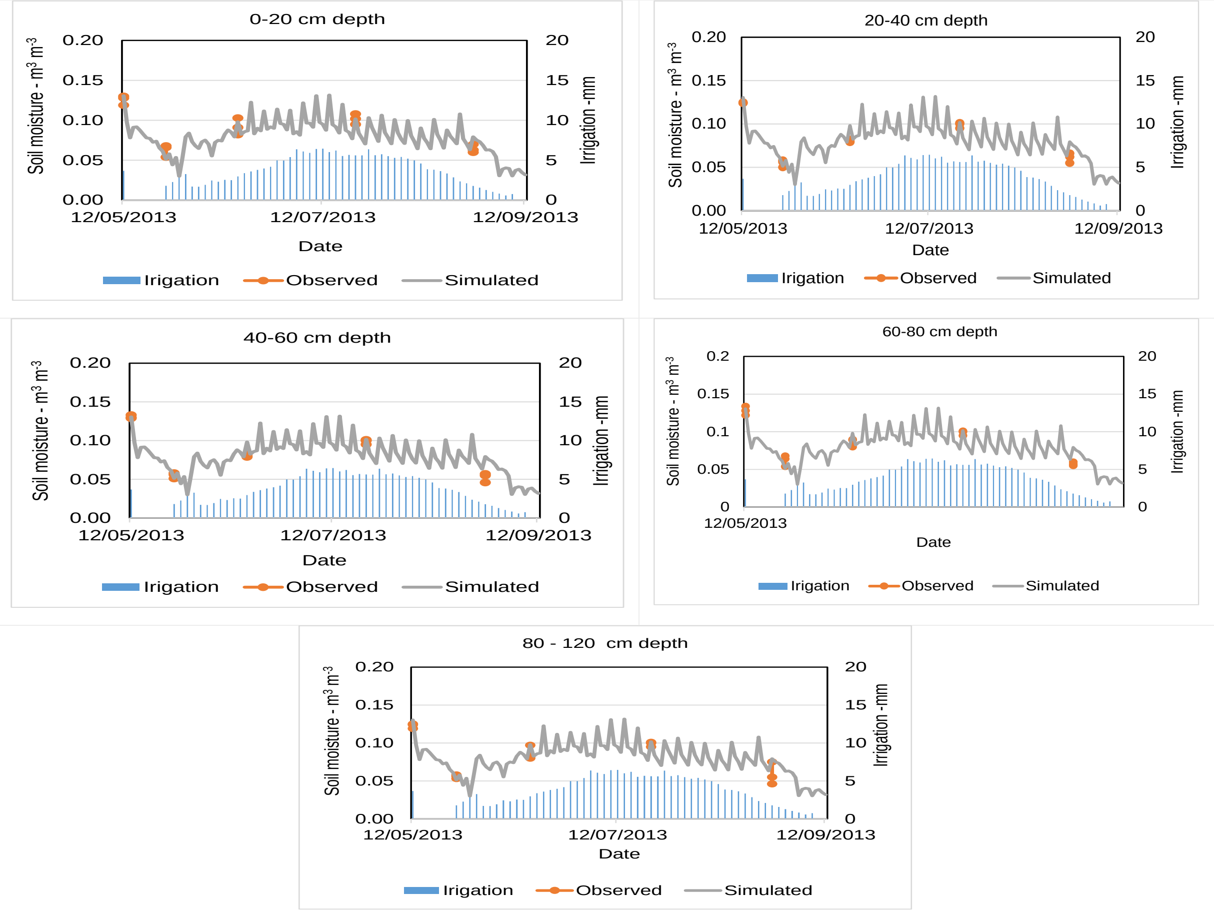
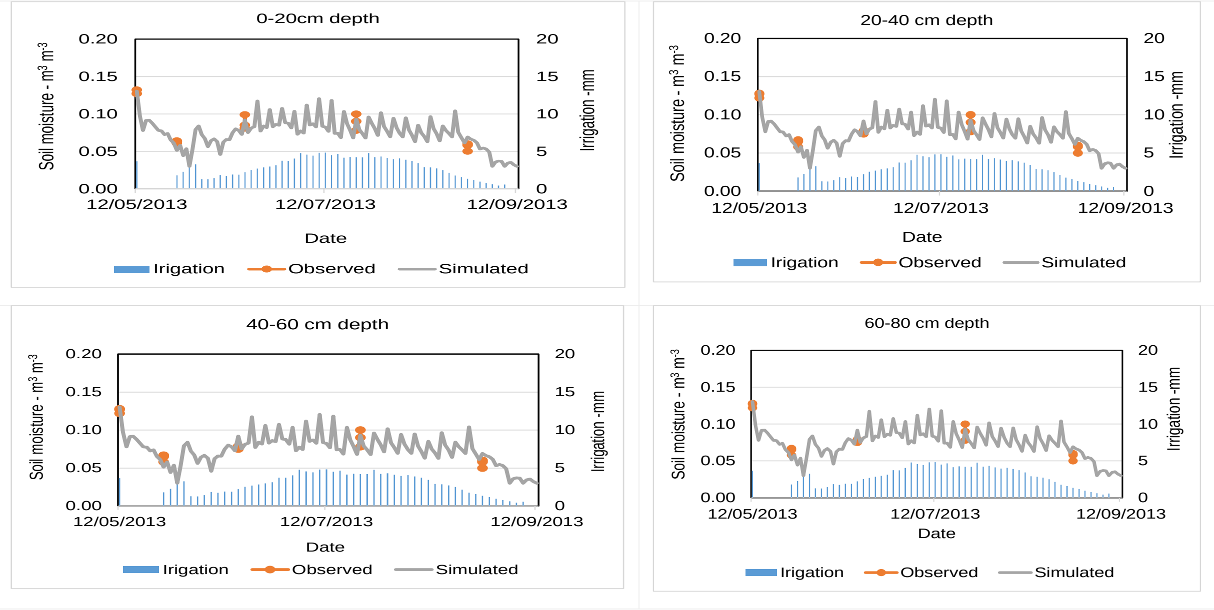


