USING YIELD-STRESS MODEL TO PREDICT THE IMPACT OF DEFICIT IRRIGATION ON ONION YIELD

Samiha A. Ouda[1*], Rashad Abou Elenin[2] and Mouhamed A. Shreif[1]

[1] Water Requirements and Field Irrigation Research Department, Soil, Water, and Environment Research Institute, Agricultural Research Center, Egypt
*Corresponding author: E-mail: samihaouda@yahoo.com
[2] IBS Coordinator, Agricultural Research Center, Egypt

ABSTRACT

The impact of deficit irrigation on onion yield and consumptive use was predicted after calibration and validation of Yield-Stress model for onion data obtained from three-year field trial (1998/99, 1999/00 and 2000/01) conducted in Beni Swief governorate, Egypt. Two irrigation treatments were used in these trials (fresh and drainage water irrigation). The goodness of fit between measured and predicted onion yield and consumptive use was done by calculating percent difference between measured and predicted values, root mean square error and Willmott index of agreement. Four deficit irrigation treatments were tested (95, 90, 85 and 80% of full irrigation). The results showed that three was a good agreement between measured and predicted values by Yield-Stress. The results also indicated that applying 80% of full irrigation of either fresh or drainage irrigation resulted in low yield losses. Furthermore, water use efficiency was the highest under irrigation with 80% of full irrigation. Therefore, 20% of the applied fresh or drainage irrigation water could be saved and used in irrigating new reclaimed areas.

Keywords: Irrigation water quality, Fresh water, Drainage water, Consumptive use

INTRODUCTION

Onion is one of the important vegetable crops in Egypt, which is cultivated in a large scale. Onion yield and grade are very responsive to careful irrigation scheduling and maintenance of optimum soil moisture (Shock et al. [1] and Shock et al. [2]). Bekele et al. [3] concluded that water deficit at first and fourth growth stages, gave non-significantly different yield from the optimum irrigation application. Furthermore, when water stress was imposed 30 days after transplanting for a period of 15 days, leaf area and bulb growth were considerably decreased with a reduction of 17–26% in onion yield (Bhatt et al. [4]). Soil water stress caused by withholding irrigation at both the third-leaf and seven-leaf stages reduced onion yield by 26% (Pelter et al. [5] and Bekele et al. [3]). Applying irrigation as 25% of ET_c, 50% of ET_c, and 75% of ET_c water deficit reduced onion yield, compared with optimal irrigation (Bekele et al. [3]).

Many simulation models using soil water budget in the root zone were developed over the past thirty years (Hill et al. [6]; Camp et al. [7]; Choeng [8]; Foroud et al. [9] Smith [10]; Prajamworng [11]; George et al. [12]). Another model called Yield-Stress (Ouda [13]) was developed using similar approach to that of CROPWAT in the estimation of soil water reserve in the root zone and the determination of crop evapotranspiration, with a different method in the calculation of yield reduction as a result of water stress. 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 pervious work of several researchers (de Wit [14]; Childs and Hanks [15]; Bresler [16]; and Shani and Dudley [17]). The Yield-Stress model was design to predict the effect of deficit irrigation scheduling on the yield of several crops and their consumptive use. The model was used in irrigation management for several crops under different stress conditions and its performance was acceptable (Ouda et al. [18]; Ouda et al. [19]; El-Mesiry et al. [20]; Khalil et al. [21]; Ouda et al. [22]; Tantawy et al. [23]; Ouda et al. [24]; Ouda et al. [25]; Ouda et al. [26]). Khalil et al. [27] concluded that the performance of Yield-Stress model in predicting the yield and consumptive use of sesame was comparable with CROPWAT model.

The objectives of this research were: (i) To calibrate and validate Yield-Stress model for onion yield and consumptive use data for three growing seasons; (ii) To use Yield-Stress model to predict onion yield under deficit irrigation treatments; (iii) To determine water use efficiency of onion under these deficit irrigation treatments.

