# INCREASING WATER PRODUCTIVITY OF FABA BEAN GROWN UNDER DEFICIT IRRIGATION AT MIDDLE EGYPT

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## ABSTRACT

The effect of several deficit irrigation scenarios on faba bean yield were simulated using Yield-Stress model through calibration and the validation of the model with three years field trials in 1998/99, 1999/00 and 2001/02 growing seasons 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 faba bean yield and consumptive use. The results of the model showed that up to 20% of full irrigation could be saved with yield reduction reached 7%. Changing irrigation schedule reduced yield losses to less than 1% and resulted in saving around 20% of full irrigation under the three growing. Water productivity was the highest when irrigation schedule was changed under irrigation with either fresh or drainage water amounts.

**Keywords:** Yield-Stress model, Fresh water irrigation, Drainage water irrigation, Consumptive use

## INTRODUCTION

Faba bean is the one of the most important pulse crop cultivated in Egypt, due to the richness in seed protein content. Furthermore, faba bean is an important crop in the crop rotation in Egypt, due to its fixation of atmospheric nitrogen, which enriches the soil with nitrogen and organic matter and improving water use efficiency of the cropping system (Pala et al. [1]), particularly in dry rain fed areas (Saxena [2] and [3]). The crop is also used as animal fodder and green manure.

Growth of faba bean is very sensitive to water stress. That sensitivity is a result of its maximum depth of rooting is relatively shallow, approximately 0.9 m (Hebblethwaite, [4]), and its disability to adjust osmotically to water stress (Sau and Mínguez [5]).

Furthermore, water stress has a determinant effect on faba bean vegetative growth, as well as reproductive growth (Mínguez et al. [6]). The early podding stage of development was the most sensitive to water stress, caused a reduction in faba bean yield by 50% (Mwanamwenge et al. [7])

Crop models are valuable tools synthesizing our understanding of physiological processes, hypothesizing genetic improvement, and evaluate crop and soil management strategies (Boote et al. [8]). Several models have been developed to simulate the growth and yield of faba bean (Turpin et al. [9]; Manschadi et al. [10] and Boote et al. [11]) with varying degree of sophistication. However, these models require large data set to be run. In the mean time, other models can be used to predict the yield of faba bean with less data set requirement and with the same level of accuracy. An example of these models is CROPWAT (Smith [12]) and Yield-Stress (Ouda [13]) models. Yield-Stress model is cable of predicting the yield and consumptive use of different winter crops under varying degree of water stress, such as wheat (Ouda et al. [14]) and barley (Khalil et al. [15]). The model was also successful in predicting the yield of different summer crops, such as sesame (Tantawy et al. [16]; Khalil et al. [17]), maize (Ouda et al. [18] and [19]) and soybean (Ouda et al. [20]; Ouda et al. [21] and [22]). Furthermore, Yield-Stress model was used to predict the yield of wheat grown under saline soil (El-Mesery et al. [23]), as well as sunflower grown under saline soil (Ouda et al. [24]). Thus, the model can be use with confidence to predict the yield of an important crop as faba bean.

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

## MATERIALS AND METHODS

### 1. Faba bean field trials

Data for faba bean 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 [25]):

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

Where: CU = the amount of consumptive use (mm), $\Theta_2$ = soil moisture percentage after irrigation, $\Theta_1$ = 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 Beni Swief are included in Table (1).

**Table (1): Season length and seasonal weather parameters of faba bean planted in the three growing seasons**

| Season | Season length (days) | Mean temperature (°C) | Relative humidity (%) | Wind speed (m/sec) | Solar radiation (MJ/m$^2$/day) |
|---|---|---|---|---|---|
| 1998/99 | 171 | 16.2 | 63 | 1.3 | 15.4 |
| 1999/00 | 175 | 17.9 | 64 | 1.3 | 15.6 |
| 2001/02 | 167 | 18.8 | 64 | 1.3 | 15.7 |

## 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. [26]). 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 faba bean yield and consumptive use data 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 faba bean yield and consumptive use, in addition to root mean squared error (RMSE) (Jamieson et al. [27]) and Willmott index of agreement (Willmott [28]).

