SIMULATION OF THE EFFECT OF IRRIGATION WATER SAVING ON WHEAT YIELD AT MIDDLE EGYPT

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ABSTRACT

Simulation of the effect of irrigation water saving on wheat yield and its consumptive use was done using data of four years field trials planted at Beni Sweif from 1998/99 to 2001/02. Wheat was irrigated with either fresh or drainage water. Yield-Stress model was calibrated and validated using the yield and consumptive use of those field trials. Then, the model was used to predict wheat yield and consumptive use under deficit irrigation (90, 85, 80 and 70% of full irrigation). The results of the simulation showed that there was a high potentiality for irrigation water saving corresponding to up to 30% of the applied full irrigation with yield losses not exceeding the 5% under both fresh and drainage water irrigation. The highest water productivity was attained when wheat was irrigated with 3530 and 3635 m^3/ha of fresh and drainage water, respectively. Changing irrigation schedule could save up to 17% of the full irrigation with low yield losses. However, the point that should be clearly identified is to what extent the applied water can be reduced without exerting harmful effects on wheat yield.

Keywords: Yield-Stress model, Deficit irrigation, Irrigation rescheduling, Consumptive use, Crop water productivity

INTRODUCTION

Wheat is a very important cereal crop in Egypt. The crop is very sensitive to the timing of a water deficient period rather than the total reduction in applied irrigation water. Exposing wheat plants to high water stress reduced seasonal consumptive use and grain yield (El-Kalla et al. [1] and Khater et al. [2]). During vegetative growth, phyllochron decreases in wheat under water stress (McMaster [3]) and leaves become smaller, which might reduce leaf area index (Gardner et al. [4]) and decrease the number of reproductive tillers, in addition to limit their contribution to grain yield (Mosaad et al. [5]). Furthermore, water stress occurring during grain growth could have a severe effect on the final yield compared with stress occurring during other stages (Hanson and Nelson [6]). The amount of wheat yield reduction as a result of water stress is affected by the stage of grain development, where the early grain development stage is the most vulnerable (El-Kholy et al. [7]). Therefore, modeling can assist in determining when to reduce the amount of applied irrigation water to wheat plants and what would be the potential yield losses.

Irrigation management can be done by modeling water depletion from root zone under the application of different amounts of irrigation water (Khalil et al. [8]). Models that simulate crop growth and water flow in the root zone can be a powerful tool for extrapolating findings and conclusions from field studies to conditions not tested (Smith et al. [9]). Several simulation models for crop water requirements have been developed using this approach (Camp et al. [10]; Smith [11]; Foroud et al. [12]; George et al. [13]). These models have been widely accepted, but their application by researchers has been very slow because it needs large set of input data.

In this context, the Yield-Stress model (Ouda [14]) was designed to predict the effect of deficit irrigation scheduling on the yield of several crops and their consumptive water use. The model was developed to be an easy irrigation management tool to be used by non-professionals. Basically, the Yield-Stress model assumes that there is a linear relationship between available water and yield, where reduction in available water limits evapotranspiration and consequently reduced yield. This assumption is supported by the work of several researchers (de Wit [15]; Childs and Hanks [16]; Bresler [17]; and Shani and Dudley [18]). The Yield-Stress model was tested in irrigation management for several crops under different stress conditions and its performance was acceptable. The model was used to predict maize yield grown under water stress (Ouda et al. [19]) and to predict maize yield under salinity stress and heat stress (Ouda et al. [20]. The model was also use for irrigation management and in soybean (Ouda et al. [21]). The model was used in irrigation optimization for sunflower grown under saline conditions (Ouda et al. [22]). Furthermore, the model was validated under skipping the last irrigation for barley and then was exploited in different irrigation management practices (Khalil et al. [8]). Similarly, the model was validated under deficit irrigation for sesame yield (Tantawy et al. [23]). Therefore, the Yield-Stress model could be utilized for developing different irrigation management scenarios for an important crop, such as wheat to save irrigation water and to minimize yield losses.

