SIMULATING THE EFFECT OF DEFICIT IRRIGATION ON EGYPTIAN CLOVER YIELD AND WATER PRODUCTIVITY

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ABSTRACT

Yield-Stress model was calibrated and validated for clover yield and consumptive use data of four-year field trials at Beni Sweif Governorate, Egypt under two treatments of irrigation water quality (fresh and drainage). The goodness of fit between measured and predicted values by the model was tested by calculated percent difference between measured and predicted values of yield and consumptive use, in addition to root mean squared error and Willmott index of agreement. Then, the model was used to predict the effect of four deficit irrigation treatments (95, 90, 85, and 80% of full irrigation). Water productivity was calculated under all cases. The results showed that the model performance was highly acceptable in predicting clover yield and consumptive use. Low yield losses occurred under both fresh and drainage deficit irrigation water as a result of 10% irrigation water saving. Water productivity was gradually increased under all deficit irrigation treatments, which suggested that there is a high potentiality to save an ample amount up to 20% of the irrigation water to be used in cultivating more lands.

Keywords: Yield-Stress model, Fresh and drainage irrigation water, Deficit irrigation, Water productivity, Consumptive use

INTRODUCTION

Crop water productivity is a quantitative term used to define the relationship between crop produced and the amount of water involved in crop production. It is a useful indicator for quantifying the impact of irrigation scheduling decisions, with regard to water management (FAO [1]). In Egypt, crop water productivity is calculated per unit of applied water. Achieving greater water productivity became the primary challenge 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. [2]).

Egyptian clover is the major winter forage crop cultivated in the Nile Valley and delta. It is the most widely grown field crop and occupies an area which totals 1.2 million feddans. Egyptian clover is playing vital role in the sustainability of Egyptian agriculture. It nourished the soils, suppressing weeds and providing a disease break in cereal-dominated crop rotations. It is a major forage crop for honey bees. It can be mowed several times for forage and then ploughed under as green manure, which helps to increase the organic matter content of the soil, thus improving soil physical, chemical and biological properties (El-Nahrawy [3]).

Many researchers have indicated that Egyptian clover yield could be decreased under low level of soil moisture. The highest yield could be obtained when three irrigations between cuttings were applied (El-Bably [4]; Abd El-Hafez et al. [5] and Abbas et al. [6]). Furthermore, Mahrous et al. [7] concluded that to obtain high yield of Egyptian clover, available moisture should be maintained between 40 to 60% depletion of the available soil moisture. Thus, low yield of Egyptian clover is correlated with low level of soil moisture (Badawi [8]).

Simulating of the effect water stress on clover yield could save a lot of time and effort. However, there is no published simulation model for clover. For that reason, Yield-Stress model (Ouda [9]) was developed to simulate the yield and consumptive use of such crops because the model uses crops parameters published in FAO publication No. 56 (Allen et al. [10]), which helps in predicting the yield of a large number of crops. The 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. Yield-Stress model was used in irrigation management for several crops under different stress conditions and its performance was acceptable (Ouda et al. [11]; Ouda et al. [12]; El-Mesiry et al. [13]; Khalil et al. [14]; Ouda et al. [15]; Tantawy et al. [16]; Ouda et al. [17]; Ouda et al. [18]; Ouda et al. [19]). Thus, the model can be safely used to explore the effect of deficit irrigation on water productivity in Egyptian clover.

The objectives of this research were: (i) To calibrate and validate Yield-Stress model for clover yield and consumptive data for four growing seasons; (ii) To use Yield-Stress model in predicting Egyptian clover yield under deficit irrigation.

MATERIALS AND METHODS

1. Clover field trials

Data for clover yield and consumptive use were available from a four-year farm trial conducted at Beni Sweif Governorate (Middle Egypt) in 1997/98 to 2000/01 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 [20]):

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

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. 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 in both locations are included in Table (1).