## 4. Prediction of faba bean yield under deficit irrigation

Faba bean yield was predicted under 95, 90, 85 and 80% of full irrigation with either fresh or drainage water irrigation amounts. Furthermore, three additional deficit irrigation scenarios were developed in an attempt to save more irrigation water and 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 [29]). It can be calculated as follows:

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

# RESULTS AND DISCUSSION

## 1. Faba bean field trials

The results in Table (2) showed the applied amounts irrigation water and its corresponding measured yield values. Faba bean yields under the application of total irrigation amounts were significantly differed (one sided t-test, $P < 0.05$). Results in that table showed that the highest faba bean yield was obtained in 1999/00 growing season under irrigation with either fresh or drainage water, where that growing season was the longest, compared with the other growing seasons (Table 1). Furthermore, the lowest yield was obtained in 2001/02 growing season, where the mean temperature prevailed during that growing season was the highest and season length was the lowest (Table 1).

**Table (2): Irrigation amounts and corresponding clover yield values 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 | 3972 | 2.90 | 4210 | 2.37 |
| 1999/00 | 3986 | 3.62 | 4442 | 4.08 |
| 2001/02 | 3912 | 2.22 | 3972 | 2.01 |

## 2. Yield-Stress model validation

### 2.1. Faba bean yield

The model prediction of faba bean yield showed a good agreement with measured values 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 0.0132 and 0.0039 ton/ha under fresh and drainage irrigation amounts, respectively (Table 3). Similar results was obtained when APSIM model was used to predict faba bean yield in Australia with RMSE equal 0.0466 ton/ha (Turpin et al. [9]). Furthermore, the value of RMSE was 0.0744 ton/ha when CROPGRO model was used to predict faba bean yield (Boote et al. [8]).

**Table (3): Measured versus predicted faba bean yield grown under fresh and drainage irrigation**

| Season | Fresh water irrigation | | | Drainage water irrigation | | |
|---|---|---|---|---|---|---|
| | Yield (ton/ha) | | PD % | Yield (ton/ha) | | PD % |
| | Actual | Predicted | | Actual | Predicted | |
| 1998/99 | 2.90 | 2.88 | 0.69 | 2.37 | 2.37 | 0 |
| 1999/00 | 3.62 | 3.60 | 0.55 | 4.08 | 4.08 | 0 |
| 2001/02 | 2.22 | 2.20 | 0.90 | 2.01 | 2.00 | 0.50 |
| RMSE | 0.0132 | | | 0.0039 | | |
| Willmott | 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

Regarding to faba bean consumptive use prediction under both fresh and drainage water irrigation amounts, there was a good agreement between measured and predicted values by Yield-Stress model. Percent difference between measured and predicted values was less than 3% under both fresh and drainage water irrigation. RMSE was 0.0344 and 0.0685 cm under both fresh and drainage water irrigation, respectively. Furthermore, Willmott index of agreement was 0.9623 and 0.9696 under both fresh and drainage water irrigation, respectively (Table 4). Similar results were found by Ouda et al. [20] and Ouda et al. ([21] and [22]), when Yield-Stress model was used to predict soybean consumptive use.

**Table (4): Measured versus predicted consumptive use of faba bean grwon under fresh and drainage irrigation**

| Season | Fresh water irrigation | | | Drainage water irrigation | | |
|---|---|---|---|---|---|---|
| | WCU (cm) | | PD % | WCU (cm) | | PD % |
| | Measured | Predicted | | Measured | Predicted | |
| 1998/99 | 30.93 | 30.71 | 0.71 | 31.69 | 31.63 | 0.19 |
| 1999/00 | 33.94 | 33.36 | 1.71 | 35.46 | 34.57 | 2.51 |
| 2001/02 | 35.45 | 34.62 | 2.34 | 35.61 | 34.67 | 2.64 |
| RMSE | 0.0344 | | | 0.0685 | | |
| Willmott | 0.9623 | | | 0.9696 | | |

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 faba bean yield

Predicted faba bean yield under different deficit irrigation treatments and its reduction percentage under fresh water irrigation are presented in Table (5). The results indicated that the lowest yield reduction could obtained in 1998/99 growing season, where saving 20% of full irrigation reduced faba bean yield by 2.43%. Whereas, the highest yield reduction was obtained in 1999/00 growing season i.e. 6.67%. Thus 15% of full irrigation could be saved with yield losses not exceeding 4%.