The objectives of this research were: (i) to calibrate and validate Yield-Stress model for wheat yield and consumptive use data for four growing seasons; (ii) to use Yield-Stress model to predict wheat yield under deficit irrigation; (iii) to use the model to develop several irrigation water saving scenarios for wheat that could result in low yield reduction.

MATERIALS AND METHODS

1. Wheat field trials

Data for wheat yield and consumptive use were available from a four-year farm trial conducted at Beni Sweif Governorate (Middle Egypt) from 1998/99 to 2001/02 growing seasons. These data was obtained from a project called "Soil and Water Resource Management" done by Agricultural Research Center, Egypt in collaboration with ICARDA. Sufficient NPK was applied to insure optimum plants growth. Irrigation was applied according to governmental enforced irrigation intervals. Applied irrigation amounts were measured through discharge from defined portable pump. 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 [24]):

$$CU = (\Theta_2 - \Theta_1) * Bd * ERZ \qquad (1)$$

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. Irrigation treatments were two treatments of water quality i.e. fresh and drainage irrigation. EC value of fresh water was equal to 0.48 dS/m, and it was equal to 0.9 dS/m for agricultural drainage water, which did not impose any salinity stress on the growing plants. Season length and seasonal weather parameters at Beni Swief are included in Table (1).

Table (1): Season length and seasonal weather parameters of wheat planted in four growing seasons

Growing season	Season length (days)	Mean temperature (°C)	Relative humidity (%)	Wind speed (m/sec)	Solar radiation (Mj/m^2/day)
1998/99	167	16.5	62	1.3	16.1
1999/00	167	18.0	63	1.3	16.1
2000/01	166	19.1	64	1.3	16.3
2001/02	166	19.2	65	1.3	16.3

2. Yield-Stress model description

Yield-Stress model is a multi-year and a multi-crop simulation model. 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 root zone after the application of each single irrigation. Thus, the user can easily determine at which irrigation he could apply deficit irrigation. The Yield-Stress model uses a daily time step. The model requires weather data, management data and soil data. Weather data consist of maximum, minimum and mean temperature, relative humidity, solar radiation, wind speed. Management data composed of planting and harvest dates, season length, irrigation date and amount, FAO's crop coefficient at each growth stage (Allen et al. [25]). Soil data are consist of clay, silt, sand, organic matter, and $CaCO_3$ percentages. The model has three main components: soil water balance routine, salinity stress routine and crop yield calculation routine.

3. Yield-Stress model calibration and validation

The model was calibrated for wheat yield and consumptive use and then the model was validated using the field trials data. The goodness of fit between measured and predicted values by the model was tested by calculated percent difference between measured and predicted values of wheat yield and consumptive use, in addition to root mean squared error (RMSE) (Jamieson et al. [26]) and Willmott index of agreement (Willmott [27]).

4. Prediction of wheat yield under deficit irrigation

Wheat yield was predicted under 90, 85, 80 and 70% of full irrigation with either fresh or drainage water amounts. Furthermore, three additional deficit irrigation scenarios were developed in an attempt to save more irrigation water and to reduce yield losses.

5. Water productivity calculations

Crop water productivity (CWP, 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 [28]). It can be calculated as follows:

$$CWP = \text{Grain yield (kg/ha)}/\text{Applied irrigation amount (m}^3\text{/ha)} \tag{2}$$

RESULTS AND DISCUSSION

1. Wheat field trials

The measured amounts of applied irrigation water and its corresponding measured yield values at Beni Sweif site are shown in Table (2). Wheat yields under the application of full irrigation amounts were significantly differed (one sided t-test, $P < 0.001$). Results in that table showed that the lowest applied irrigation amount in both fresh and drainage water produced the highest measured wheat yield in 2001/02 growing season. On the contrary, the highest applied irrigation water in 1999/00 produced the lowest wheat yield. This finding implied that there is a potential to save irrigation water.