MATERIALS AND METHODS

1. Onion field trials

Data for onion yield and consumptive use were available from a three-year farm trial conducted at Beni Sweif governorate (Middle Egypt) in 1998/99, 1999/00 and 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 [28]):

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

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 are included in Table (1).

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

Season	Season length (days)	Mean temperature (°C)	Relative humidity (%)	Wind speed (m/sec)	Solar radiation ($MJ/m^2/day$)
1998/99	145	15.5	63	1.2	15.1
1999/00	140	17.1	64	1.2	15.3
2001/02	142	18.1	64	1.2	15.1

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. [29]). Soil data are 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.

3. Yield-Stress model calibration and validation

The model was calibrated for onion 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 onion yield and consumptive use, in addition to root mean squared error (RMSE) (Jamieson et al. [30]) and Willmott index of agreement (Willmott [31]).

4. Prediction of onion yield under deficit irrigation

Onion yield was predicted under 95, 90, 85 and 80% of full irrigation with either fresh or drainage water irrigation amounts.

5. Water use efficiency calculation

Water use efficiency (WUE, kg/m^3) values for the three varieties were calculated by the following equation (Vites [32]).

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

RESULTS AND DISCUSSION

1. Onion field trials

The measured amounts of applied irrigation water for onion and its corresponding measured yield values are shown in Table (2). Onion yield under the application of full irrigation amounts were significantly differed (one sided t-test, $P < 0.001$). Results in that table showed that the highest applied irrigation amount in both fresh and drainage water produced the lowest measured onion yield in 1999/00 growing season. This result could be attributed to the seasonal mean temperature was high during that growing season (Table 1), which could imposed heat stress on the growing plants and increased evapotranspiration and the applied irrigation amount. Whereas, medium applied irrigation water in 1998/99 growing season produced the highest yield under fresh and drainage water irrigation (Table 2), which could be an imply of the potentiality to save irrigation water.

Table (2): Irrigation amounts and onion yield for both fresh and drainage irrigation water

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	3518	18.37	3684	15.33
1999/00	3857	11.43	3996	9.48
2001/02	3240	12.09	3312	10.07

2. Yield-Stress model Validation

2.1. Prediction of onion yield

The model predicted onion yield with high degree of precision under both fresh and drainage irrigation amounts. RMSE was 0.0032 and 0.0030 ton/ha under fresh and drainage water irrigation, respectively. Willmott index of agreement was close to one under both fresh and drainage irrigation amounts (Table 3). Similar results were obtained by Yield-Stress model when it was used to predict the yield of some winter crops such as wheat (Ouda et al. [25]) and barley (Khalil et al. [21]).

Table (3): Measured versus predicted onion yield irrigated with fresh and drainage water

Growing Season	Fresh water irrigation			Drainage water irrigation		
	Yield (ton/ha)		PD %	Yield (ton/ha)		PD %
	Measured	Predicted		Measured	Predicted	
1998/99	18.37	18.33	0.22	15.33	15.3	0.20
1999/00	11.43	11.42	0.09	9.48	9.48	0
2001/02	12.09	11.90	1.57	10.07	10.06	0.10
RMSE	0.0032			0.0030		
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. Prediction of consumptive use

Regarding to onion consumptive use prediction under both fresh and drainage water irrigation amounts, there was a good agreement between measured and predicted consumptive use values. Percent difference between measured and predicted values were less than 3%, RMSE was 0.0404 cm and Willmott index of agreement was 0.9605 under fresh water irrigation (Table 4). With respect to drainage water irrigation, the highest percent difference between measured and predicted value of consumptive use was 4.22%, RMSE was 0.0746 cm and Willmott index of agreement was 0.9541. Similar results were obtained by Yield-Stress model when it was used to predict the consumptive use of some winter crops such as wheat (Ouda et al. [25]) and barley (Khalil et al. [21])

Table (4): Measured versus predicted consumptive use for onion irrigated with fresh and drainage water

