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Determination of Water Productivity of Maize Yield under Deficit Irrigation in Middle Egypt

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ABSTRACT

A Yield-Stress model was calibrated and validated for maize yield and consumptive use data using a three-year field trial at Beni Sweif governorate, Middle Egypt under two treatments of water quality (fresh and agricultural drainage irrigation) and two irrigation treatments of water quantity (required and excess irrigation). The goodness of fit between measured and predicted values by the model was tested by calculating the percentage difference between measured and predicted values of yield and consumptive use, in addition to root mean squared error per observation and Willmott index of agreement. Then, the model was used to predict the effect of three deficit irrigation treatments (skipping the last irrigation, and 80 and 70% of full required irrigation or 80 and 60% of full excess irrigation). Water productivity was calculated in all cases. The results showed that the model performance was highly acceptable in predicting maize yield and consumptive use. Low yield losses occurred under both fresh and agricultural drainage irrigation water as a result of 30 and 40% irrigation water saving under required and excess irrigation, respectively. Water productivity gradually increased under all deficit irrigation treatments, which suggested that there is a high potentiality to save an ample amount of irrigation water to be used in cultivating more lands.

Keywords: consumptive use, water quality, water quantity, Yield-Stress model

INTRODUCTION

Maize occupies a unique position in science and agriculture, in addition to being a crop with enormous uses. Water stress during maize vegetative growth resulted in reduced plant height, leaf area index (Cassel *et al*. 1985) and total leaf area (El-Shenawy 1990). In addition, the number of ovules that were fertilized and that developed into grains decreased rapidly when drought occurred during flowering (Gomma 1981). Both final maize yield and kernel number were reduced as a result of water stress during the grain-filling period (Ritchie *et al*. 1993). However, under scarce and costly water supplies, it may sometimes be advantageous to stress the crop to some degree. Water stress may reduce crop yield to some extent but it will remain economically feasible as long as the marginal benefit from the reduced cost of water is equal to or greater than the marginal cost of reduced yield (Tariq *et al*. 2003) and that could increase water productivity.

Achieving greater water productivity has become one of the primary challenges for scientists in agriculture. This should include the employment of techniques and practices that deliver more accurate supply of water to crops (Tariq *et al*. 2003). Furthermore, there is a need to quantify the impact of water limitation on crop productivity. Therefore, the need to develop a crop simulation model arose based on the use of existing knowledge of yield response to water supply and to quantify that in terms of yield losses (Smith 1991). Crop simulation models are mathematical representations of plant growth processes as influenced by interactions among genotype, environment, and crop management. They have become an indispensable tool for supporting scientific research, crop management, and policy analysis (Fischer *et al.* 2001; Hammer *et al*. 2002; Hansen 2002). Many crop simulation models have been developed with a high degree of sophistication and significant data requirements. Among them, DSSAT and CropSyst models, which simulate potential production as well as water and nitrogen-limited production (George *et al*. 2000). However, the considerable information needed on crop, soil, and environmental characteristics to run these models is a limitation. For that purpose, a further need arose to develop a simpler, mechanistic model that focuses on water-limited crop production to predict the potential yields for a given water supply.

Several simulation models using soil water budget in the root zone were developed over the past 30 years (Hill *et al*. 1987; Camp *et al*. 1988; Smith 1991; Choeng 1992; Foroud *et al*. 1992; Prajamworng 1994; George *et al*. 2000). These models have been widely accepted, but their adoption has been very slow because they needs to be run by professionals. On the contrary, a simpler simulation model called Yield-Stress (Y-S) (Ouda 2006) was developed. This model simulates soil water budgeting over the root zone to predict crop yield under different water stress conditions, which could be very helpful in the management of deficit irrigation applications. The model was calibrated and validated in Egypt for several crops i.e. maize (Ouda *et al*. 2008d), soybean (Ouda *et al*. 2007, 2008a, 2008c), and wheat (Ouda *et al*. 2008b). The model was also tested at several locations i.e. Delta region (Ouda 2006), Middel Egypt (Khalil *et al*. 2007) and Upper Egypt (Tantawy *et al*. 2007). Furthermore, the model was tested under several soil types i.e. clay soil (Ouda *et al*. 2006a), silty clay (Ouda *et al*. 2007) and saline soil (Ouda *et al*. 2006a; El-Mesiry *et al*. 2007) in Egypt. The common goal for using the model in those previous papers was to predict the potential yield reduction when deficit irrigation was applied under Egyptian conditions.