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

Season	Season length (days)	Mean temperature (°C)	Relative humidity (%)	Wind speed (m/sec)	Solar radiation (MJ/m^2/day)
1997/98	115	14.60	65	1.23	13.48
1998/99	97	15.40	65	1.24	13.30
1999/00	118	16.94	66	1.23	13.62
2000/01	121	17.22	66	1.00	14.00

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. 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 clover 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 clover yield and consumptive use, in addition to root mean squared error (RMSE) (Jamieson et al. [21]) and Willmott index of agreement (Willmott [22]).

4. Prediction of clover yield under deficit irrigation

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

RESULTS AND DISCUSSION

1. Clover field trials

The measured amounts of applied irrigation water and its corresponding measured yield values in the four growing seasons are shown in Table (2). Clover yields were significantly differed (one sided t-test, $P < 0.01$) under the application of fresh and drainage irrigation amounts at both locations. The Results in that table also indicated that clover yield was the lowest in 1997/98 growing season, compared with the rest of the growing seasons. This could be attributed to the low applied irrigation amount for both fresh and drainage water, compared with the rest of the growing seasons. Furthermore, the highest yield was obtained in 1998/99 growing season under both fresh and drainage irrigation water amount; although the applied amount was lower than what was applied in 1999/00 and 2000/01 growing season. This finding implied that increasing the applied irrigation amount for clover up to a certain limit could adversely affect yield as a result nutrients leaching away from root zone and/or oxygen deficiency at root zone.

Table (2): Irrigation amounts and corresponding clover yield values under fresh and drainage water irrigation

Growing season	Fresh water irrigation		Drainage water irrigation	
	Irrigation amounts (m^3/ha)	Yield (ton/ha)	Irrigation amounts (m^3/ha)	Yield (ton/ha)
1997/98	3273	5.29	3319	4.97
1998/99	3725	7.88	3866	8.74
1999/00	3859	7.66	3998	7.51
2000/01	3864	7.55	3960	7.88

2. Yield-Stress model validation for clover yield and consumptive use

2.1. Prediction of clover yield

Yield-Stress model predicted clover yield with high degree of precision under both fresh and drainage irrigation amounts. Percent difference between measured and predicted values was less than 1.6% for fresh water irrigation treatments. The highest percent reduction between measured and predicted yield was obtained in 1997/98 growing under irrigation with drainage water, i.e. 2.82%. Willmott index of agreement was the highest and root mean square error per observation was 0.0188 and 0.0221 ton/ha for both fresh and drainage water irrigation amounts, respectively (Table 3).

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

Growing season	Fresh water irrigation			Drainage water irrigation		
	Yield (ton/ha)		PR %	Yield (ton/ha)		PR %
	Measured	Predicted		Measured	Predicted	
1997/98	5.29	5.21	1.51	4.97	4.83	2.82
1998/99	7.88	7.88	0.00	8.74	8.74	0.00
1999/00	7.66	7.59	0.91	7.51	7.48	0.40
2000/01	7.55	7.43	1.59	7.88	7.75	1.65
RMSE	0.0188			0.0221		
WI	0.9873			0.9723		

PR%= percent reduction between measured and predicted yield; RMSE= root mean square error; WI= Willmott index of agreement.

2.2. Prediction of consumptive use

The Results in Table (4) implied that there was a good agreement between measured and predicted consumptive use of clover under both fresh and drainage irrigation water amounts. Under fresh water irrigation, the highest percent difference between measured and predicted consumptive use values were less than 2.5%, RMSE was 0.1527 cm and Willmott index of agreement was 0.9216. Similar results was obtained from the model under drainage water irrigation, where 3.19% was the highest percent difference between measured and predicted consumptive use values, RMSE was 0.1496 cm and Willmott index of agreement was 0.9197 (Table 4).

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

Growing season	Fresh water irrigation			Drainage water irrigation		
	CU (cm)		PR	CU (cm)		PR
	Measured	Predicted	%	Measured	Predicted	%
1997/98	22.30	22.82	2.33	22.94	22.68	1.13
1998/99	20.53	20.46	0.34	20.78	20.46	1.54
1999/00	26.01	26.35	1.31	26.17	26.36	0.73
2000/01	26.35	26.99	2.43	26.36	27.20	3.19
RMSE WI	0.1527 0.9216			0.1496 0.9197		

PR%= percent reduction between measured and predicted yield; RMSE= root mean square error; WI= Willmott index of agreement.

