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Modeling the effects of different irrigation schedules and drain depths for soil salinity management: A case study from Southern Iraq

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Soil-water-atmosphere-plant (SWAP) relationship model is used to evaluate the impact of current irrigation practices on groundwater table depth, soil salinity and crop yields and to determine optimal irrigation requirements and drain depth for the study area. The results indicate that current irrigation practices of applying 600 mm to wheat and 1000 mm to maize are wasting more than 30% of applied irrigation water as deep percolation, which causes rise in groundwater table, increase in profile salinity and reduction in crop yields. The simulation results reveal that in the absence of an effective drainage system in the study area, a groundwater table depth of approximately 200 cm together with an irrigation application of 5000 m^3 ha^{-1} for wheat and 6000 m^3 ha^{-1} for maize will be the most appropriate combination for obtaining optimum yields of wheat (3.0 t ha^{-1}) and maize (1.80 t ha^{-1}). However, to achieve potential yields, leaching of excessive salts from the root zone through freshwater application would be essential. Therefore a drainage system in these areas should be installed to maintain groundwater table depth around 200 cm. Installation of deeper drains would not be feasible as it will increase the costs and without much gains in crop yields.

Key words: Irrigation management, drain depth, soil salinity, crop yields, transient modeling.

INTRODUCTION

In arid and semi-arid regions, accumulation of salts in soil and groundwater are the greatest threats to the sustainability of irrigated agriculture (Qureshi et al., 2010). Ideally, salts added through irrigation water must be removed from the soil system at the same rate at which they are added. If leaching of salts does not occur, salts build up in the soil hampered plant growth as plants are restricted in their capacity to extract water under saline conditions. In shallow and saline groundwater areas, even if leaching occurs, salts enter the top soil layer through capillary rise as a result of high soil evaporation during the summer. This vertical recycling of

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salts ultimately increases the soil salinity to intolerable levels. The southern irrigated areas of Iraq are located between the Tigris and Euphrates Rivers, which produces more than 70% of the total cereal production in the country (Qureshi et al., 2013).

Excessive use of irrigation water and poor drainage conditions are the major factors contributing to rising groundwater tables in southern Iraq. To overcome the problems of waterlogging and soil salinity, a drainage network of open field drains consists of collector drains and branch and secondary drains was installed in the area.

However, due to poor maintenance, this drainage network has been partially destroyed or become non-functional. This has resulted in rising groundwater table in most areas with serious consequences of soil salinization and reduction in crop yields (FAO, 2011).

In the absence of an effective drainage system, precise irrigation applications could be a feasible solution to control groundwater table rise and soil salinity in southern Iraq. The drainage requirements of (semi-) arid areas are largely dependent on the irrigation component. Therefore the groundwater table should be maintained at a depth which can maximize groundwater contribution to the crops through capillary rise without permanently accumulating salts in the root zone (Hendrickx et al., 1990).

In the areas where groundwater quality is of concern, water table should be kept deep enough to minimize capillary rise to avoid secondary soil salinization (Prathapar and Qureshi, 1999). This makes irrigation and groundwater table management of (semi-) arid regions much more complex than in other irrigation conditions (Sarwar and Feddes. 2000). This necessitates the calculation of precise irrigation amounts and determination of suitable groundwater table depths to halt environmental degradation and foster crop production.

The complex interaction between irrigation, crop production, and soil salinity under variety of climatic and physical conditions can be better explained by transient simulation models. These models can be used to evaluate long-term effects of different irrigation regimes on groundwater table depth, soil salinity, and crop growth.

In this study, the Soil-Water-Atmosphere-Plant (SWAP) relationship model (Van Dam et al., 1997) was used to determine optimum irrigation requirements and groundwater table depth for maximizing wheat and maize crops in Al-Dujaila project area located in the southern Iraq. Before application, SWAP model was calibrated for the soil, crop and climatic conditions prevailing in the area.

MATERIAL AND METHODS

The SWAP model

SWAP is a field scale one-dimensional agro-hydrological model, which was developed by Feddes et al. (1978) and modified by Belmans et al. (1983) and Van dam et al. (1997). SWAP is designed to simulate unsaturated flow and solute transport and has successfully been applied in the field of agriculture and water management under variety of climatic and environmental conditions (Qureshi et al. 2010, 2013).

SWAP is designed to simulate unsaturated flow, solute transport, heat flow and crop growth in the soil–plant–atmosphere environment at the field scale. The model has been successfully applied to evaluate the effects of different irrigation and drainage conditions on crop production and soil salinity in the Bhakra irrigation system of India (Bastiaanssen et al., 1996).

Sarwar (2000) used the SWAP model to re-evaluate drainage design criteria for the Fourth Drainage Project of Pakistan and also to investigate the effects of conjunctive management of surface and groundwater on soil salinity and crop production. Qureshi et al. (2010) used the SWAP model to determine optimum groundwater table depth for maximizing cotton production in the Syrdarya Province of Uzbekistan.