Figure 8. Observed and simulated soil moisture for 0-120 cm depth under 80% PRD



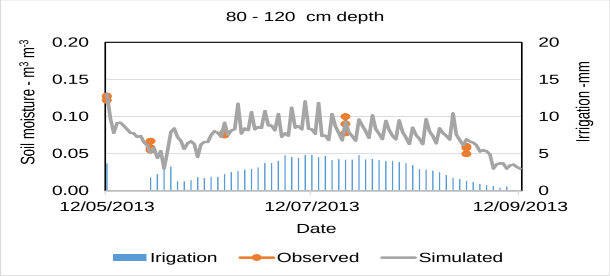


Figure 9. Observed and simulated soil moisture for 0-120 cm depth under 60% PRD

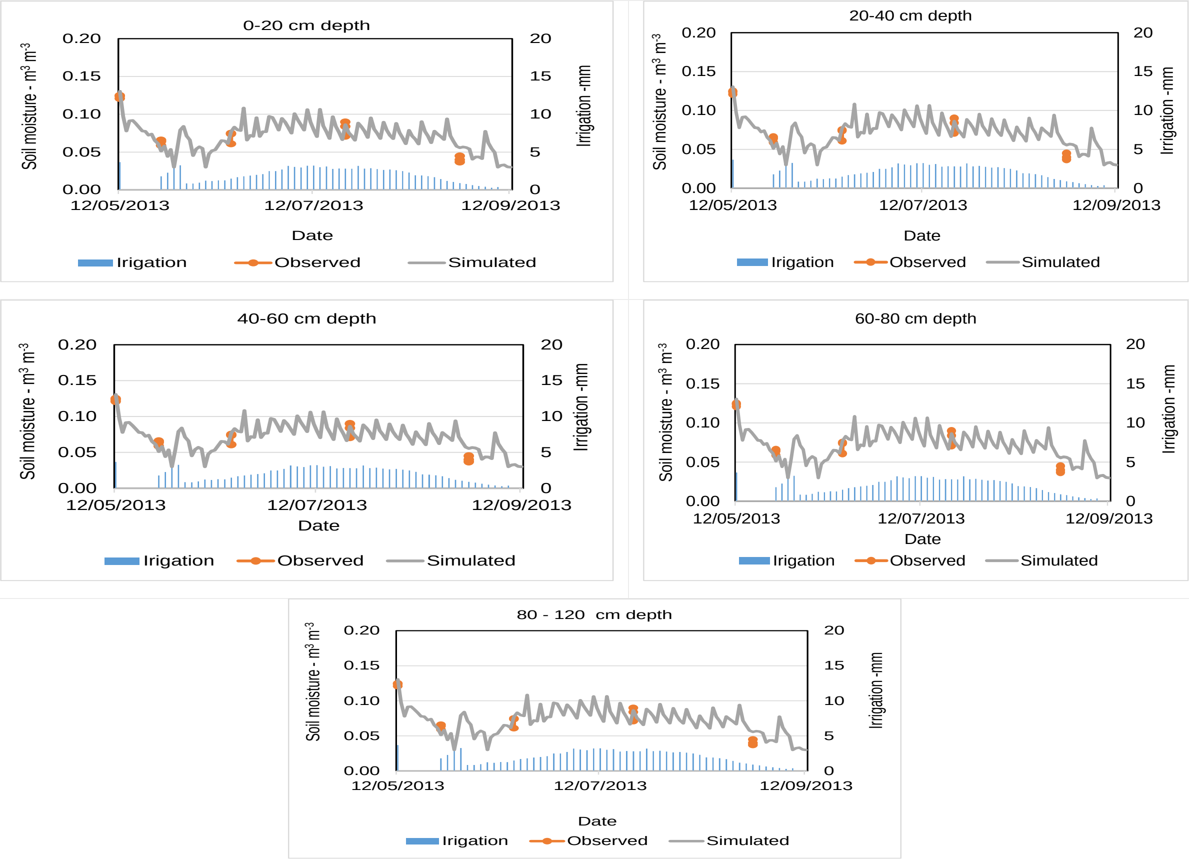


Figure 10. Observed and simulated soil moisture for 0-20 cm depth under 40% PRD

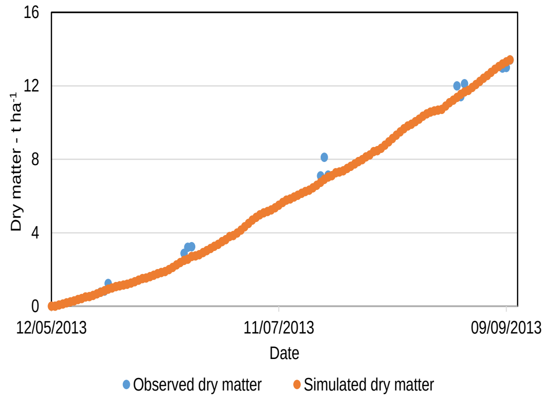
Table V. The coefficient of determination, RMSE and CRM for soil moisture in the layers from 0-120 cm

Irrigation strategy	Treatment	Soil layer, cm																	
		0-20 cm			20 – 40 cm			40 – 60 cm			60 – 80 cm			80 – 120 cm			Overall 0-120 cm		
		R^2	RMSE	CRM	R^2	RMSE	CRM	R^2	RMSE	CRM	R^2	RMSE	CRM	R^2	RMSE	CRM	R^2	RMSE	CRM