The objectives of this research were: (i) To calibrate and validate the Y-S model for maize yield and consumptive use data; (ii) To use the Y-S model to predict maize yield under deficit irrigation.

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MATERIALS AND METHODS

Maize field trials

Data for maize (*Zea mays* L.) yield and consumptive use were available from three years trial conducted at Beni Sweif governorate (Middle Egypt), in 1997, 1998 and 2000 growing seasons for maize hybrid TWC 310. These data was obtained from a project called "Soil and Water Resource Management" conducted by the Agricultural Research Center, Egypt in collaboration with ICARDA. Beni Sweif governorate is classified as an old land. The aim of these field trails was to compare between the effect of farmer practice and researcher practice on water productivity of maize. In the 1997 growing season, maize was planted on the 17th of May and harvested on the 31st of August. During the 1998 growing season, maize was planted on the 27th of May and harvested on the 15th of September, whereas it was planted on the 14th of June in 2000 growing season and harvested on 22nd of September. Nitrogen fertilizer was applied in the form of ammonium nitrate (288 unit/ha, 33% N) and was added before the 2nd irrigation. Phosphorus fertilizer was applied in the form of single super phosphate (72 unit/ha, 15.5% P_2O_5) and was incorporated into the soil during land preparation. Potassium sulfate was applied before the second irrigation (58 unit/ha, 48% KO_2). The amount of NPK applied was sufficient to ensure optimum plant growth during the three growing seasons. Irrigation was applied according to governmental enforced irrigation intervals, which are a time period where irrigation water is available in the irrigation canals to be used by farmers. Applied irrigation water was measured through discharge from a defined portable pump. Irrigation treatments were two treatments of water quality (fresh and agricultural drainage irrigation) and two treatments of water quantity (required and excess irrigation). The source of the fresh water is the Nile River and its EC value is equal to 0.48 dS/m. The source of agricultural drainage irrigation water is the agricultural drainage canals and its EC value was equal to 0.9 dS/m, which did not impose any salinity stress on the growing plants. The required irrigation water treatment was the amount of soil moisture that was removed from the soil profile as a result of evapotranspiration plus 20% to satisfy leaching requirements; it was applied by the researcher. The excess irrigation water treatment applied by the farmer was the amount of soil moisture that was removed from the soil profile as a result of evapotranspiration plus 50%, as it was measured by the researcher. Both researcher and farmers applied both water quality treatments. Soil moisture sampling was collected before irrigation to calculate the needed amount of applied irrigation water to reach field capacity. Consumptive use was calculated using the following equation (Israelsen and Hansen 1962):

$$CU = (\Theta_2 - \Theta_1) * Bd * ERZ \quad [1]$$

where CU = the amount of consumptive use (mm), Θ_2 = soil moisture percentage after irrigation, Θ_1 = soil moisture percentage before the following irrigation, Bd = bulk density (g/cm^3) and ERZ = effective root zone.

Yield-Stress model description

The Y-S model is a multi-year and a multi-crop simulation model. A detailed description of the model is included in Ouda (2006) at the following web site: http://www.insinet.net/journals.html. The model can be used by non-professionals, where the input of the model is easy to prepare and the output of the model is very descriptive of the process of the depletion of readily available water from the root zone after the application of each single irrigation. Thus, the user can easily determine at which irrigation he could apply deficit irrigation. The Y-S model uses a daily time step. The model requires weather data, management data and soil data. Weather data consists of maximum, minimum and mean temperature, relative humidity, solar radiation, and wind speed. Management data composed of planting and harvest dates, harvest index, irrigation date and amount, FAO's crop coefficient at each growth stage (Allen *et al*. 1998) and crop yield coefficient (Yc). Yc is a crop-specific dry matter accumulation coefficient, where its value is between 0 and 1. For maize grown in this location, Yc was between 0.5-0.8. Soil data consist of clay, silt, sand, organic matter, and $CaCO_3$ percentages. The model has three main components: soil water balance calculation routine, salinity stress routine and crop yield calculation routine.