Table (2): Irrigation amounts and corresponded wheat yield values grown under fresh and drainage water irrigation

Growing season	Fresh water irrigation		Drainage water irrigation	
	Irrigation amount (m^3/ha)	Yield (ton/ha)	Irrigation amount (m^3/ha)	Yield (ton/ha)
1998/99	4932	5.28	5174	5.23
1999/00	5426	5.73	5683	4.73
2000/01	4920	5.74	4980	6.32
2001/02	4891	6.82	4932	6.55

2. Yield-Stress model validation

2.1. Wheat yield prediction

The model predicted wheat yield with high degree of precision under both fresh and drainage irrigation amounts. Percent difference between measured and predicted values was less than 1%, Willmott index of agreement was the highest and root mean square error was 0.0044 and 0.0046 ton/ha under fresh and drainage irrigation amounts, respectively (Table 3). Similar results were obtained by Lobell and Ortiz-Monasterio [29] when CERES-Wheat model was used to predict crop yield for different irrigation treatments with a root mean squared error of 0.23 ton/ha. Panda et al. [30] stated that root mean squared error was 0.246 ton/ha between measured and predicted wheat yield when CERES-Wheat model was used.

Table (3): Measured versus predicted wheat yield grown under fresh and drainage irrigation

Growing season	Fresh water irrigation			Drainage water irrigation		
	Yield (ton/ha)		PD %	Yield (ton/ha)		PD %
	Measured	Predicted		Measured	Predicted	
1998/99	5.28	5.28	0	5.23	5.23	0
1999/00	5.73	5.73	0	4.73	4.73	0
2000/01	5.74	5.73	0.17	6.32	6.31	0.16
2001/02	6.82	6.79	0.44	6.55	6.52	0.46
RMSE	0.0044			0.0046		
WI	0.9999			0.9999		

PD%= percent difference between measured and predicted values; RMSE= root mean square error; WI= Willmott index of agreement.

2.2. Water consumptive use prediction

Regarding to wheat consumptive use prediction under both fresh and drainage water irrigation amounts, there was a good agreement between measured and predicted values. Percent difference between measured and predicted values of consumptive use were less than 3%, RMSE was 0.0301 cm and Willmott index of agreement was 0.9631 under fresh water irrigation (Table 4). With respect to drainage water irrigation, percent difference between measured and predicted values was less than 3%, RMSE was 0.0332 cm and Willmott index of agreement was 0.9715 (Table 4). These findings are in agreement with what was obtained by El-Mesrity et al. [31] and Ouda et al. [21] when the Yield-Stress model was used to predict wheat consumptive use.

Table (4): Measured versus predicted consumptive use for wheat grown under fresh and drainage irrigation

Growing season	Fresh water irrigation			Drainage water irrigation		
	CU (cm)		PD %	CU (cm)		PD %
	Measured	Predicted		Measured	Predicted	
1998/99	40.04	41.03	2.47	40.72	41.03	0.76
1999/00	41.28	41.88	1.45	42.64	41.88	1.78
2000/01	44.73	44.32	0.92	45.63	44.32	2.87
2001/02	44.90	45.84	2.09	46.66	45.84	1.76
RMSE	0.0301			0.0332		
WI	0.9631			0.9715		

CU= consumptive use; PD%= percent difference between measured and predicted values; RMSE= root mean square error; WI= Willmott index of agreement.

3. Prediction of the effect of deficit irrigation on wheat yield

Predicted wheat yield under different deficit irrigation treatments and its reduction percentage under fresh water irrigation are presented in Table (5). The results indicated that in 1998/99 and 1999/00 growing seasons, 30% of full irrigation could be safely saved with yield reduction less than 4%. However, in 2000/01 and 2001/02 growing seasons, only 20% of full irrigation could be saved with less than 4% yield reduction. This may be attributed to the weather conditions that were prevailing in last two growing seasons, i.e. higher seasonal temperature, compared with the first two growing seasons (Table 1). Similar results were obtained by Khalil et al. [32], where 4% losses in wheat yield was occurred when 10% of the irrigation water was saved.