RDI	100% FI	0.98	0.00	-0.03	0.93	0.01	-0.11	0.92	0.01	-0.10	0.91	0.02	-0.15	0.94	0.01	-0.06	0.87	0.01	-0.06
	80% FI	0.93	0.01	-0.05	0.93	0.01	-0.11	0.91	0.01	-0.11	0.89	0.01	-0.12	0.95	0.01	-0.02			
	60% FI	0.97	0.00	-0.02	0.87	0.01	-0.09	0.88	0.01	-0.09	0.88	0.01	-0.09	0.95	0.01	-0.08			
	40% FI	0.90	0.01	0.09	0.92	0.01	0.08	0.91	0.01	0.04	0.82	0.02	0.11	0.92	0.01	0.10			
PRD	PRD	0.88	0.01	-0.10	0.81	0.01	-0.12	0.81	0.01	-0.12	0.86	0.01	-0.07	0.85	0.01	-0.11			
	80% PRD	0.83	0.01	-0.03	0.88	0.01	-0.13	0.83	0.01	-0.14	0.81	0.01	-0.08	0.83	0.01	-0.11			
	60% PRD	0.86	0.00	-0.03	0.83	0.01	-0.06	0.83	0.01	-0.06	0.83	0.01	-0.06	0.86	0.01	-0.07			
	40% PRD	0.87	0.01	-0.08	0.87	0.01	-0.08	0.87	0.01	-0.08	0.87	0.01	-0.08	0.87	0.01	-0.08			