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

| Irrigation | 1998/99 | | 1999/00 | | 2001/02 | |
|---|---|---|---|---|---|---|
| | Predicted yield (ton/ha) | PR % | Predicted yield (ton/ha) | PR % | Predicted yield (ton/ha) | PR % |
| FI | 2.88 | 0 | 3.60 | 0 | 2.20 | 0 |
| 95% of FI | 2.88 | 0 | 3.58 | 0.56 | 2.19 | 0.45 |
| 90% of FI | 2.87 | 0.35 | 3.56 | 1.11 | 2.17 | 1.36 |
| 85% of FI | 2.84 | 1.39 | 3.49 | 3.06 | 2.13 | 3.18 |
| 80% of FI | 2.81 | 2.43 | 3.36 | 6.67 | 2.08 | 5.45 |

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 depletion of readily available water from root zone under the application of full irrigation and 80% of full irrigation was graphed with days after planting to help to understand the reason behind the high yield reduction in the growing season of 1999/00. Figure (1) indicated that there are 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 3rd, where water stress was prevailed for 5 days. Figure (2) showed that after deducting 20% of the full irrigation, readily available water was completely depleted from root zone after the 3rd, the 4th and the 5th irrigation; where water stress was existed for 31 days between these individual irrigations. The highest number of water stress days was between 91 and 108 days after planting. According to Allen et al. [26], this period is the beginning of the developmental stage, where water stress in it could have harm effect on the final yield.

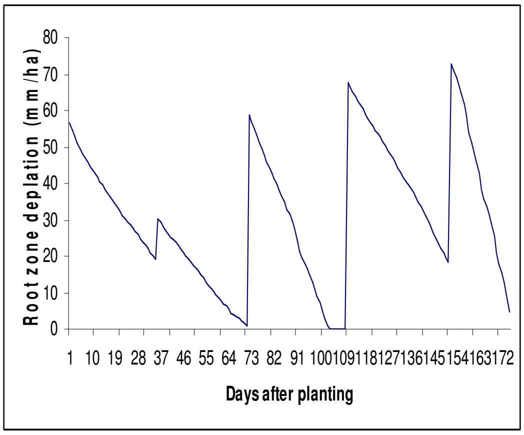


**Figure (1): Readily available water depletion from root zone after the application of each irrigation for faba bean grown under full fresh irrigation amount in 1999/00 growing season**

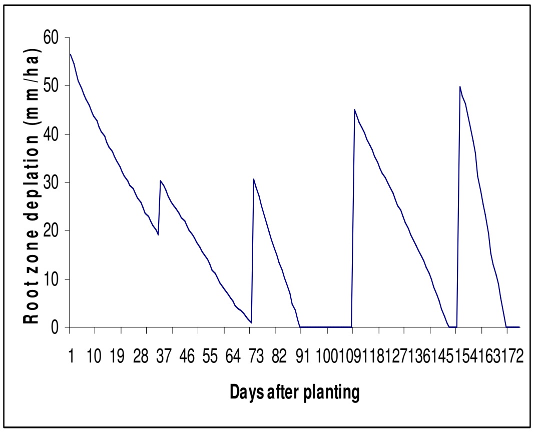


**Figure (2): Readily available water depletion from root zone after the application of each irrigation for faba bean grown under full fresh irrigation amount less 20% in 1999/00 growing season**

Under drainage water irrigation, 80% of full irrigation could be applied with yield losses not exceeding 5% (Table 6). Under this treatment, the lowest yield reduction occurred in 1998/99 growing season, i.e. 1.69%, whereas, the highest yield reduction occurred in 2001/02 growing season.