Yield-Stress model calibration and validation

The model was calibrated for maize yield and consumptive use. Maize yield was calibrated by a specific crop yield coefficient for maize ranging from 0.5 to 0.8 in all the growing seasons. Regarding consumptive use, FAO's crop coefficient (Allen *et al*. 1998) was calibrated to local conditions. After calibration, the model was validated using data from field trials.

The goodness of fit between measured and predicted values by the model was tested by calculated percent difference between measured and predicted values of maize yield and consumptive use, in addition to root mean squared error per observation (RMSE/obs) (Jamieson *et al*. 1998) and the Willmott index of agreement (Willmott 1981).

Prediction of maize yield under deficit irrigation

Maize yield was predicted under skipping the last irrigation, and 80 and 70% of full irrigation under applying either required fresh or required amounts of agricultural drainage water. Under excess irrigation with either fresh or agricultural drainage water, maize yield was predicted under skipping the last irrigation, and 80 and 60% of full irrigation.

Water productivity calculations

Under all cases water productivity was calculated. Water productivity (WP, kg/m^3) is a quantitative term used to define the relationship between crop produced and the amount of water involved in crop production (FAO 2003). It can be calculated as followed:

$$WP = \text{Grain yield (kg/ha)}/\text{Applied irrigation amount (m}^3\text{/ha)} \quad [2]$$

RESULTS AND DISCUSSION

Maize field trials

The measured amounts of applied irrigation water and its corresponding yield values in the three growing seasons are shown in **Table 1**. Maize yields were significantly different (one sided *t*-test, $P < 0.05$) under the application of fresh and agricultural drainage irrigation amounts. Results in that table imply that increasing the amount irrigation increased maize yield within each growing season. This could be

Table 1 Irrigation amounts and corresponding maize yield values under fresh and drainage water irrigation amount.

Irrigation treatments	1997 growing season		1998 growing season		2000 growing season	
	Irrigation (m^3/ha)	Yield (ton/ha)	Irrigation (m^3/ha)	Yield (ton/ha)	Irrigation (m^3/ha)	Yield (ton/ha)
Fresh water						
Required	7459	6.91	6262	5.6	6665	8.0
Excess	8366	9.53	9046	5.7	9749	8.5
Drainage water						
Required	8266	7.3	6403	4.9	6799	7.9
Excess	9374	7.6	9118	7.4	9859	8.2

Table 2 Measured versus predicted maize yield (ton/ha) irrigated with fresh water irrigation.

Growing season	Required irrigation			Excess irrigation		
	Measured	Predicted	PD%	Measured	Predicted	PD%
1997	6.91	6.89	0.14	9.53	9.49	0.42
1998	5.60	5.58	0.36	5.70	5.69	0.18
2000	7.96	8.01	0.63	8.52	8.48	0.47
RMSE/obs	0.0048					
WI	0.9999					

PD% = percent difference between measured and predicted values, RMSE/obs = root mean square error per observation and WI = Willmott index of agreement.

Table 3 Measured versus predicted maize yield (ton/ha) irrigated with agricultural drainage water irrigation.

Growing season	Required irrigation			Excess irrigation		
	Measured	Predicted	PD%	Measured	Predicted	PD%
1997	7.30	7.26	0.95	7.60	7.56	0.53
1998	4.90	4.89	0.20	7.40	7.34	0.81
2000	7.90	7.88	0.25	8.20	8.14	0.73
RMSE/obs	0.0070					
WI	0.9997					

PD% = percent difference between measured and predicted values, RMSE/obs = root mean square error per observation and WI = Willmott index of agreement.

Table 4 Measured versus predicted maize consumptive use (cm) irrigated with fresh water irrigation.