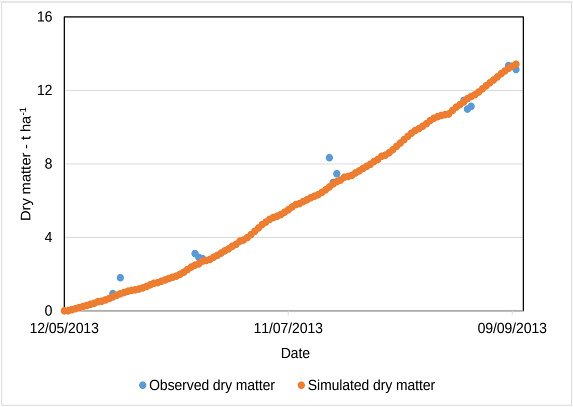
RDI: Regulated Deficit Irrigation, RMSE: Root Mean Square Error, CRM: Coefficient of Residual Mass FI: Full Irrigation, PRD: Partial Root Drying, R^2:is the coefficient of determination

Dry matter

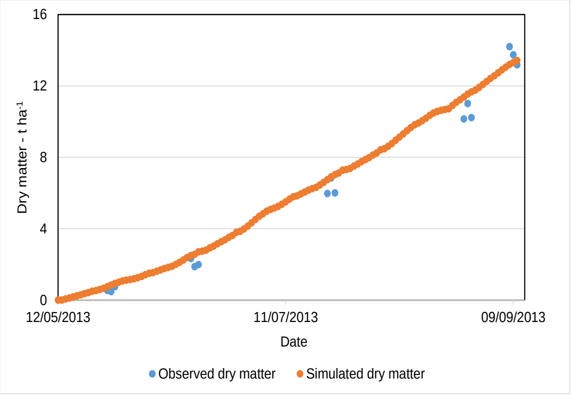
The time series of observed and simulated dry matter under different irrigation treatments for the maize crop are shown in Figure 11. The observed and the simulated dry matter for RDI and PRD treatments were very close. In general, there was a good correlation between simulated and observed dry matter for all treatments. The correlation between the observed and simulated dry matter for maize crop shows that the model was able to simulate the total dry matter with R^2 of 0.99 for the 100%FI and 80%FI treatments; 0.98 for the 60%FI, 40%FI and 80% PRD treatments; 0.97 for the PRD treatment; and 0.96 for both the 60% PRD and 40% PRD treatments. The model also showed a good fit for dry matter for all treatments put together where the average R^2 was 0.96 (Figure 12).