The model applies Richard's equation for soil water flow in the soil matrix described as below:

$$C(h)\frac{\partial h}{\partial t}=\frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right]-S(h)$$

Where h is the soil water pressure head (cm), K is the hydraulic conductivity (cm/day), C is the soil water capacity ($d\theta/dh$) (cm^{-1}), S is the soil water extraction rate by plant roots, z is the vertical coordinate positive in the upward direction and t is the time (d). SWAP solves the above partial differential equation using an implicit finite difference mechanism.

The upper boundary of the system is described by potential evapotranspiration rate (ET_{pot}), irrigation and precipitation. ET_{pot} is divided into potential transpiration rate (T_{pot}) and potential soil evaporation rate (E_{pot}) based either on the leaf area index (*LAI*) or the soil cover fraction (*SC*), both as a function of crop development. Reduction of the E_{pot} into actual soil evaporation (E_{act}) is calculated by an empirical function following Boesten and Stroosnijder (1986) model. Irrigations may be prescribed at fixed times or scheduled according to a number of criteria. The bottom boundary conditions of the model can be described with various options (Van Dam et al., 1997).

These include groundwater level as a function of time, flux to/from semi-confined aquifers, flux to/from open surface drains, an exponential relationship between bottom flux and groundwater table or zero flux, free drainage and free outflow (Van Dam et al., 1997). Irrigations in SWAP may be prescribed at fixed times or scheduled according to a number of criteria. The scheduling options allow the evaluation of alternative application strategies.

Under water limiting conditions, it is important to know the minimum amount of irrigation water needed to ensure the maximum production of a certain crop. For this study, a linear relationship between relative yield and relative transpiration was assumed. The validity of linear relationship in field experiments was confirmed by several researchers in different climates [(Hanks, 1974; Hanks 1983; Stewart et al., 1977; Feddes, 1985). Further details of SWAP are described by Van Dam et al. (1997) and the program use is documented by Kroes et al. (1999).

The potential root water extraction rate is equal to the potential transpiration rate, which is governed by atmospheric conditions. Stresses due to dry or wet conditions and/or high salinity concentrations may reduce water extraction. Water stress in SWAP is described by the function proposed by Feddes et al. (1978). For salinity stress the response function of Maas and Hoffman (1977) is used. They found that the reduction in crop yield due to salinity can be linearly related to the soil solution electrical conductivity. Crops

Figure 1. Geographic location of Al-Dujaila project area in Iraq.

can tolerate increases in soil salinity up to a threshold value, after which yield reduces linearly with increasing salt concentration.

$$\frac{Y_{act}}{Y_{pot}} = 1 \quad \text{for } 0 \le EC_e \ge EC_e^*$$

$$\frac{Y_{act}}{Y_{pot}} = 1 - a(EC_e - EC_e^*) \quad \text{for } EC_e > EC_e^*$$

Where EC_e is the electrical conductivity of the soil saturation extract (dS m^{-1}), EC_e^* is the electrical conductivity of the soil saturation extract at which yield begins to decrease (dS m^{-1}) and *a* is the slope which equals the fraction yield decrease per unit of electrical conductivity increase. Salt tolerance data have been listed for a number of crops by Maas (1990).

Water stress in SWAP is described by the function proposed by Feddes et al. (1978). For salinity stress the response function of Maas and Hoffman (1977) is used, which considers a linear relationship between reduction in crop yield due to salinity and EC_e. For this study, a linear relationship between relative yield and relative transpiration was assumed.

The validity of linear relationship in field experiments was confirmed by several researchers in different climates (Hanks 1974; Feddes, 1988). Further details of SWAP are described by (Van Dam et al., 1997).

Description of the study area

This study was conducted in the Al-Dujaila project area, which is one of the oldest irrigation projects in Iraq and is located on the right bank of the Tigris River. The study area falls under the Mesopotamian plain and represents the typical climate and environment of the southern Iraq. Average annual rainfall is 135 mm, which mainly occurs in winter from December to February. Summers are dry and hot to extremely hot and long season with day temperature of over 44°C and dropping at night to 26°C. Location of the study area is shown in Figure 1.

The total area of the Al-Dujaila project is 72,500 ha with net irrigated area of 22,418 ha. The project lands are irrigated from the right side of Tigris River. Irrigation water to the fields is supplied through a network of unlined canals. During the 1950s, the project area was equipped with a surface drainage network which consists of open field drains, collector drains and branch and secondary drains connected to the main outlet drains of the project. Due to years of neglect and poor maintenance and the on-going war in Iraq, the drainage network has been partially destroyed or become non-functional. This has led to rising groundwater tables with serious consequences of soil salinization and reduction in crop yields in most of the project area. Currently, groundwater table varies between 45 and 200 cm. Groundwater salinity is extremely high with seasonal variations of 4 to 43 dS m^{-1}. The major crops cultivated in the area are wheat, barley, corn, and winter/summer vegetables. The cropping intensity is 80 percent in winter and 20% in the summer.