Growing season	Fresh water irrigation			Drainage water irrigation		
	CU (cm)		PD %	CU (cm)		PD %
	Measured	Predicted		Measured	Predicted	
1998/99	20.66	20.41	1.21	21.16	20.49	3.17
1999/00	20.92	20.34	2.77	21.32	20.44	4.13
2001/02	21.46	21.03	2.00	22.06	21.13	4.22
RMSE	0.4040			0.0746		
WI	0.9605			0.9541		

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

3.1. Prediction of onion yield

Predicted onion 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, 20% of full irrigation could be safely saved with yield reduction less than 2%. However, in 2000/01 growing season, yield reduction was higher, i.e. 4% under irrigation with 80% of full irrigation. Bekele et al. [4] stated that saving 25% of the applied irrigation water reduced onion yield by 6%.

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

Irrigation	1998/99		1999/00		2000/01	
	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %
FI	18.33	0	11.42	0	12.09	0
95% of FI	18.33	0	11.42	0	12.07	0.17
90% of FI	18.29	0.22	11.41	0.09	12.00	0.74
85% of FI	18.12	1.15	11.39	0.26	11.86	1.90
80% of FI	18.02	1.69	11.31	0.96	11.60	4.05

FI= full irrigation (m^3/ha); 95% of FI= 95% of full irrigation; 90% of FI= 90% of full irrigation; 85% of FI= 85% of full irrigation; 80% of FI= 80% of full irrigation; PR%= percent reduction between measured and predicted yield.

In an attempt to find out what is the reason for the high yield reduction in 2000/01 growing season, the depletion of readily available water from root zone under the application of full irrigation and 80% of full irrigation amounts was graphed. Figure (1) indicated that there were five hills shown in that graph, each top of these hills represent irrigation day and the amount of readily available water at root zone. The graph also showed that all the readily available water at root zone was depleted after the 2nd irrigation, where water stress was prevailed for 8 days (zero readily available water). Figure (2) showed that when 80% of full irrigation was applied, readily available water was completely depleted from root zone after the 2nd and the 3rd irrigations; where water stress was existed for 25 days and yield was reduced by 4.05%. This result could be attributed to the fact that water stress commenced 75 days after planting, which was the start of mid season growth period for onion (Allen et al. [29]) and that was reflected on the growing plants and reduced yield.

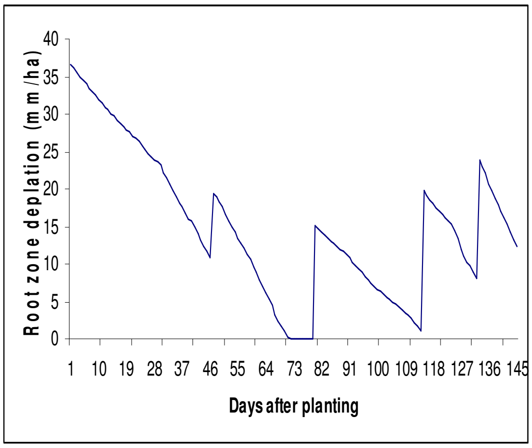

Figure (1): Readily available water depletion from root zone after the application of each irrigation for onions grown under full fresh irrigation amount in 2000/01 growing season

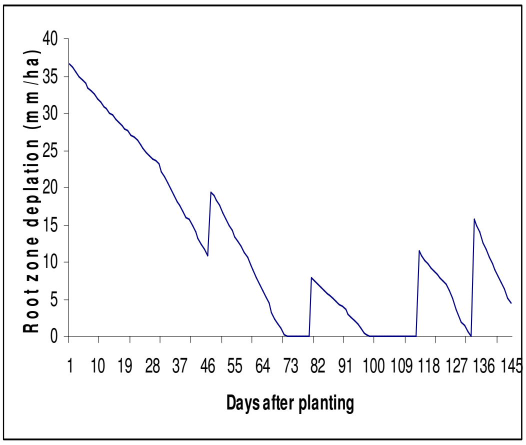

Figure (2): Readily available water depletion from root zone after the application of each irrigation for onions grown under 80% of full fresh irrigation amount in 2000/01 growing season

Similar results could be obtained under drainage water irrigation, where 20% of full irrigation water could be saved in the three growing seasons, with yield reduction less than 2% (Table 6).