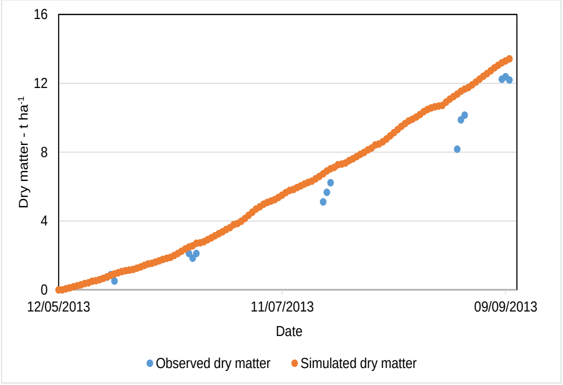
100% Full irrigation



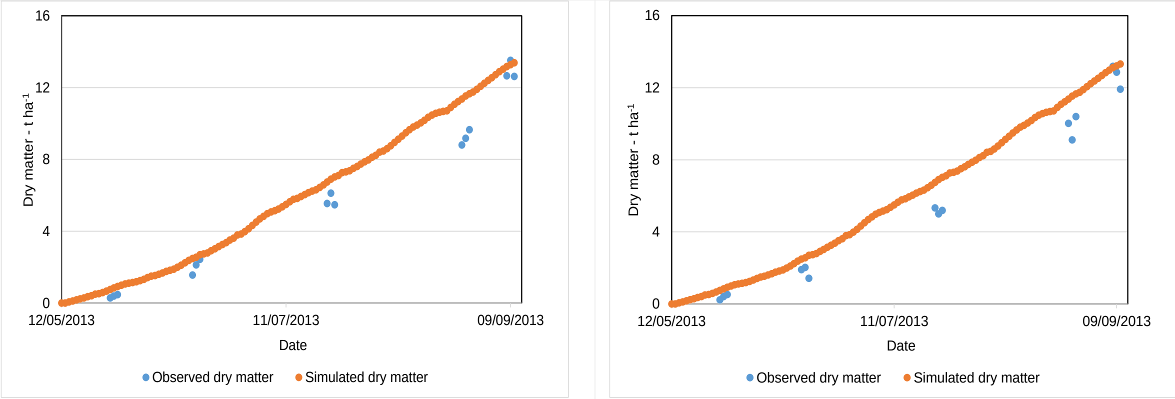
80% Full irrigation



60% Full irrigation

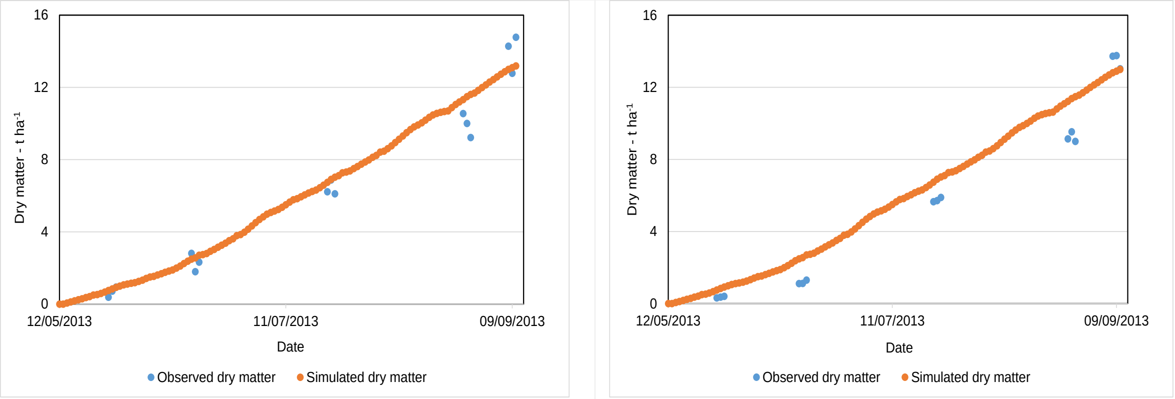


40% Full irrigation



PRD

80% PRD



60% PRD

40% PRD

Figure11. Observed and simulated dry matter for treatments

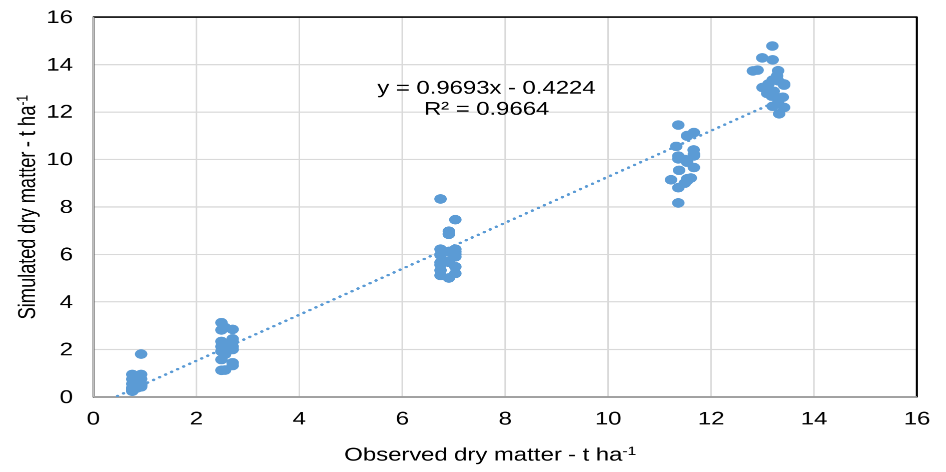


Figure12.Overall observed vs simulated dry matter for all treatments

Grain yield

The impact of deficit irrigation by RDI and PRD on yield and water productivity of maize under sandy soil conditions is shown in Table VI. There were significant differences between the control treatment (100% fully Irrigated) and the other treatments. The yield was reduced due to the decrease of irrigation water applied under RDI and PRD strategies. The yield values under RDI were higher than the yield values under PRD. This may be due to the lower irrigation water quantity applied under PRD, hence, increasing the drought stress under PRD conditions where the amount of irrigation water was less than 50% of the water amount applied under full irrigation. The higher yield under the 100% FI than PRD treatments is attributed to the higher soil moisture content stored within the root zone, hence decreasing the plant water stress.