Table (5): Predicted wheat yield and its reduction percentages under fresh deficit irrigation water

Irrigation	1998/99		1999/00		2000/01		2001/02	
	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %
FI	5.28	0	5.73	0	5.73	0	6.79	0
90% of FI	5.27	0.19	5.72	0.17	5.71	0.35	6.70	1.33
85% of FI	5.26	0.38	5.68	0.87	5.69	0.70	6.65	2.06
80% of FI	5.16	2.27	5.68	0.87	5.59	2.44	6.53	3.83
70% of FI	5.07	3.98	5.52	3.66	5.31	7.33	6.18	8.98

FI= full irrigation (m^3/ha); 90% of FI= 90% of full irrigation; 85% of FI= 85% of full irrigation; 80% of FI= 80% of full irrigation; 70% of FI= 70% of full irrigation; PR%= percent reduction between measured and predicted yield.

Similar situation could occur under drainage water irrigation, where yield reduction under the first two growing seasons was lower than the yield reduction under the second two growing seasons (Table 6). Applying 70% of full irrigation reduced wheat yield by approximately 3% in the first two growing season, whereas applying 80% of full irrigation could reduce yield by 4% in the second two growing seasons.

Table (6): Predicted wheat yield and its reduction percentages under drainage deficit irrigation water

Irrigation	1998/99		1999/00		2000/01		2001/02	
	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %
FI	5.23	0	4.73	0	6.31	0	6.52	0
90% of FI	5.22	0.19	4.73	0.00	6.30	0.16	6.45	1.07
85% of FI	5.19	0.76	4.72	0.21	6.26	0.79	6.36	2.45
80% of FI	5.16	1.34	4.71	0.42	6.19	1.90	6.27	3.83
70% of FI	5.07	3.06	4.61	2.54	5.89	6.66	5.97	8.44

FI= full irrigation (m^3/ha); 90% of FI= 90% of full irrigation; 85% of FI= 85% of full irrigation; 80% of FI= 80% of full irrigation; 70% of FI= 70% of full irrigation; PR%= percent reduction between measured and predicted yield.

4. Proposed scenarios to save on the applied fresh irrigation water

4.1. Scenario 1: Application of 70% of full irrigation averaged over all growing seasons

The applied amount of 70% of full irrigation water in all the studied growing seasons was averaged, which resulted in an amount of 3530 and 3635 m^3/ha of fresh and drainage water, respectively. The model was run using these two irrigation amounts and the results are presented in Table (7). Wheat yield losses under the application of 3530 m^3/ha of fresh water was lower, compared with the losses when 70% of full irrigation was applied in all growing seasons, except of 1999/00 growing season, where yield losses was higher. Furthermore, under drainage water irrigation, applying 3635 m^3/ha increased wheat yield losses in 1998/99 and 1999/00 growing seasons and reduced yield losses in 2000/01 and 2001/02 growing seasons.

Table (7): Measured versus predicted wheat yield irrigated with average of 70% of full irrigation

Season	Fresh water irrigation			Drainage water irrigation		
	Yield (ton/ha)		% Reduction	Yield (ton/ha)		% Reduction
	Measured	Predicted		Measured	Predicted	
1998/99	5.28	5.10	3.41	5.23	5.03	3.82
1999/00	5.73	5.34	6.81	4.73	4.47	5.50
2000/01	5.74	5.39	6.10	6.32	6.02	4.75
2001/02	6.82	6.26	8.21	6.55	6.06	7.48

4.2. Scenario 2: Skipping the last irrigation

After examining the depletion of readily available water from root zone under the four growing seasons, it became clear that the growing season of 1999/00 was found to be the one that did not contains any water stress days (Table 8). The applied fresh irrigation amount of full irrigation was 5426 m^3/ha. The results in that table indicated that the amount of 1^{st} irrigation was not completely depleted before the 2^{nd} irrigation was applied and 37 mm of readily available water was remained in the root zone. Similarly, before the application of the 3^{rd} irrigation, there was 8 mm of readily available water was remaining in the root zone, and so on. Thus, these results implied that there is a potential to save irrigation water after the 4^{th}, 5^{th} and the 6^{th} irrigations, where readily available water was 37, 72 and 61 mm, respectively.