Growing season	Required irrigation			Excess irrigation		
	Measured	Predicted	PD%	Measured	Predicted	PD%
1997	52.21	52.70	0.93	58.56	57.49	1.84
1998	58.43	58.55	0.21	75.07	72.37	3.60
2000	63.91	63.61	0.47	72.43	71.69	1.02
RMSE/obs	0.1797					
WI	0.9988					

PD% = percent difference between measured and predicted values, RMSE/obs = root mean square error per observation and WI = Willmott index of agreement.

Table 5 Measured versus predicted maize consumptive use (cm) irrigated with drainage water irrigation.

Growing season	Required irrigation			Excess irrigation		
	Measured	Predicted	PD%	Measured	Predicted	PD%
1997	57.86	57.50	0.62	60.62	60.44	0.30
1998	75.07	72.37	3.60	57.66	57.47	0.33
2000	72.43	71.69	1.02	65.38	65.04	0.52
RMSE/obs	0.1680					
WI	0.9987					

PD% = percent difference between measured and predicted values, RMSE/obs = root mean square error per observation and WI = Willmott index of agreement.

attributed to the fact that maize is a C4 species, which is characterized by having high water use efficiency (Gardner *et al*. 1985).

Yield-Stress model calibration and validation

1. Maize yield prediction

The model predicted maize yield with a high degree of precision under both required and excess fresh irrigation amounts. The percentage difference between measured and predicted values was less than 1%, the Willmott index of agreement was the highest and the root mean square error per observation was 0.0048 ton/ha (**Table 2**). Comparable results were obtained by Ouda *et al*. (2006b), when the Y-S model was used to predict maize yield grown under four different irrigation intervals and Ouda *et al*. (2008d), when the model was used to predict maize yield under water stress (20% of full irrigation), salinity stress and heat stress. Kiniry *et al*. (2004) reported that the ALMANAC model provided simulation of maize yield with a mean square error of 0.010 ton/ha.

A similar trend was observed when the Y-S model was used to predict maize yield under required and excess agricultural drainage water amounts (**Table 3**). Diaz-Ambrona *et al*. (2004) stated that the predicted maize yield values by the CropSyst model were close to measured values, where RMSE was 1.2 ton/ha. However, CROPWAT calculated maize grain yield with an RMSE of 14% (Campo *et al*. 2000).

2. Consumptive use prediction

Regarding maize consumptive use prediction under both required and excess fresh water irrigation amounts, there was good agreement between measured and predicted values. The percentage difference between actual and predicted values of consumptive use was less than 1 and 4% under required and excess irrigation, respectively. RMSE/obs was 0.1797 cm and the Willmott index of agreement was 0.9988 (**Table 4**). This result was in agreement with what was found by Ouda *et al*. (2006b) and Ouda *et al*. (2008d) when the Y-S model was used to predict maize consumptive use.

Analogous to consumptive use prediction under fresh water irrigation, the same trend was observed for consumptive use prediction under agricultural drainage water irrigation. Results in **Table 5** show good agreement between measured consumptive use and predicted values. Cavero *et al*. (2000) stated that the EPICphase model simulated maize evapotranspiration with a root mean square error of 40 mm.

Accurate results obtained from running the model under all irrigation treatments and growing seasons implied that the model can be used to simulate maize yield under water stress. Although the above situation provides only a limited evaluation of the model, the model should be further tested as more data from more treatments in different locations and growing seasons become available. However, for the purposes of this study we felt that the model worked sufficiently well to warrant the exploration of the effect of deficit irrigation on maize yield.

Table 6 Effect of deficit irrigation on predicted maize yield (ton/ha) irrigated with required irrigation.