3. Prediction of clover yield and consumptive use under deficit irrigation

3.1. Clover yield prediction

The presented results in Table (5) and (6) indicated that the gradual decrease in the applied irrigation water volumes with respect to the full irrigation gradually reduced clover yield. This was the case under the four successive growing seasons and under fresh and drainage irrigation water application. The reduction in clover yield as a result of the application of deficit irrigation was different from one growing season to the other. In 1997/98 and 2000/01 growing season and under fresh water irrigation, 10% of full irrigation water could be saved with yield reduction being 5.37 and 2.44% for the two growing season, respectively. Whereas, 3.68 and 5.40% reduction in clover yield could occur in 1998/99 and 1999/00 growing seasons, respectively under the application of 85% of full irrigation amount (Table 5).

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

Irrigation	1997/98		1998/99		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	5.21	---	7.88	---	7.59	---	7.43	---
95% of FI	5.04	3.26	7.88	0	7.55	0.53	7.16	3.63
90% of FI	4.93	5.37	7.79	1.14	7.42	2.24	7.10	4.44
85% of FI	4.84	7.10	7.59	3.68	7.18	5.40	6.98	6.06
80% of FI	4.75	8.83	7.34	6.85	6.91	8.96	6.72	9.56

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.

The situation was different under the application of drainage water irrigation, where more irrigation water could be saved with similar values of clover yield reduction (Table 6). Yield reduction was 4.35, 3.66, 4.53 and 5.03% in 1997/98, 1998/99, 1999/00 and 2000/01 growing seasons, respectively under the application of 95, 80, 85, 85% of full irrigation amount under the same respective growing seasons. Such results give the evidence that clover can be irrigated successfully with water of low salinity level (drainage water) without any notable deterioration in its yield.

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

Irrigation	1997/98		1998/99		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	4.83	----	8.74	---	7.48	----	7.75	----
95% of FI	4.74	1.86	8.74	0	7.48	0.40	7.45	3.87
90% of FI	4.62	4.35	8.74	0	7.39	1.60	7.44	4.00
85% of FI	4.45	7.87	8.64	1.14	7.17	4.53	7.36	5.03
80% of FI	4.25	12.01	8.42	3.66	6.96	7.32	7.12	8.13

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.

Concerning the possible irrigation water saving under the investigated deficit irrigation treatments, the presented results indicated that irrigation with water of volume corresponding to 90% of that of full irrigation did not result in any notable losses in clover yield. This, indeed, is a very satisfactory result as 10% of the applied irrigation water could be saved and, in the same time, obtaining a yield very near to the one where full irrigation is practiced. The results also implied that for clover there is still further potentiality in saving more irrigation water and keeping the yield at values very similar to that where full irrigation is practiced. That is proved to be correct in the case where irrigation was practiced with a volume of water 20% of full irrigation. Irrigation with such volume of water within the 4 successive growing seasons resulted in an average yield reduction not exceeding the 7% of that under full irrigation. This result is supported with what was found by El-Babley [4], where reducing irrigation water amount by about 17% could reduce clover yield by about 9%. For arid and semi-arid regions, such data are technically and economically sound. Furthermore, for such areas suffering freshwater shortages, it is wisely to irrigate clover with water of a salinity level that the growing crop could tolerate, such as in our case of drainage water irrigation. The beneficial effect will be saving relatively large quantities of fresh water which can be used in expanding the irrigated areas and compensating the shortage in the used water by other sectors.