Table (8): Irrigation number and the amount of readily available water after each irrigation and before the following irrigation for wheat in 1999/00 season

Irrigation number	Readily available water (mm)	
	After irrigation was applied	Before the following irrigation
1st	57	37
2nd	24	8
3rd	57	2
4th	97	37
5th	119	72
6th	142	61
Harvest	61	---

Therefore, a proposed scenario was used to save irrigation water (Table 9). Under this scenario, the last irrigation was omitted and the interval between 4th and the 5th irrigations was increased. The applied irrigation amount was 4295 m^3/ha. Thus, the amount of readily available water was reduced from 37 mm before the 5th irrigation (Table 8) to 2 mm (Table 9), which saved about 17% of the applied irrigation amount.

Table (9): Irrigation number and the amount of readily available water after each irrigation and before the following irrigation for wheat in 1999/00 season under scenario 2

Irrigation number	Readily available water (mm)	
	After irrigation was applied	Before the following irrigation
1st	57	37
2nd	24	8
3rd	57	2
4th	97	2
5th	118	24
Harvest	24	---

The above mentioned irrigation schedule was used to run the model for each of the studied growing seasons. The results in Table (10) implied that using irrigation amount of 4295 m^3/ha (5 irrigations instead of 6 irrigations) resulted in no yield losses in 1998/99 and 1999/00 growing seasons and reduced wheat yield by 0.52 and 1.47% in 2000/01 and 2001/02 growing seasons, respectively. Consumptive use was slightly reduced under this irrigation scenario.

Table (10): Measured versus predicted wheat yield and water consumptive use under irrigation with 4295 (m^3/ha)

Growing season	Wheat yield (ton/ha)			Consumptive use (cm)		
	Measured	Predicted	% Reduction	Measured	Predicted	% Reduction
1998/99	5.28	5.28	0	40.04	41.03	2.47
1999/00	5.73	5.73	0	41.28	41.88	1.45
2000/01	5.74	5.71	0.52	44.73	44.09	1.43
2001/02	6.82	6.72	1.47	44.90	45.25	0.78

4.3. Scenario 3: Saving the last irrigation plus 5%

The irrigation amount of 4295 m^3/ha (scenario 2) was reduced by 5%, which resulted in 4080 m^3/ha. The model was run using this irrigation amount to examine the effect of saving more irrigation water on wheat yield in the four growing seasons (Table 11). Low yield reduction could occur under that scenario, where the highest yield reduction was obtained in 2001/02 growing season, i.e. 2.64%. Furthermore, low reduction in consumptive use occurred under this irrigation scenario.

Table (11): Measured versus predicted wheat yield and consumptive use using irrigation amount of 4080 (m^3/ha)

Growing season	Wheat yield (ton/ha)			Consumptive use (cm)		
	Measured	Predicted	% Reduction	Measured	Predicted	% Reduction
1998/99	5.28	5.28	0.00	40.04	40.99	2.37
1999/00	5.73	5.72	0.17	41.28	41.81	1.28
2000/01	5.74	5.67	1.22	44.73	43.66	2.39
2001/02	6.82	6.64	2.64	44.90	44.57	0.73

5. Crop water productivity

The results presented in Table (12) showed that water productivity was gradually increased with increasing the deducted percentage of full irrigation. Furthermore, the results also implied that crop water productivity could be increased if wheat was irrigated with 3530 m^3/ha in the four growing seasons. The lowest crop water productivity was obtained under irrigation with 4295 m^3/ha.

Table (12): Water productivity for wheat irrigated with different fresh water amounts

Growing season	Water productivity (kg/ha) under			
	Full irrigation	Scenario 1	Scenario 2	Scenario 3
1998/99	1.07	1.44	1.23	1.29
1999/00	1.06	1.51	1.33	1.40
2000/01	1.17	1.53	1.33	1.39
2001/02	1.39	1.77	1.56	1.63

Scenario 1= irrigation with 3530 m^3/ha; Scenario 2: irrigation with 4295 m^3/ha; Scenario 3: irrigation with 4080 m^3/ha.