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

| Irrigation | 1998/99 | | 1999/00 | | 2001/02 | |
|---|---|---|---|---|---|---|
| | Predicted yield (ton/ha) | PR % | Predicted yield (ton/ha) | PR % | Predicted yield (ton/ha) | PR % |
| FI | 2.37 | 0 | 4.08 | 0 | 2.00 | 0 |
| 95% of FI | 2.37 | 0 | 4.07 | 0.25 | 1.99 | 0.50 |
| 90% of FI | 2.37 | 0 | 4.06 | 0.49 | 1.98 | 1.00 |
| 85% of FI | 2.35 | 0.84 | 4.03 | 1.23 | 1.95 | 2.50 |
| 80% of FI | 2.33 | 1.69 | 3.99 | 2.21 | 1.90 | 5.00 |

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 amount of 80% of full irrigation water that was applied each growing season was averaged, which resulted in 3165 and 3366 $m^3$/ha of fresh and drainage water, respectively. Irrigation was rescheduled using these two amounts and used to run the model. The results presented in Table (7) indicated that low yield losses, less than 1%, were obtained under those irrigation water amounts of fresh and drainage water.

**Table (7): Measured versus predicted faba bean yield under irrigation with 3165 and 3366 $m^3$/ha of fresh and drainage water**

| Season | Fresh water irrigation | | | Drainage water irrigation | | |
|---|---|---|---|---|---|---|
| | Yield (ton/ha) | | % Reduction | Yield (ton/ha) | | % Reduction |
| | Measured | Predicted | | Measured | Predicted | |
| 1998/99 | 2.9 | 2.9 | 0 | 2.37 | 2.37 | 0 |
| 1999/00 | 3.62 | 3.60 | 0.55 | 4.08 | 4.08 | 0 |
| 2001/02 | 2.22 | 2.21 | 0.45 | 2.01 | 2.00 | 0.50 |

## 4. Water productivity calculations

Results presented in Table (8) indicated that water productivity was higher under irrigation using 3156 and 3366 $m^3$/ha of fresh and drainage water, respectively. This finding hold true under the three growing season. These results implied that low yield losses could be attained if irrigation schedule was changed for faba bean, with around 20% saving in the applied irrigation water under both water quality treatments. Furthermore, the highest water productivity value was obtained in 1999/00 growing season, i.e. 1.14 and 1.21 kg/$m^3$ under the application of 3156 and 3366 $m^3$/ha of fresh and drainage water, respectively.

**Table (8): Water productivity for faba bean irrigated with different deficit irrigation water amounts**

| Growing season | Water productivity (kg/$m^3$) under | | | |
|---|---|---|---|---|
| | Fresh water irrigation | | Drainage water irrigation | |
| | Irrigation with 80% of full amount | Irrigation with 3156 $m^3$/ha | Irrigation with 80% of full amount | Irrigation with 3366 $m^3$/ha |
| 1998/99 | 0.88 | 0.92 | 0.69 | 0.70 |
| 1999/00 | 1.05 | 1.14 | 1.12 | 1.21 |
| 2001/02 | 0.66 | 0.70 | 0.60 | 0.59 |

## CONCLUSION

Increasing water productivity is a major goal in modern agriculture and should accomplish to maintain food security and agriculture sustainability. Weather, soil, genetic and management factors affect the way a crop will respond to irrigation, fertilizer and other management practices. Determining appropriate crop management strategies under these uncertainties has major economic and environmental implications. Computer simulation models of the soil/plant/atmosphere system can make a valuable contribution to both furthering our understanding of the processes that determine crop responses and predicting crop performance, resource use and environmental impacts for different environments and management scenarios. Thus, using simulation models to predict the effect of different scenarios of deficit irrigation could be the ultimate solution to save resources.

Our results showed that irrigating faba bean with 80% of full fresh or drainage water could reduce yield by 7%. However, reschedule irrigation and applying 3156 and 3366 $m^3$/ha of fresh and drainage water, respectively reduced yield losses to less than 1%. These findings implied that avoiding sensitive growth stages to water stress in faba bean could help in saving an ample amount of irrigation water. Furthermore, under the new irrigation schedule, water productivity was the highest for both fresh and drainage irrigation water.

## REFERENCES

[1] Pala, M., E. Armstrong and C. Johansen. The role of legumes in sustainable cereal production in rainfed areas. Linking research marketing opportunities for pulses in the 21st century. In: Knight, R.(Ed.), Proceedings of the Third International Food Legumes Research Conference, 22-26 September 1997, Adelaide, Australia, 2000.

[2] Saxena, M.C. Status and scope for the production of faba beans in the Mediterranean countries. In: Options méditerranéennes CIHEAM, séries séminaires 10, I.A.M., Montpellier, pp: 125-150, 1991.