3.2. Prediction of consumptive use

The reduction in clover consumptive use as a result of applying either fresh or drainage deficit irrigation was tabulated with its corresponded clover yield reduction values (Tables 7 and 8). The presented results showed that under the investigated deficit irrigation treatments, the reduction in the consumptive use values under deficit irrigation followed a trend similar to reduction percentages for the yield under all growing seasons. This is clearly reflecting the existed relationship between the two studied parameters. The lesser is the volume of applied irrigation water, the greater is reduction in both clover yield and consumptive use percentages. This was also the case when irrigation was practiced with drainage water. However, within the four successive growing seasons, the reduction in clover consumptive use under irrigation with drainage was lower, compared with under irrigation using fresh water amount (Tables 7 and 8).

Table (7): Percent reduction in predicted clover yield and consumptive use under different deficit fresh water irrigation

Irrigation	1997/98		1998/99		2000/01		2001/02	
	PY %	PCU %	PY %	PCU %	PY %	PCU %	PY %	PCU %
95% of FI	3.20	0.44	0.00	0.00	0.53	0.27	3.63	1.17
90% of FI	5.37	1.05	1.14	0.05	2.24	1.02	4.44	1.87
85% of FI	7.10	2.10	3.68	0.54	5.40	2.85	6.06	3.81
80% of FI	8.83	3.64	6.85	1.91	8.96	6.30	9.50	7.29

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; PY%= percent reduction between measured and predicted yield; PCU= percent reduction between measured and predicted consumptive use.

Generally, under irrigation with water of EC values exceeding that of the fresh water, it is expected that the predicted reduction in the consumptive use under the investigated deficit irrigation treatments (Table 7) will be with lower percentages than those where irrigation is practiced with fresh water (Table 8). This was quite evident in the case of the clover crop. The reduction percentages in the consumptive use under deficit drainage irrigation treatments shown to be with values either very near or slightly greater than those predicted where fresh water irrigation was practiced. Such dissimilarity in this parameter under the drainage irrigation as compared with the fresh water irrigation could be attributed to the variation in the clover yield under both irrigation water sources and the predicted yield losses under deficit irrigation.

Table (8): Percent reduction in clover predicted yield and consumptive use under different deficit drainage water irrigation

Irrigation	1997/98		1998/99		2000/01		2001/02	
	PY %	PCU %	PY %	PCU %	PY %	PCU %	PY %	PCU %
95% of FI	1.86	0.18	0.00	0.00	0.40	0.73	3.87	2.60
90% of FI	4.35	1.01	0.00	0.10	1.60	0.50	4.00	2.92
85% of FI	7.87	2.82	1.14	0.10	4.53	0.53	5.03	4.29
80% of FI	12.01	6.17	3.60	0.54	7.32	2.94	8.13	7.11

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; PY%= percent reduction between measured and predicted yield; PCU= percent reduction between measured and predicted consumptive use.

4. Water productivity under deficit irrigation

The highest value of water productivity could be obtain under 80% of full irrigation for either fresh or drainage irrigation under all growing seasons (Table 9). The highest value of water productivity under both fresh and drainage water irrigation was obtained in 1998/99 growing season, i.e. 2.46 and 2.72 kg/m^3, respectively. Clover yield was the highest in 1998/99 growing season, which was produced with relatively medium amount of irrigation amount of both fresh or drainage irrigation water (Table 2). This result implied that the agroclimatological conditions prevailed in 1998/99 growing season were suitable for clover plants (Table 1), which enhanced growth and resulted in higher yield (Table 2). The results in that table also implied that, under the four growing seasons, it is very safe to conserve 20% of the applied irrigation water (fresh or drainage) because water productivity was the highest.

Table (9): Water productivity under both fresh and drainage water irrigations in the four growing seasons

Irrigation	Water productivity (kg/m^3)							
	1997/98		1998/99		2000/01		2001/02	
	Fresh	Drainage	Fresh	Drainage	Fresh	Drainage	Fresh	Drainage
FI	1.62	1.50	2.12	2.26	1.98	1.88	1.95	1.97
95% of FI	1.62	1.50	2.23	2.38	2.06	1.97	1.95	1.98
90% of FI	1.67	1.55	2.32	2.51	2.14	2.05	2.04	2.09
85% of FI	1.74	1.58	2.40	2.63	2.33	2.11	2.13	2.19
80% of FI	1.81	1.60	2.46	2.72	2.24	2.18	2.17	2.25

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

Water scarcity is a major cause of crops yield reduction in many parts of the world. For that reason, a more rational use of irrigation water should be adapted and deficit irrigation principles should be accepted with a certain level of reduction in yield level (Hamdy et al. [23]). Therefore, modeling yield reduction under deficit irrigation should be done. Modeling has become a major research tool in agriculture for resource management, which could help in extending findings and conclusions to conditions not tested in the field.