CONCLUSION

Expressive information on the effect of deficit irrigation on wheat productivity could be very useful in determining yield losses for economical purposes. Therefore, modeling the effect of different deficit irrigation treatments could be the ultimate solution. Yield-Stress model employed soil water depletion equations to instantly predict potential wheat yield under varying degree of deficit irrigation, which could partially replacing expensive field experiments. The good agreement between measured and predicted wheat yield and consumptive use values implied that the model is capable of investigating radical alternatives of irrigation water to increase water productivity and reduce yield losses to a minimal.

Our results showed that saving of 20% to 30% of both fresh and drainage irrigation water could reduce wheat yield by up to 5%. Furthermore, irrigation with 3530 m^3/ha of fresh water could save 30% of full irrigation with yield losses could reach 7%. Whereas, yield losses could be reduced to less than 1.5%, if irrigation was reschedule (4295 m^3/ha) and irrigation number was reduced to 5 irrigations instead of 6 irrigations. More irrigation water could be saved when 5% of the amount of 4295 m^3/ha was saved with a total of 4020 m^3/ha and yield losses could be less than 3%. However, water productivity was the highest under the application of 3530 m^3/ha. Therefore, it could be recommended to irrigate wheat with 70% of full irrigation to save irrigation water and increase water productivity.

REFERENCES

[1] El-Kalla, S.E., Leilah, A.A., Basiony, A.H., Hussien, S.M. Effect of Irrigation and foliar nutrition treatments on growth and yield of some wheat cultivars under El-Arish area condition. 6^{th} conf. Agron., Fac. Agric., Al-Azhar Uni., Egypt, 1994.

[2] Khater, A.N, Abdel Maksoud, H.H, Eid, H.M. Response of some wheat cultivars and their water relations to different irrigation level in Middle Delta. Egypt, J. Appl. Sci. 11(2):15-29, 1997.

[3] McMaster, G.S. Phonology, development, and growth of wheat (Triticum aestivum L.) shoot apex: A review. Adv. Agron. 59:63-118, 1997.
[4] Gardner, F.P., Pearce, R.B, Mitchell, R.L. Physiology of crop plants. Iowa State University Press. Ames, 1985.
[5] Mosaad, M.G., Ortiz-Ferrara, G., Mahalak-Shmi, V. Tiller development and contribution to yield under different moisture regimes in two Triticum species. J. Agron. 174: 173-180, 1995.
[6] Hanson, A.D., Nelson E.C. The biology of crop production. New York Academic Press, 1980.
[7] El-Kholy, M.A., Ouda, S.A., Gaballah, M.S., Hozayn, M. Predicting the interaction between the effect of anti-transpirant and weather on productivity of wheat plant grown under water stress. J. Agron. 4(1):75-82, 2005.
[8] Khalil, F.A., Ouda, S.A., Tantawy, M.M. Predicting the effect of optimum irrigation and water stress on yield and water use of barley. J. App. Sci. Res. 3(1):1-6, 2007.
[9] Smith, M., CROPWAT: a computer program for irrigation planning and management. FAO Land and Water Development Division, FAO, Rome, 1991.
[10] Camp, C.R., G.D. Christenbury, and C.W. Doty. Scheduling irrigation for corn and soybeans in the southern coastal plains. Trans. ASAE. 31, 513-518, 1988.
[11] Smith, M., Kivumbi, D., Heng, L.K. Use of the FAO CROPWAT model in deficit irrigation studies. Defic. Irrig. Pract. 22:17-27, 2000.
[12] Foroud, N., Hobbs, E.H., Riewe, R., Entz, T., Field verification of a micro computer irrigation model. Agric. Water Manag. 21, 215-234, 1992.
[13] Georgea. B.A., Shende, S.A., Raghuwanshi, N.S. Development and testing of an irrigation scheduling model. Agric. Wat. Manag. 46:121-136, 2000.
[14] Ouda, S.A. Predicting the effect of water and salinity stresses on wheat yield and water needs. J. Appl. Sci. Res. 2(10):746-750, 2006.
[15] de Wit, C.T. Transpiration and crop yield. Versl. Landbouwk. Onderz. 64.6 Inst. of Biol. Chem. Res. Field Crops Herbage, Wageningen, the Netherlands, 1958.
[16] Childs, S.W., and Hanks R.J. Model of soil salinity effects in crop growth. Soil Sci. Soc. Am. Proc. 39:112–115, 1975.
[17] Bresler, E. Application of conceptual model to irrigation water requirement and salt tolerance of crops. Soil Sci. Soc. Am. J. 51:788–793, 1987.
[18] Shani, U. and. Dudley, L. M. Field studies of crop response to water and salt stress. Soil Sci. Soc. Am. J. 65:1522–1528. 2001.
[19] Ouda, S.A., Khalil, F.A., Tantawy, M.M. Predicting the impact of water stress on the yield of different maize hybrids. Res. J. Agric. Bio. Sci. 2(6):369-374, 2006.
[20] Ouda, S.A., S.A. Mohamed and F.A. Khalil. Modeling the effect of different stress conditions on maize productivity using Yield-Stress model. Inter. J. Natural. Eng. Sci. 2(1)57-62, 2008.
[21] Ouda, S., R. Abou Elenin, M. A. K. Shreif, B. Benli and M. Qadir. Prediction of soybean yield and water productivity under deficit irrigation using Yield-Stress model. Inter. J. Nat. Eng. Sci. 2(2)05-12, 2008.