Water quality	Irrigation	1997 growing season		1998 growing season		2000 growing season	
		Predicted yield	PR %	Predicted yield	PR %	Predicted yield	PR %
Fresh	Full irrigation	6.89	---	5.58	---	8.01	----
	Skipping last irrigation	6.79	1.50	5.58	0	7.97	0.50
	80% of full irrigation	6.89	0	5.56	0.36	7.99	0.25
	70% of full irrigation	6.80	1.30	5.50	1.43	7.82	2.37
Drainage	Full irrigation	7.26	---	4.89	---	7.88	---
	Skipping last irrigation	7.22	0.60	4.89	0	7.85	0.38
	80% of full irrigation	7.26	0	4.89	0	7.86	0.25
	60% of full irrigation	7.24	0.30	4.85	0.8	7.78	1.27

PR% = percent reduction between measured and predicted values.

Table 7 Effect of deficit irrigation on predicted maize yield (ton/ha) irrigated with excess irrigation.

Water quality	Irrigation	1997 growing season		1998 growing season		2000 growing season	
		Predicted yield	PR %	Predicted yield	PR %	Predicted yield	PR %
Fresh	Full irrigation	9.49	---	5.69	---	8.48	---
	Skipping last irrigation	9.43	0.63	5.69	0	8.48	0
	80% of full irrigation	9.49	0	5.69	0	8.48	0
	60% of full irrigation	9.21	2.95	5.66	0.53	8.46	0.24
Drainage	Full irrigation	7.56	---	7.34	---	8.14	---
	Skipping last irrigation	7.55	0.13	7.34	0	8.14	0
	80% of full irrigation	7.56	0	7.34	0	8.14	0
	60% of full irrigation	7.48	1.06	7.32	0.27	8.14	0

PR%= percent reduction between measured and predicted values.

Table 8 Water productivity (kg/m^3) for required irrigation amounts of both fresh and drainage water.

Irrigation	1997 growing season		1998 growing season		2000 growing season	
	Fresh	Drainage	Fresh	Drainage	Fresh	Drainage
Full irrigation	0.92	0.88	0.89	0.76	1.20	1.16
Skipping last irrigation	1.02	0.98	0.99	0.85	1.30	1.26
80% of full irrigation	1.15	1.10	1.11	0.95	1.50	1.45
70% of full irrigation	1.30	1.25	1.25	1.08	1.68	1.63

Prediction of maize yield under deficit irrigation

1. Maize yield prediction under required irrigation water

With respect to fresh water irrigation and under skipping the last irrigation (about 10% of full irrigation), low yield reduction could be attained (**Table 6**). Maize yield reductions were 1.5, 0 and 0.50% in 1997, 1998 and 2000 growing seasons, respectively. Low yield reduction was also obtained under irrigation with 80% of full irrigation. Under irrigation with 70% of full irrigation, maize yield losses were increased to 1.3, 1.43 and 2.37% in 1997, 1998 and 2000 growing seasons, respectively.

Regarding the agricultural drainage water irrigation treatment, lower yield losses were obtained, compared with fresh water irrigation. Yield losses were 0.3, 0.8 and 1.27% in 1997, 1998 and 2000 growing seasons, respectively under the application of 60% of full irrigation (**Table 6**). This situation is a result of using a larger amount of agricultural drainage water, compared with fresh water amount.

Similar results were obtained in Egypt for wheat planted at the same location in the winter growing seasons (Ouda *et al*. 2008b) and soybean in the summer growing season (Ouda *et al*. 2008a), where low yield reduction was obtained when 30% of the amount of irrigation water applied by the farmer was saved.

2. Maize yield prediction under excess irrigation water

More irrigation water could be saved under excess fresh and agricultural drainage water amounts (**Table 7**). Under fresh water irrigation, applying 60% of full irrigation water reduced maize yield by 2.95% in 1997 growing season and with less than 1% in 1998 and 2000 growing seasons.

Furthermore, under agricultural drainage water irrigation, 1.06% reduction in maize yield was obtained in the 1997 growing season under saving 40% of full irrigation whereas yield reduction was 0.27% in the 1998 growing season. In the 2000 growing season, no yield reduction was obtained under the same deficit irrigation treatment (**Table 7**).

Previous research in Egypt on irrigation water saving for maize at two locations in Egypt i.e. El-Kalubia (Lower Egypt) and Giza (Middle Egypt) showed that 20% of fully applied irrigation water for maize could be saved with low yield losses (Ouda *et al.* 2006b, 2008d).