The gravity run irrigation system is owned by the Government, where fix water duties are fixed at the beginning of a cropping season. The irrigation duty is 3 mm d^{-1} for gross cultivated area. Water distribution in the fields is entirely the responsibility of farmers. The soils of the Mesopotamian plain are rich in calcium carbonate, moderate in lime (25 to 30% lime is quite common and less than 20% is rare) and low in organic matter (Al-Jaboory, 1987; Buringh, 1960; Boumans et al., 1977). Large tracts of the irrigated lands of the project area are salinized.

The degree of salinization varies along the latitude, depending on various factors which include quality of irrigation water, irrigation practices, soil types, natural drainage and the status of groundwater table. Irrigation applications without proper drainage facility have added huge amounts of salts in the soil profile.

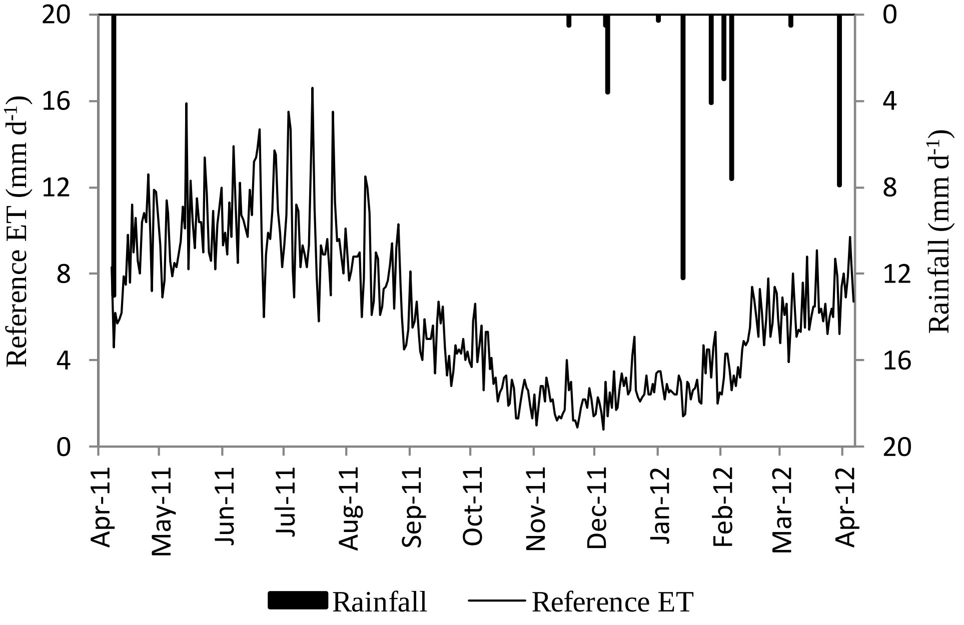

Figure 2. Rainfall and reference evapotranspiration during the calibration period.

Main crops cultivated in the project area are wheat, barley and maize with small proportions of clover, sunflower, and winter/summer vegetables.

The cropping intensity is 80 percent in winter and 20 percent in the summer (Al-Zubaidi, 1992). Irrigation water use efficiencies are low, which waste a considerable amount of water as deep percolation. This causes groundwater table to rise resulting in increased soil salinity and low crop yields. The average yields of wheat and maize are around 2.0 t ha^{-1} compared to the production potential of up to 4-5 t ha^{-1}.

Data collection and model inputs

To collect data for model calibration, a 0.5 ha farmer field was extensively monitored during April 2011 to May 2012. Wheat and maize crops were grown during the monitoring period. Reference evapotranspiration (ET_o) was calculated by the Penman-Monteith (PM) method (FAO, 1998) using daily climatic data obtained from the nearby meteorological station. ET_{pot} was calculated by multiplying ET_o by the crop coefficient (K_c). The K_c values were taken from (Al-Falahi and Qureshi, 2011).

Soil samples were collected at depths of 0-30, 30-60 and 60-90 cm and analyzed in the laboratory for the determination of electrical conductivity of the saturation extract (EC_e) values. These values were then used to compare model simulated EC_e values. Precipitation and ET_o values during the calibration period is shown in Figure 2.

Data on rooting depth, leaf area index (LAI) and soil cover values as a function of crop development stage were taken from Qureshi et al. (2013). The threshold values for salinity stress for wheat and maize were taken as 6.0 and 1.7 dS m^{-1}, respectively (Mass and Hoffman, 1977).

Crops react differently to soil water limitations and their sensitivity to matric potential needs to be specified in the model as input. The *h1* to *h4* values refer to the sink term theory of Feddes et al. (1978). The sink term values for this study were taken from Qureshi et al. (2013). The agronomic and crop parameters used in this study are summarized in Table 1.

Irrigations were applied to bring soil moisture up to 70% of the field capacity. In this study, good quality canal water (EC = 0.80 dS m^{-1}) was used for all irrigations. During the study period, farmers applied 7 irrigations (600 mm) to wheat and 9 irrigations (1000 mm) to maize crop. Amount and date of all irrigations to wheat and maize during the calibration period is given in Table 2.