Although Egyptian clover is a very important forage crop, no researcher took the time to develop a simulation model for it. Being applicable to predict the yield of many crops, Yield-Stress model was successful in predicting clover yield and consumptive use with high level of accuracy. As a consequence, the model was explored in predicting the effect of deficit irrigation on clover yield.

Our results showed that applying irrigation water when 90% of full irrigation volume to clover as an average over the four growing seasons could be safely practiced, which resulted in low clover yield reduction under both fresh and drainage water irrigation. However, inter-seasons analysis showed that up to 20% of both fresh and irrigation water could be save with low yield reduction (Tables 5 and 6). Furthermore, water productivity was also the highest under deficit irrigation application of 80% of full irrigation, which could emphasize on the benefits of saving more irrigation water to use it to cultivate more land and increase crops production horizontally.

REFERENCES

[1] FAO, Unlocking the Water Potential of Agriculture. FAO Corporate Document Repository. 260pp, 2003.

[2] Tariq, J.A., M.J. Khan and K. Usman. Irrigation scheduling of maize crop by pan evaporation method. Pakistan J. of Wat. Resources. 7(2):29-35, 2003.

[3] El-Nahrawy, M.A. Vital role of berseem in Egyptian agriculture. Ninth International Conference on Dry land Development, Alexandria, Egypt, 2008.

[4] El-Bably, A. Z. Effect of Irrigation and Nutrition of Copper and Molybdenum on Egyptian Clover (*Trifolium alexandrnium* L.). Agron. J. 94:1066–1070, 2002.

[5] Abd El Hafez, S.A., A.A. El-Sabbagh, and El Abou-Ahmed. Effect of irrigation intervals and methods of sowing on the productivity of berseem (*Trifolium alexandrium* L.) and its water relations. J. Agric. Res., Tanta Univ. 23:122–129, 1997.

[6] Abbas, F.A., A.A. Rayan, K.A. Mohamed, and N.G. Ainer. Evaluation of water management system for clover in Egypt. 2nd Conference of On-farm irrigation and Agrometrology. Giza, Egypt. 2–4 Jan, 1995.

[7] Mahrous, F.N., A.Y. Badawi, M.N. Seif El-Yazal, H.W. Tawadros, and A. Serry. Effect of soil moisture stress on Egyptian clover. Proc. Conf. of ARC, 2nd, Cairo, Egypt. Agric. Res. Rev., Agric. Res. Cent., Giza, Egypt, 1984.

[8] Badawi, A.Y. Water requirements of clover and main crops in 2- and 3-year crop rotation after the completion of High Dam. M.S. thesis. Faculty of Agric., Cairo Univ., Giza, Egypt, 1970.
[9] 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.
[10] Allen, R. G., L. S. Pereira, D. Raes, and M. Smith. Crop evapotranspiration: Guideline for computing crop water requirements. FAO N^{o}56, 1998.
[11] 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.
[12] 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.
[13] 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.
[14] 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.
[15] 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.
[16] 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.
[17] 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.
[18] 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.
[19] 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.
[20] Israelsen, O.W., Hansen, V.E. Irrigation Principles and Practices. John Wiley & Sons, Inc. New York, 1962.
[21] 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.
[22] Willmott, C.J. On the validation of models. Phys. Geogr. 2:184–194, 1981.
[23] Hamdy, A., Sardo, V., Ghanem, K.A.F. Saline water in supplemental irrigation of wheat and barley under rain fed agriculture. Agrci. Wat. Manag. 78:122-127, 2005.