Water productivity

The highest value of water productivity could be obtain under 70% of fully required irrigation for either fresh or agricultural drainage irrigation for all growing seasons (**Table 8**). In general, fresh water irrigation resulted in higher water productivity, compared with agricultural drainage irrigation. This could be explained by a lower amount of applied fresh water, compared with agricultural drainage amount. Results in **Table 8** also imply that, under the three growing seasons, it was very safe to conserve 30% of the applied irrigation water (fresh or agricultural drainage) because water productivity was the highest.

A similar trend of water productivity values was observed under irrigation with 60% of full excess water for either fresh or agricultural drainage irrigation for all growing seasons (**Table 9**). Thus, it is significant to reduce the amount of applied irrigation water as long as water productivity is high.

In an attempt to determine whether to apply deficit required irrigation or deficit excess irrigation, the amount of irrigation water, maize yield and water productivity were included in a table to help drawing a conclusion (**Table 10**). Regarding fresh water irrigation under the 1998 and 2000 growing seasons, saving 40% of full excess irrigation produced greater maize yield with lower water productivity as a result of a higher amount of applied irrigation water, compared with irrigation under saving 30% of full required irrigation. However, 1997 growing season was an exception as

Table 9 Water productivity (kg/m^3) for excess irrigation amounts of both fresh and drainage water.

Irrigation	1997 growing season		1998 growing season		2000 growing season	
	Fresh	Drainage	Fresh	Drainage	Fresh	Drainage
Full irrigation	1.13	0.81	0.63	0.81	0.87	0.83
Skipping last irrigation	1.26	0.91	0.71	0.91	0.95	0.91
80% of full irrigation	1.42	1.01	0.79	1.01	1.09	1.03
60% of full irrigation	1.83	1.33	1.04	1.34	1.45	1.38

Table 10 Irrigation amount, corresponding maize yield values and water productivity under applying 70 and 60% of full required and full excess irrigation.

Growing season	Fresh irrigation			Drainage irrigation		
	Irrigation (m^3/ha)	Yield (ton/ha)	WP (kg/m^3)	Irrigation (kg/m^3)	Yield (ton/ha)	WP (m^3/ha)
70% of full required irrigation						
1997	5221	6.80	1.30	5786	7.24	1.25
1998	4383	5.50	1.25	4482	4.85	1.08
2000	4666	7.82	1.68	4759	7.78	1.63
60% of full excess irrigation						
1997	5020	9.21	1.83	5625	7.48	1.33
1998	5428	5.66	1.04	5471	7.32	1.34
2000	5849	8.46	1.45	5916	8.14	1.38

a result of relatively high maize yield obtained under full excess irrigation.

The situation was reversed under excess agricultural drainage irrigation; a higher amount of applied irrigation water resulted in higher yield and higher water productivity under the 1998 and 2000 growing seasons, with an exception in 1997 growing season because the amount of applied irrigation water was lower under excess agricultural drainage irrigation (40% saving in irrigation water), compared with required agricultural drainage irrigation (30% saving in irrigation water) (**Table 10**). Under these circumstances, a question arises: which is more economical, to save irrigation water, or to increase crop production?

ELABORATION AND CONCLUSION

Maize is one of the important cereal crops in Egypt, where its consumption is increasingly rising from year to year due to an increase in the population. Egypt is suffering from the existence of a large gap between maize consumption and production and such shortage is compensated through imports, adding a heavy burden on the country's national budget, where in 2006 Egypt imported 3692,000 tons of maize (AEC 2007). The appropriate way to overcome such an existing gap is to increase crop production to meet increasing rise in its consumption. This is not an easy task since only a few approaches are available. An increase in production could be realized through augmenting the irrigated area; however, shortage of available water and productive lands are the major limiting factors impeding such an approach. Thus, two approaches exist without the need for additional water supply. The first one is to increase crop water productivity, i.e. to increase the yield with the same amount of water. The second one is to produce the same amount of maize yield with less applied irrigation water. Under Egyptian conditions, farmers are used to applying more irrigation water than crops need. Previous research on irrigation water saving proved that a relatively large amount of irrigation water could be saved with no or low yield reduction (Ouda *et al.* 2006b; Khalil *et al.* 2007; Tantawy *et al*. 2007; Ouda *et al.* 2008d).