Groundwater table depth was monitored on a bi-weekly basis with the help of three observation wells which were installed in the monitoring field. The average value of these three observation wells was used in the model as input. The analysis shows that there was very little variation in groundwater table values recorded by the three observation wells. The bottom boundary condition of the soil profile was described as "*free drainage*" and model was set to simulate daily groundwater table depths.

The simulated groundwater table depth was compared with the observed groundwater table depth data for model calibration. The salinity parameters in the classical convection–dispersion equation that describe salt transport are dispersivity, $D_{dis,}$ and diffusion, D_{dif}. The model is more sensitive to dispersion than to diffusion. The value of D_{dis} typically ranges from 0.5 cm, or less, for laboratory-scale experiments involving disturbed soils, to about 10 cm or more for field-scale experiments (Nielsen et al., 1986). The values for D_{dis} and D_{dif} that gave the best results during model calibration were 0.48 and 15 cm^2 day^{-1}, respectively. For salinity stress the response function of Maas and Hoffman (1977) was used. The threshold values for salinity stress for wheat and maize were taken as 6.0 and 1.7 dS m^{-1}, respectively.

The 300 cm soil profile was divided into three layers based on laboratory analysis of samples. For each soil layer, soil hydraulic properties were described by the Van Genuchten-Mualem (VGM) parameters (Mualem, 1976; Van Genuchten, 1987). These parameters are saturated soil moisture content (θ_{sat}), residual soil moisture content (θ_{res}), saturated hydraulic conductivity (K_{sat}), empirical shape parameters (λ, α, n). Soil hydraulic functions were taken from pedo-transfer functions (Wösten et al., 1998) and were slightly adjusted during the calibration process. Final calibrated VGM parameters are given in Table 3.

Table 1. Agronomic and crop parameters used for simulations with the SWAP model.

Parameter	Wheat	Maize
Sowing date	05-11-2011	10-05-2011
Harvesting date	17-04-2012	28-09-2011
Number of irrigations	6	9
Total irrigation depth (mm)	600	1000
Maximum rooting depth (cm)	100	120
Maximum crop factor	1.15	1.2
Limiting pressure heads (cm)	$h_1 = -0.1; h_2 = -20.0;$ $h_3^h = -500; h_3^l = -900;$ $h_4 = -16000$	$h_1 = -10; h_2 = -20.0;$ $h_3^h = -325;$ $h_3^l = -600; h_4 = -8000$

Table 2. Irrigation schedule followed for wheat and maize crops during the calibration period.

Wheat		Maize	
Date	**Irrigation depth (mm)**	**Irrigation date**	**Irrigation depth (mm)**
01-01-2012	80	23-07-2012	100
17-01-2012	85	01-08-2012	100
02-02-2012	85	12-08-2012	120
18-02-2012	95	23-08-2012	120
06-03-2012	90	03-09-2012	120
22-03-2012	85	14-09-2012	120
07-04-2012	80	25-09-2012	120
		06-10-2012	100
		17-10-2012	100

Table 3. Calibrated Van Genuchten-Mualem (VGM) parameters.

Parameter	Al-Dujaila		
	Layer 1	**Layer 2**	**Layer 3**
Depth of layer (cm)	0 - 60	60 - 150	150 - 300
Soil texture	Loam	Silt Loam	Silt Loam
Residual moisture content θrs (cm^3/cm^3)	0.01	0.01	0.01
Saturated water content θsat (cm^3/cm^3)	0.4500	0.4692	0.4698
Saturated hydraulic conductivity K_{sat} (cm day^{-1})	21.25	21.12	24.38
Shape parameter α (cm^{-1})	0.099	0.075	0.068
Shape parameter λ (-)	1.98	1.60	1.74
Shape parameter n (-)	1.0426	1.0394	1.0342

RESULTS AND DISCUSSION

Model calibration

Comparison of measured and simulated groundwater table depths

Figure 3 shows a comparison of observed and simulated groundwater table (GWT) depth for the study area during the calibration period. The simulated values are on daily basis whereas observed values are on bi-weekly basis. It is pertinent to note that irrigation has a significant effect on the groundwater table depth as the amount of precipitation during the calibration period was only 35 mm. It is evident that current irrigation practices led the groundwater rise to 70 cm below soil surface at the end of wheat season, which made the root zone saturated causing increase in salinity and reduction in crop yields. This implies that in the absence of drainage system, reduction in irrigation amounts may help in keeping