The observed and simulated total yield for the maize crop under different irrigation strategies is shown in Figure 13. The results show different yields are obtained under different irrigation strategies. The highest yield, 8.54 t ha^{-1}, was obtained under the 100% FI treatment where 5063 m^{3} irrigation water was applied per ha per season. The lowest yield, 4.05 t ha^{-1}, was obtained under the 40% PRD treatment, where the amount of irrigation water applied was 1126 m^{3} ha^{-1} per season. This means there was a 52% reduction in the yield between 100%FI and 40% PRD. The yield under PRD was 27% lower than under 100% FI. This is due to the fact that, under PRD, much less water was added (2062 m^{3} per ha per season), which under the sandy soil conditions led to a much reduced wetted soil volume. In addition, the wetted soil width and depth at the peak of the season’s water requirements were 60 and 70 cm, respectively, for the 100%FI treatment, but were only 30 and 35 cm, respectively, for PRD and 15 and 20 cm, respectively, for the 40% PRD treatment.

The correlation between the observed and simulated grain yield shows that the model was able to simulate grain yield very well, with R^{2}of 0.98 for all treatments (Figure 14).

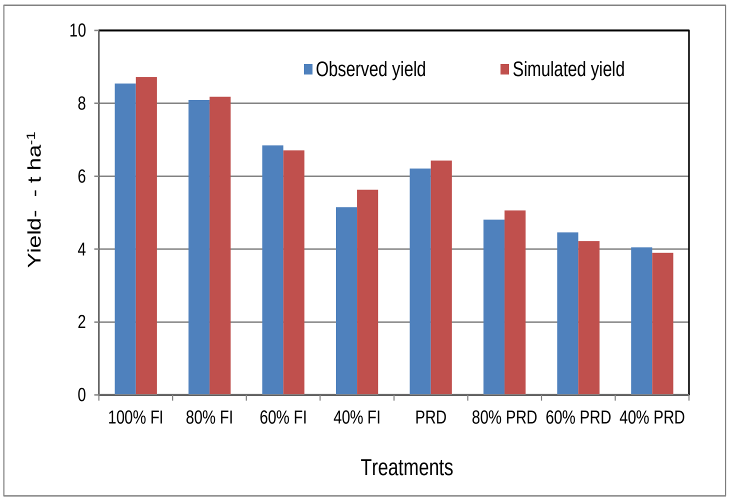


Figure13.Observed and simulated yield for all treatments

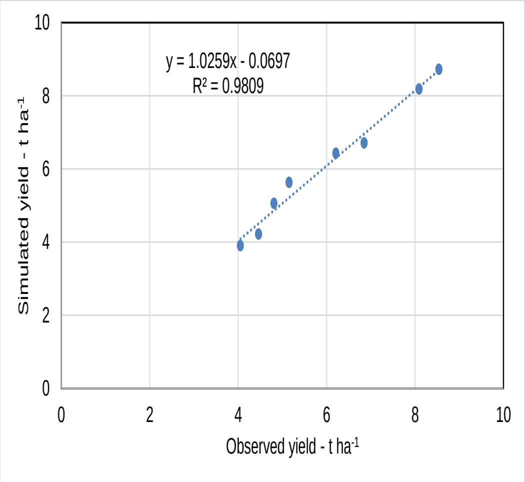


Figure14.Observed versus simulated yield for all treatments

Water productivity

The water productivity was calculated as the amount of grain yield produced, in kg, per cubic meter of irrigation water applied. The results show that, for maize crop, the water productivity was slightly higher under PRD (Figure 15). The amount irrigation water applied for PRD treatments was 50% lower than the amount irrigation water for RDI treatments. Overall the water productivity in relation to irrigation strategy showed that the water productivity of maize crop for PRD treatments was higher than the values for RDI treatments (Figure 15). The highest water productivity of maize, 3.6 kg m^{-3}, was obtained with the 40% PRD treatment and the lowest value, 1.69 kg m^{-3}, for the 100% FI treatment. Although, the highest water productivity of maize occurred under the 40% PRD treatment, the yield under 40% PRD was very low (4.05 t ha^{-1}). This pseudo high productivity, if associated with a small yield, merits careful interpretation in more economic and revenue terms.