[3] Saxena, M.C. Status of chickpea in the Mediterranean basin. In: Present Status and Future Prospects of Chickpea Crop Production and Improvement in the Mediterranean Countries, Seminar, Zaragoza, Spain, 1990.

[4] Hebblethwaite, P. The effects of water stress on the growth, development and yield of *Vicia faba* L. *In* Faba Bean Improvement (Ed. by G. Hawtin & C. Webb), pp. 165-176, 1982.

[5] Sau, F. and Mínguez, M.I. Adaptation of indeterminate faba beans to weather and management under a Mediterranean climate. Field Crops Res. 66, 81-99, 2000.

[6] Mínguez, M.I., Ruiz-Nogueira, B. and Sau, F. Faba bean productivity and optimum canopy development under a Mediterranean climate. Field Crops Res. 33, 435-447, 1993.

[7] Mwanamwenge, J., Loss, S.P., Siddique, K.H.M. and Cocks, P.S. Effect of water stress during floral initiation, flowering and podding on the growth and yield of faba bean (Vicia faba L.). Euro. J. Agron. 9(4): 273-293, 1999.

[8] Boote, K.J., Mınguez, M.I., and Sau, F. Adapting the CROPGRO Legume Model to Simulate Growth of Faba Bean. Agron. J. 94:743–756, 2002.

[9] Turpin, J.E., Robertson, M.J., Haire, C., Moore, A.D. and Rose, I. Simulating fababean development, growth, and yield in Australia. Aust. J. Agric. Res. 54(1)39 – 52, 2001.

[10] Manschadi, M.A., Sauerborn, J., Stützel, H., Göbel, W. and Saxena, M. C. Simulation of faba bean (*Vicia faba* L.) growth and development under Mediterranean conditions: Model adaptation and evaluation. 9(4):370-377, 1998.

[11] Boote, K.J., J.W. Jones, and N.B. Pickering. Potential uses and limitations of crop models. Agron. J. 88:704–716, 1996.

[12] Smith, M. CROPWAT: a computer program for irrigation planning and management. FAO Land and Water Development Division, FAO, Rome, 1991.

[13] 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.

[14] Ouda, S.A., F.A., 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. Appl. Bio. Sci. 2(1):57-65, 2008a.

[15] Khalil. F.A., S.A. Ouda, and M.M. Tantawy. Predicting the effect of optimum irrigation and water stress on yield and water use of barley. Res. J. Agric. Bio. Sci. 3(1): 1-6, 2007.

[16] Tantawy, M.M., S.A. Ouda, and F.A. Khalil. Irrigation optimization for different sesame varieties grown under water stress conditions. Res. J. Agric. Bio. Sci. 3(1): 7-12, 2007.

[17] 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., 2008e.

[18] Ouda, S.A., F.A. Khalil and M.M. Tantawy. Predicting the impact of water stress on the yield of different maize hybrids. Res. J. Agric. Bio. Sci. 2(6):369-374, 2006.

[19] 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.

[20] Ouda, S.A., T. El-Mesiry and M.S. Gaballah. Using Yield-Stress model to simulate soybean yield reduction under imposing water stress conditions. Res. J. Bio. Sci.. 3(6):827-834, 2007.

[21] Ouda, S.A., 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. Natural. Eng. Sci. 2(2)05-12, 2008.

[22] Ouda, S.A., F.A., Khalil, M.R.K. Ashry and K.M.R. Yousef. Effect of water stress on soybean yield and water relations. 12th International Water Technology Conference. Egypt, 2008.

[23] 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.

[24] Ouda, S.A., M.S. Gaballah, M.M. Tantawy and T. El-Mesiry. Irrigation optimization for sunflower grown under saline conditions. Res. J. Agric. Bio. Sci. 2(6):323-327, 2006.

[25] Israelsen, O.W., Hansen, V.E. Irrigation Principles and Practices. John Wiley & Sons, Inc. New York, 1962.

[26] Allen, R.G., Pereira, L.S., Raes, D., M. Smith. Crop evapotranspiration: Guideline for computing crop water requirements. FAO N°56, 1998.

[27] 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.

[28] Willmott, C.J. On the validation of models. Phys. Geogr. 2:184–194, 1981.

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