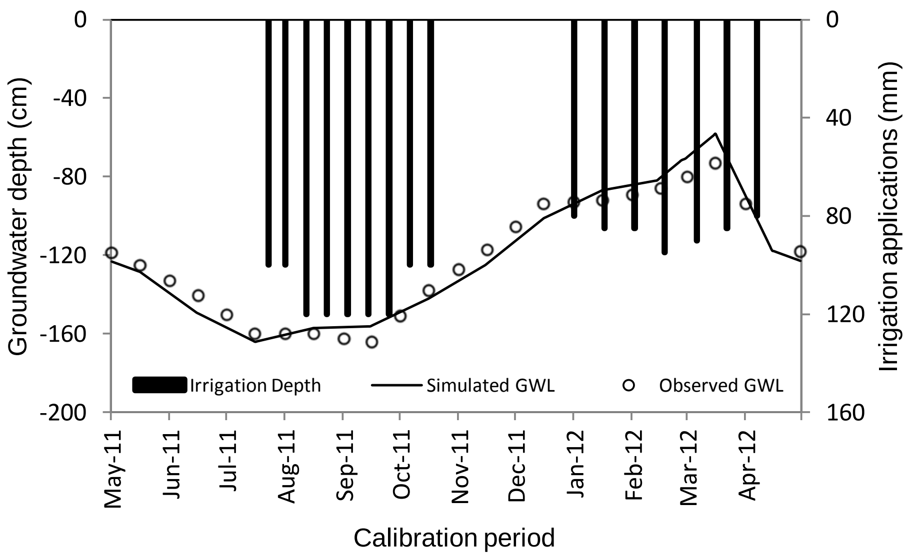

Figure 3. Observed and simulated groundwater depths in the study area.

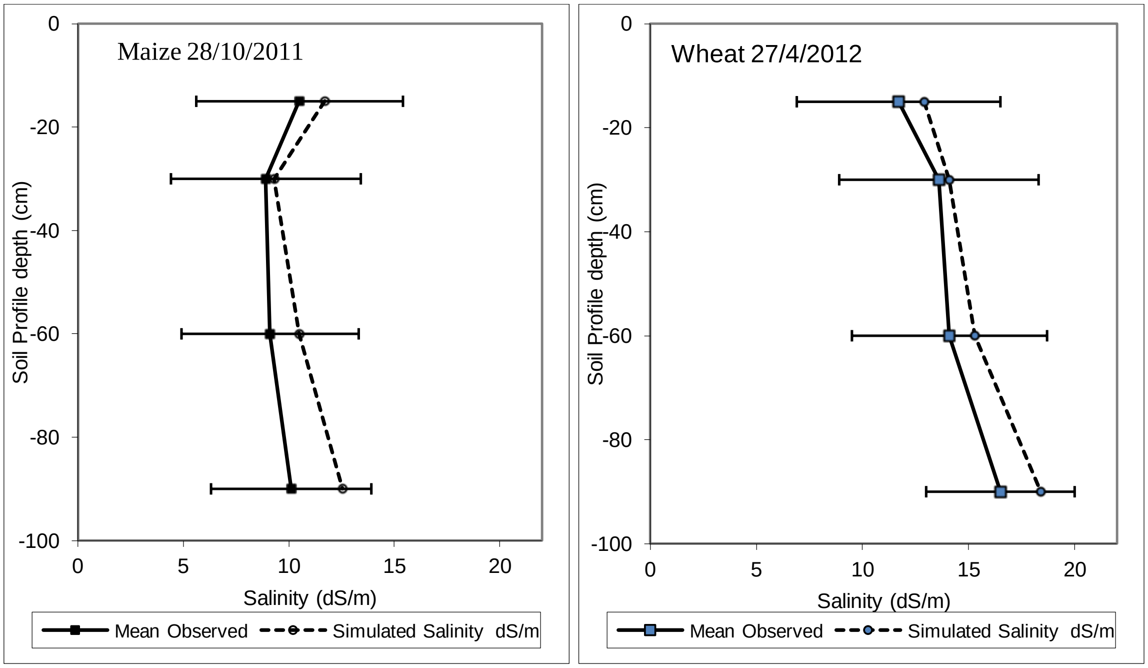

Figure 4. Observed and simulated *ECe* at different depths in the study area.

groundwater table below root zone. A good agreement between observed and simulated groundwater depths gives confidence on calibrated parameters to represent processes in the unsaturated zone.

Comparison of measured and simulated soil salinity profiles

The measured EC_e values were available only for 2 days during the study period therefore a comparison could only be accomplished for those days (Figure 4). The simulated values are within the standard deviations of the observed salinity values. The close proximity between measured and simulated values reveals that the calibrated model is good enough to represent salinity at the field scale. The high standard deviation values show that there are large variations in salinity within same field. These differences are attributed to non-uniform application of irrigation water in the field due to poor land leveling.

Table 4. Simulated water balance components for wheat and maize crops.

Water balance component	Al-Dujaila	
	Wheat	Maize
Irrigation (mm)	600	1000
Rainfall (mm)	35	0
Actual Evapotranspiration, ET_{act} (mm)	175	307
Potential Evapotranspiration, ET_{pot} (mm)	609	1080
Actual Transpiration, T_{act} (mm)	135	235
Potential Transpiration, T_{pot} (mm)	495	830
Relative Transpiration, T_{act} / T_{pot} (-)	0.27	0.28
Measured Yield, $Y_{measured}$, (t ha^{-1})	1.20	0.90
Simulated Yield $Y_{simulated}$, (t ha^{-1})	1.08	0.85
Bottom flux, q_{bot} (mm)	188	255
Salt Storage Change, *SSC*	0.910	0.775

SSC ($\Delta C/C_{initial}$) is the salt storage change in top one meter of the soil profile. ΔC is the salt concentration change over the crop growing period and $C_{initial}$ is the initial salt concentration.