Table (6): Predicted onion yield and its reduction percentages under the investigated deficit irrigation treatments using drainage water irrigation

Irrigation	1998/99		1999/00		2000/01	
	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %
FI	15.30	0	9.48	0	10.06	0
95% of FI	15.29	0.07	9.47	0.11	10.06	0
90% of FI	15.28	0.13	9.45	0.32	10.05	0.10
85% of FI	15.26	0.26	9.39	0.95	10.04	0.20
80% of FI	15.24	0.39	9.35	1.37	10.01	0.50

FI= full irrigation (m^3/ha); 95% of FI= 95% of full irrigation; 90% of FI= 90% of full irrigation; 85% of FI= 85% of full irrigation; 80% of FI= 80% of full irrigation; PR%= percent reduction between measured and predicted yield.

4. Water use efficiency under deficit irrigation

The results in Table (7) indicted that the growing season of 1998/99 was characterized by high water use efficiency under both fresh and drainage water irrigation, compared with the other growing seasons. This could be attributed to that growing season produced the highest yield (Table 2). The lowest water use efficiency was obtained in 1999/00 growing season under both fresh and drainage water irrigation as a result of high amount of applied irrigation water, which produced low yield compared with the other two growing seasons (Table 2). Regarding to deficit irrigation treatments, the highest water use efficiency was obtained under irrigation with 80% of full irrigation in the three growing seasons. Similar results were obtained by Bekele et al. [3], who stated that deficit irrigation application for onion increased water use efficiency.

Table (7): Water use efficiency under both fresh and drainage water irrigation in the three growing seasons

Irrigation	Water use efficiency (kg/m^3)					
	1998/99		1999/00		2000/01	
	Fresh	Drainage	Fresh	Drainage	Fresh	Drainage
FI	5.21	4.15	2.96	2.37	3.73	3.04
95% of FI	5.48	4.37	3.12	2.49	3.92	3.20
90% of FI	5.78	4.61	3.29	2.63	4.12	3.37
85% of FI	6.06	4.87	3.47	2.76	4.31	3.57
80% of FI	6.40	5.17	3.67	2.92	4.48	3.78

FI= full irrigation (m^3/ha); 95% of FI= 95% of full irrigation; 90% of FI= 90% of full irrigation; 85% of FI= 85% of full irrigation; 80% of FI= 80% of full irrigation.

CONCLUSION

Over the last three decades, models have become a major research tool for resource management. In arid regions, water scarcity, on one hand, and the important role of irrigation water saving in the agriculture sector could have, on the other hand, both pushing towards having drastic changes in the ways we are using and managing our water resources. 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 duration process. Therefore, using simulation models, indeed, could be the most appropriate tools to predict the effect of irrigation with less water volumes than full irrigation on the yield of the primary cultivated crops. In the different regions of Egypt, irrigation management can be done by modeling water depletion from root zone under the application of different amounts of irrigation water.

Our results showed implied that 20% of either fresh or drainage applied irrigation water for onion can be saved, where yield losses was relatively low. Furthermore, water use efficiency was the highest under saving 20% of either fresh or drainage irrigation water. Therefore, to save irrigation water and to increase water use efficiency, 80% of full irrigation could be safely applied to onion.

REFERENCES

[1] Shock, C.C., E.B.G. Feibert, and L.D. Saunders. Onion yield and quality affected by soil water potential as irrigation threshold. Hort. Science 33:188-191, 1998.

[2] Shock, C.C., E.B.G. Feibert, and L.D. Saunders. Irrigation criteria for drip-irrigated onions. Hort. Science 35:63-66, 2000.

[3] Bekele, S. and Tilahun, K. Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. Agric. Wat. Manag. 89(2):148-152, 2007.