The correlation analysis between the observed and the simulated water productivity shows that the model gave a good fit when simulating water productivity, with R^2 of 0.95 for all treatments (Figure 16).

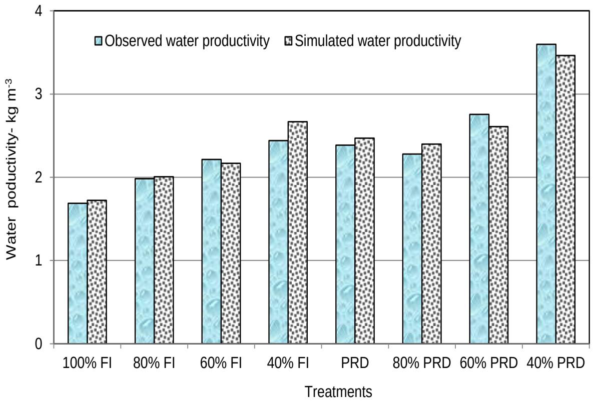


Figure 15. Observed and simulated water productivity for all treatments

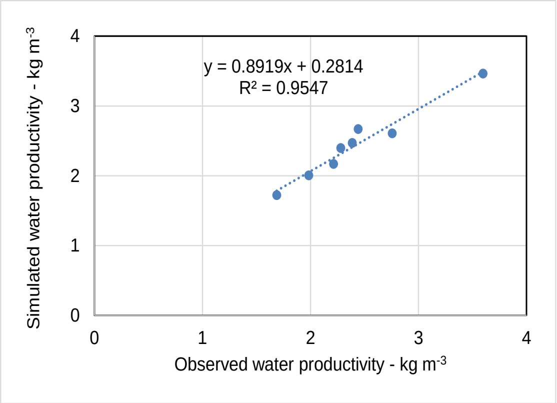


Figure 16. Observed versus simulated water productivity for all treatments

Table VI. Impact of RDI and PRD on Harvest index, % relative error and observed and simulated yield and water productivity of maize

Irrigation water application strategy	Treatment	HI	Yield, t ha^{-1}		Relative error, %	Irrigation water, m^{-3}	Water productivity, kg m^{-3}	
			observed	simulated			observed	simulated
RDI	100% FI (Control)	0.65	8.54 a	8.72 (Calibration)	-2.1	5060	1.69	1.72
	80% FI	0.61	8.09 b	8.18	-1.1	4080	1.98	2.01
	60% FI	0.5	6.85 c	6.71	2.0	3090	2.21	2.17
	40% FI	0.42	5.15 e	5.63	-9.3	2110	2.44	2.67
PRD	PRD	0.48	6.21 d	6.43	-3.5	2600	2.39	2.47
	80% PRD	0.38	4.81 f	5.06	-5.2	2110	2.28	2.40
	60% PRD	0.32	4.46 g	4.22	5.4	1620	2.76	2.61
	40% PRD	0.3	4.05 h	3.9	3.7	1130	3.60	3.46

RDI: Regulated deficit irrigation**,** PRD: Partial root drying, FI: Full irrigation

CONCLUSION

The study concluded that the yields obtained under RDI were relatively higher than those obtained under PRD, this may be due to the fact that the soil is sandy soil and the PRD treatment received less irrigation. The latter perhaps have led to a smaller and narrower wetted soil volume within the root zone and possibly some of the water was lost below the root zone due to the high infiltration rate commonly associated with sandy soils.

For most treatments, the SALTMED model was able to predict the soil moisture for all layers reasonably well. The correlation analysis between the observed and simulated grain yield shows that the SALTMED model was able to simulate grain yield very well, with R^2 of 0.98 for all treatments.

The correlation analysis between the observed and the simulated water productivity showed that the SALTMED model was able to simulate water productivity very well, with R^2 of 0.95 for all treatments. Although, the highest water productivity of maize was associated with the 40% PRD treatment, the yield was very low. This pseudo high productivity, if associated with a small yield, merits careful interpretation in more economic and revenue terms.

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