This uneven distribution of water produces patches of low and high water infiltration, which in turn produces patches of low and high salinity within the same field. Relatively high groundwater table conditions during the wheat season are the probable reason for higher root zone salinity and reduction in wheat yield as compared to maize.

Simulated soil water balance components

Table 4 summarizes simulated water and salt balance components for the wheat and maize crops. The calibrated soil hydraulic parameters, measured irrigation depths and other input data were used in the SWAP model to simulate the salt and water balance components. The simulated water balance components include ET_{act}, E_{act}, T_{act}, salt storage change (*SSC*) and bottom flux (q_{bot}). The positive value of qbot represents addition of water to the soil profile from the groundwater. Table 3 reveals that 25 to 30% of the applied irrigation water was wasted as deep percolation which causes groundwater table to rise and affect T_{act} and reduced relative transpiration (T_{act}/T_{pot}). In the study area, T_{act}/T_{pot} ratio was significantly low (that is, 0.30) mainly due to high soil and groundwater salinity. T_{act}/T_{pot} ratio is considered equivalent to relative crop yields because it takes into account the effect of both soil water and salinity and reflects overall conditions in the unsaturated zone and their effect on crop yields. The maximum attainable yields of wheat and maize for Al-Dujaila area are taken as 4.0 and 3.0 t ha^{-1}, respectively (Qureshi and Al-Falahi, 2011). Using this criterion, simulated yields for wheat and maize were 1.08 and 0.85 t ha^{-1}, respectively. These simulated yields were within 5% of the measured yields, which confirms the validity of agronomic and crop parameters used for model calibration. The significant addition of salts over the calibration period reflects that salt stress was also the major factor in reducing crop yields.

Table 3 shows that during the calibration period, addition of salts in the root zone is considerably small, which does not affect the crop yield. This suggests that saturated root zone conditions caused by an intensive rise in the groundwater table were the major factors in reducing crop yields. In addition to water and salt stress under field conditions, other factors such as nutrition deficiency, pests and diseases may affect crop yields. However, SWAP does not consider these factors and assumes optimum nutrition conditions without any pest or disease stress.

Determination of optimum irrigation requirements

The calibrated SWAP model was used to perform simulations for the determination of optimal irrigation amounts and optimal groundwater table depth under the current situation to maximize crop yields and control soil salinization. The model simulations were performed to evaluate the effect of four different groundwater table depths (that is, 150, 175, 200 and 250 cm) and four irrigation regimes for wheat (600, 550, 500 and 450 mm) and six irrigation regimes for maize (that is, 1000, 700, 600, 500, 400 and 300 mm) on root zone salinity and crop yields. The groundwater table depth was maintained at different depths by setting the bottom boundary condition. However, the groundwater table was allowed to fluctuate during the growing season based on irrigation and evapotranspiration activity. The results of these simulations are presented in Figure 5.

Figure 5 shows the relationship between groundwater table depth, irrigation application and crop yields in the Al-Dujaila area. It seems that wheat is very sensitive to groundwater table depth condition. Under existing