[4] Bhatt, R.M., Rao, N.K. Srinivasa, G. and Veere, R. Response of bulb onion (*Allium cepa* L.) to water stress: photosynthesis, stomatal conductance and osmotic adjustment. Indian J. Hort. 63(3):20-25, 2006.

[5] Pelter, G.Q., Mittelstad, R. and Redulla, C.A. Effects of water stress at specific growth stages on onion bulb yield and quality. Agric. Wat. Manag. 68(2):107-115, 2004.

[6] Hill, R.W., R.J. Hanks and J.L. Wright. Crop Yield Models Adapted to Irrigation Scheduling Programs. Proc. Irrigation Systems for the 21st Century Proceedings International Conference on Genetic Algorithms, Portland, OR, 1987.

[7] 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.

[8] Cheong, B.H. Improving Irrigation System Performance for Rice Culture. Ph.D. Dissertation, Utah State University, Logan, Utah, 1992.
[9] Foroud, N., Hobbs, E.H., Riewe, R., Entz, T. Field verification of a micro computer irrigation model. Agric. Water Manag. 21, 215-234, 1992.
[10] Smith, M. CROPWAT: a computer program for irrigation planning and management. FAO Land and Water Development Division, FAO, Rome, 1991.
[11] Prajamwong, S. Command Area Decision Support System for Irrigation Projects. Ph.D. Dissertation, Utah State University, Logan, Utah, 1994.
[12] Georgea. B.A., Shende, S.A., Raghuwanshi, N.S. Development and testing of an irrigation scheduling model. Agric. Wat. Manag. 46:121-136, 2000.
[13] Ouda, S.A. Predicting the effect of water and salinity stresses on wheat yield and water needs. J. Appl. Sci. Res. 2(10):750-750, 2006.
[14] 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.
[15] Childs, S.W. and Hanks R.J. Model of soil salinity effects in crop growth. Soil Sci. Soc. Am. Proc. 39:112–115, 1975.
[16] Bresler, E. Application of conceptual model to irrigation water requirement and salt tolerance of crops. Soil Sci. Soc. Am. J. 51:788–793, 1987.
[17] 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.
[18] 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.
[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] El-Mesiry, T., E.F Abdallh, M.S. Gaballah and S.A. Ouda. Using Yield-Stress model in irrigation management for wheat grown under saline conditions. Aust. J. Bas. App. Sci. 1(4):600-609, 2007.
[21] 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.
[22] Ouda, S., T. El-Mesiry, M.S. Gaballah. Using Yield-stress model to simulate soybean yield reduction under imposing water stress. Res. J. Agric. Bio. Sci. 3(6):827-834, 2007.
[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] 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.
[25] Ouda, S.A., F. Khalil, R. Abou Elenin, M.A.K. Shreif, B. Benli and M. Qadir. Using Yield-Stress model in irrigation management for wheat grown in Egypt. J. App. Bio. Sci. 2 (1): 57-65, 2008.

[26] Ouda, S.A., F.A.F. Khalil, M. R. K. Ashrhy and K. M. R. Yousef. Effect of water stress on soybean yield and water relations. 12th International Conference of Water Technology. Egypt, 2008.
[27] Khalil, F.A., Ouda, S.A. and Ashry, M. Comparison between CROPWAT and Yield-Stress models in predicting sesame yield and consumptive use under water stress conditions. J. Agric. Sci. Mansoura Univ. 33(12):9105-9119, 2008.
[28] Israelsen, O.W., Hansen, V.E. Irrigation Principles and Practices. John Wiley & Sons, Inc. New York, 1962.
[29] Allen, R.G., Pereira, L.S., Raes, D., M. Smith. Crop evapotranspiration: Guideline for computing crop water requirements. FAO N°56, 1998.
[30] 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.
[31] Willmott, C.J. On the validation of models. Phys. Geogr. 2:184–194, 1981.
[32] Vites, F.G. Jr. Increasing water efficiency by soil management. Amer. Soci. Agron. 26:259-274, 1965.