Crop simulation models are used as tools to optimize agricultural management practices. Robust crop simulation models can provide a quantitative means to predict crop yield under different environmental and climatic conditions. Simulation models serve different purposes, and the intended purpose influences the level of details needed for mechanistic description of key processes, sensitivity to the environment and management, data requirements, and model outputs (Yang *et al*. 2004). Models that adequately simulate the effects of water stress on yield can be valuable tools in irrigation management. These models can be used to optimize the allocation of irrigation water between different crops and/or the distribution of water during the crop season (Howell *et al.* 1989). Several studies predicted maize yield under adequate irrigation using simulation models, such as the Hybrid-maize model (Yang *et al*. 2004) and the ALMANAC model (Kiniry *et al.* 2004). These models provide an opportunity to test conditions not applied in the field, which could be very economical in resource management. Furthermore, Cavero *et al*. (2000) used two simulation models i.e. EPICphase and CROPWAT to simulate maize yield under water stress; they concluded that these two models can be adequately used to predict maize yield reduction as a result of water stress under semi-arid conditions.

In semi-arid areas of the world, high yields of field crops can be attained if irrigation water were to be applied properly. However, because of the high demand for irrigation water by crops in these areas, yields can be very low if water is not supplied adequately both in quantity and in time (Singh and Singh 1995). Furthermore, in Egypt as a semi-arid region, water scarcity, on one hand, and the necessity of water saving in the agriculture sector, on the other, is pushing towards more drastic changes in the ways we are using and managing our water resources. The Egyptian government is very concerned about the spread of the concept of saving on the applied irrigation water between farmers and encourages researchers to develop techniques to increase the amount saved. Saving water in the irrigation sector through the improvement of on-farm water use efficiency and crop water productivity is now a must, which requires the exploration of different water management practices. However, this could be an expensive and a long process. Therefore, using simulation models, indeed, could be the most appropriate tools to predict the effect of irrigation with less water volumes or quality than the one of full irrigation on maize yield. Thus, this paper is a part of a series of experiments to explore the effect of saving irrigation water on the yield of several crops planted in various locations in Egypt.

The presented results clearly indicated that under deficit irrigation of fresh required water, a gradual reduction in the volume of applied water up to 30% did not result in any significant differences in the predicted maize yield, being near the same values obtained under full irrigation (**Table 6**). This situation holds true under irrigation with deficit required agricultural drainage water, where 70% of the full irrigation water could only reduce maize yield by less than 1.5% (**Table 6**). Furthermore, either excess fresh deficit irrigation or agricultural drainage irrigation produced low yield losses, less than 3% with 40% of full irrigation could be conserved, which is a very promising result and draws the attention to the high potential of saving water under maize cropping, as long as sensitive growth stages to water stress are avoided (**Table 7**).

Improving crop water productivity could be attained through implementing a deficit irrigation technique through which we can produce more or less than the same yield using less irrigation water. Furthermore, several improved agricultural management practices, such as land levelling and planting on wide furrows are used in Egypt to increase water productivity through the reduction of irrigation water losses in the field (unpublished data). Under such techniques, there is a high potential to save an ample amount of irrigation water to be used in cultivating more lands. Thus, an answer was presented for the question posed above "which is more important to save irrigation water, or to increase crop production?"

Our results showed that maize water productivity was gradually increased as less water volume was applied up to 30% of full required irrigation or 40% of full excess irrigation water (**Table 10**).

Therefore, implementing deficit irrigation successfully on a large scale requires an adequate updated know-how, fundamentally based on experimental findings and modelling results, in order to decide on the irrigation regime to be followed, which could provide on one hand, a satisfactory yield and on the other hand, a good irrigation water saving policy.

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