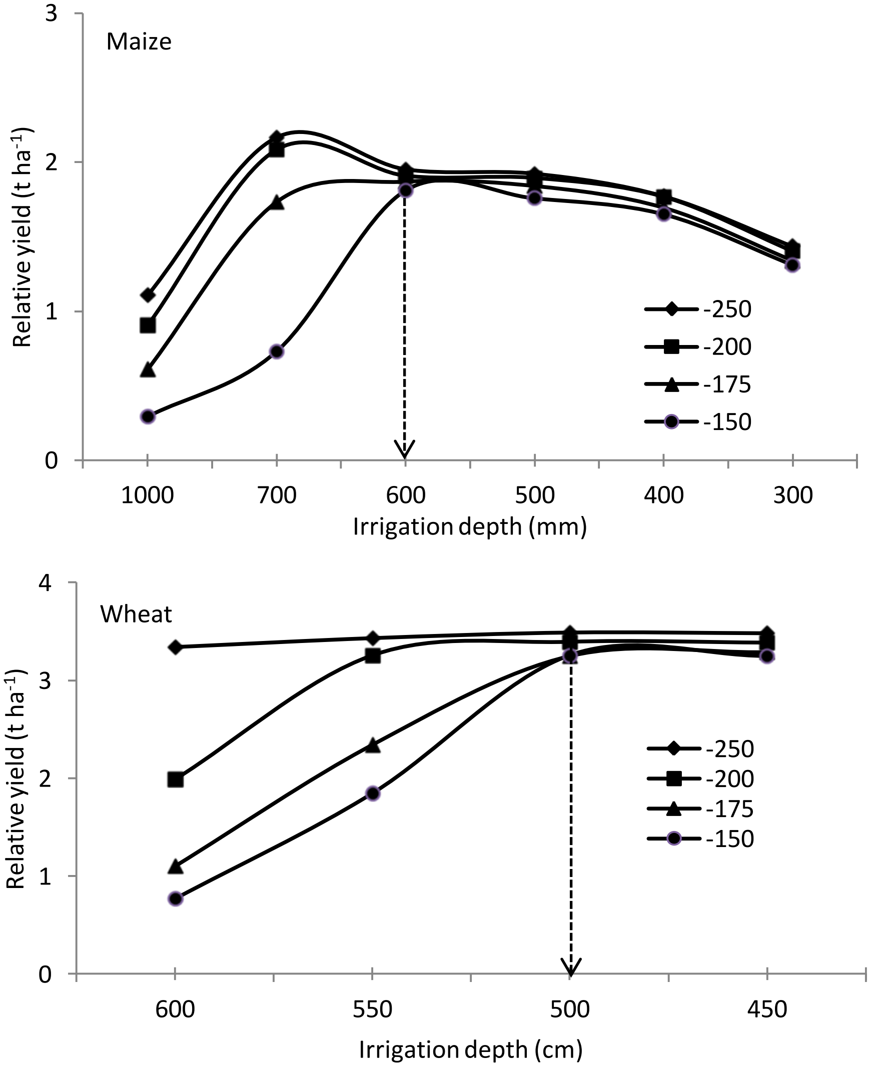

Figure 5. Wheat and maize yields as affected by different groundwater table depths and irrigation regimes.

conditions, reduction in wheat yield is almost inevitable with the irrigation application of 600 mm. It is evident that increasing groundwater table depth will have positive impact on wheat yields. Wheat yields will be increased to 1.10 t ha^{-1} at groundwater depth of 175 cm and 2.0 t ha^{-1} at or below 200 cm. Reducing irrigation applications to 500 mm to wheat will lower the groundwater table depth, which will increase the wheat yield to 3.39 t ha^{-1}.

However, further reduction in irrigation amounts could result in yield reductions.

The maize yields obtained under existing irrigation and drainage conditions are far below than the potential of 3 t ha^{-1} (FAO, 2011), Figure 5 illustrates that reduction in irrigation amounts to 600 mm would almost double the maize yield (regardless of groundwater table depth). Irrigation amounts lower than 600 mm seems insufficient to meet crop water requirements and maintain favorable salt balance in the root zone resulting in drastic reductions in maize yield. This suggests that in Al-Dujaila area, the situation is much more fragile therefore keeping groundwater out of root zone is of extreme importance to control soil salinization especially because drainage systems in the area are non-functional.

However, this must be realized that these management measures are for short-term benefits and does not guarantee long-term improvements in the soil health. To ensure long-term sustainability of irrigated agriculture in these areas, rehabilitation of existing drainage systems should be done on priority basis. These results are consistent with the findings of Qureshi et al. (2013).

They also found that reduction in irrigation application amounts can help keeping groundwater table depth below root zone which have positive impact on the yields of maize and wheat in the Al-Mussayab area in Central