[22] Ouda, S.A., Gaballah, M.S., Tantawy, M.M., El-Mesiry, T. Irrigation optimization for sunflower grown under saline conditions. Res J. Agric. Bio. Sci. 2(6):323-327, 2006.
[23] Tantawy, M.M., Ouda, S.A., Khalil, F.A. Irrigation optimization for different sesame varieties grown under water stress conditions. J. App. Sci. Res. 3(1):7-12, 2007.
[24] Israelsen, O.W., Hansen, V.E. Irrigation Principles and Practices. John Wiley & Sons, Inc. New York, 1962.
[25] Allen, R.G., Pereira, L.S., Raes, D., M. Smith. Crop evapotranspiration: Guideline for computing crop water requirements. FAO N^{o}56, 1998.
[26] Jamieson, P.D., J.R. Porter, J. Goudriaan, J.T. Ritchie, H. van Keulen, and W. Stol. A comparison of the models AFRCWHEAT2, CERES-Wheat, Sirius, SUCROS2 and SWHEAT with measurements from wheat grown under drought. Field Crops Res. 55:23–44, 1998.
[27] Willmott, C.J. On the validation of models. Phys. Geogr. 2:184–194, 1981.
[28] FAO, Unlocking the Water Potential of Agriculture. FAO Corporate Document Repository. 260pp, 2003.
[29] Lobell, D.B. and Ortiz-Monasterio, J.I. Evaluating strategies for improved water use in spring wheat with CERES. Agric. Wat. Manag. 84:249-258, 2006.
[30] Panda, R.K., Behera, S.K., P.S. Kashyap. Effective management of irrigation water for wheat under stressed conditions. Agric. Wat. Mange. 63:37-56, 2003.
[31] El-Mesiry, T., M.S. Gaballah and S.A. Ouda. Using Yield-Stress model in irrigation management for wheat grown under saline conditions. Aust. J. Basic Appl. Sci. 1(4):600-609, 2007.
[32] Khalil, F.A.F., G.A. El-Shaarawy and H.Y.M. Hasan. Irrigation scheduling for some wheat cultivars through pan evaporation norms and its effect on growth, yield and water use efficiency. Fayoum J. Agric. Res. Dev. 21(1):222-233, 2005.