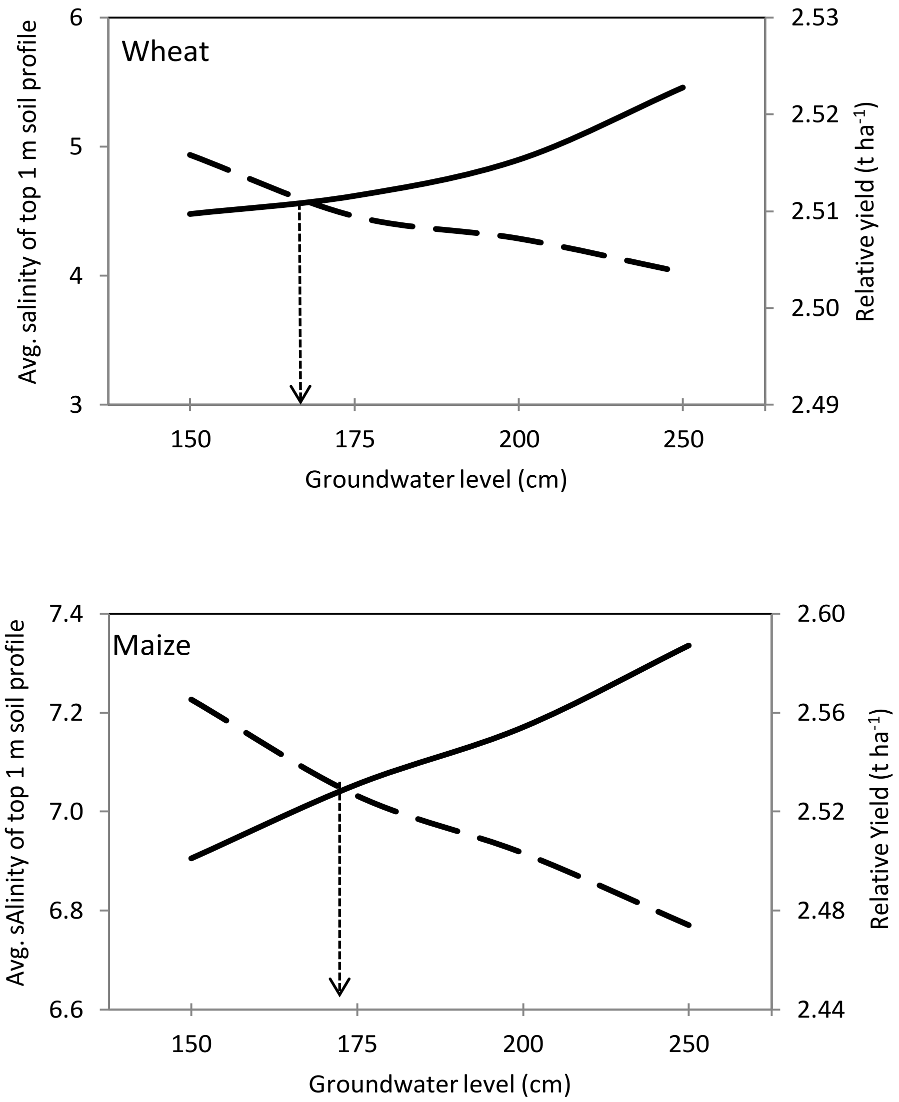

Figure 6. Relationship between root zone salinity and crop yields as affected by different groundwater table depths.

Iraq. This clearly indicates that in the Al-Dujaila area, reducing irrigation applications would be a useful strategy to control rising groundwater tables and incipient soil salinization which ultimately affect crop yields. However, for long-term sustainability of irrigated agriculture, rehabilitation of existing drainage systems would be needed.

Determining optimal groundwater table depth

Before finalizing groundwater table depth for optimal crop production and soil salinization, the effect of optimal irrigation requirements on profile salinity under different groundwater table conditions was evaluated. For this purpose, additional simulations were performed using optimal irrigation amounts (that is, 500 mm for wheat and 600 mm for maize) and their effect on salinity development in the top 1m of the soil profile was evaluated.

Figure 6 shows that application of 500 mm of irrigation water to wheat will maintain groundwater table at 200 cm, salinity around 4.3 dS m^{-1} and will produce 2.52 t ha^{-1} of wheat yield. As maize is more sensitive to root zone salinity, salinity levels above 5.0 dS m^{-1} will cause significant reduction in yields. Therefore maximum achievable yield under optimal irrigation schedule will be restricted to 1.80 t ha^{-1}. The simulated maize yield is almost double the yield obtained under current irrigation practices although they still remain well below the potential yields of the area. Qureshi et al. (2010) have also used the SWAP model to determine optimal drain depths for maximizing cotton production in the Syrdarya Province of Uzbekistan. Using a similar approach, they also found that maintaining drain depths at 200 cm would be the most viable option to maximize crop production and control soil salinity. Using SWAP model, Sarwar and Feddes (2000) also found an optimal drain depth of 220 cm for the semiarid conditions of the Fourth Drainage Project of Pakistan. This shows that for semi-arid areas of Al-Dujaila area, a drain depth of 200 cm is suitable for maximizing crop production and controlling soil salinization.

The modeling results reveal that under the shallow and saline groundwater conditions of the study area, a groundwater table depth of approximately 200 cm and irrigation amounts of 5000 m^3 ha^{-1} to wheat and 6000 m^3 ha^{-1} to maize will be adequate to get optimum yields of wheat (2.52 t ha^{-1}) and maize (1.80 t ha^{-1}).

However, to achieve potential yields, leaching of excessive salts from the soil profile through freshwater application will be unavoidable. This will require rehabilitation of existing drainage system on priority basis and installation of new drainage systems wherever necessary. The network of surface drains also need to be cleaned to improve their efficiency in transporting saline drainage effluent away from irrigated areas. This requires substantial financial resources and time. Under the existing geo-political situation of the country, this seems difficult in the immediate future. Till then, managing irrigation to optimize crop production and control rising groundwater table and soil salinity could be a useful strategy to sustain irrigated agriculture.

Conclusions

The modeling results reveal that under the shallow GWT conditions prevailing in the southern Iraq, current irrigation practices are detrimental to crop growth because they lead to extensive groundwater table rise.

Therefore precise calculations of irrigation amounts could be beneficial in stabilizing groundwater table, conserving irrigation water and reducing drainage needs. The modeling results suggest that optimum yields of wheat (2.52 t ha^{-1}) and maize (1.80 t ha^{-1}) can be obtained by applying an irrigation amount of 5000 m^3 ha^{-1} to wheat and 6000 m^3 ha^{-1} to maize and maintaining groundwater depth at 200 cm. For potential yields, leaching of excessive salts from the soil profile will be inevitable. This will require rehabilitation of existing surface and subsurface drainage network. Under the existing geo-political and economic situation of the country, this seems difficult in near future. Till then, managing irrigation to optimize crop production by controlling rising groundwater table and soil salinity could be a useful strategy.

Conflict of Interest

The authors have not declared any conflict of interest.

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