USING YIELD-STRESS MODEL IN IRRIGATION MANAGEMENT FOR WHEAT GROWN UNDER SALINE CONDITIONS

M. S. Gaballah[1] and S. A. Ouda[2]

[1] Water Relations and Field Irrigation Department; National Research Centre; Egypt
[2] Agroclimatology and Climate Change Unit; Irrigation Research Department; Soil, Water, and Environment Institute; Agriculture Research Center; Egypt

ABSTRACT

A field experiment was conducted for two growing seasons at three different sites of soil salinity levels (4.72, 7.79 and 10.86 dS/m). The experiment was designed to study the influence of saline affected soil in addition to yeast (*Candida tropicalis*) application on two wheat cultivars (Sakha 93 and Sakha 94). Recorded data was subjected to yield-stress model, which proved that ability to calculate the effect of water and salinity stresses provide an appropriate irrigation management tool to maximize yield under three salinity levels for both wheat cultivars and the application of biofertilizer. Readily available water at the root zone was studied which helped in proposing for irrigation scenario scheduling at soil salinity level of EC 4.7 dS/m resulted in saving 5% of total applied irrigation water and increase in yield by 0.19% for Sakha 93 cultivar and 1.71% for Sakha 94 whereas at 7.87 dS/m soil salinity level the irrigation scheduling saved by the model 2% of the total applied irrigation water accompanied by 0.93% decrease in yield of Sakha94 cultivar. The model was not successful for the third salinity level 10.86 dS/m.

Keywords: Soil salinity, irrigation, wheat yield, stress model, biofertilization.

INTRODUCTION

Salinity problem is defined as a condition where the salts in solution within the crop root zone accumulate in high concentrations which decrease crop yield (Ayers and Westcot, 1985). Salts in the soil water solution can reduce evapotranspiration by making soil water less available for plant root extraction (Allen et al., 1998). The inherent ability of crop to withstand the effects of elevated solute concentration in their root zone solutions and still produce a measurable agricultural product defines the magnitude of crop tolerance or resistance to salinity (Steppuhn et al., 2005). However, under saline conditions, many plants are able to partially compensate for low osmotic potential of the soil water by building up higher internal solute contents (Allen et al., 1998). Shalhevet (1994) reported that the effect of salinity and water stress are generally additives in their impacts on crop evapotranspiration. Under saline conditions, plant growth is usually reduced by reducing the rate of leaf elongation, enlargement and cells division in the leave (Allen et al., 1998).

Developing simulation models could help in evaluating the interaction between numerous factors that affect plant growth. However, these models should be satisfactorily describing the real plant systems to be efficiently used in simulating plant growth. Several models were developed in the recent years dealing with plant growth (DSSAT, IBSNAT 1985), evapotranspiration (CROPWAT, FAO 1992), and agricultural chemical movement (GLEAMS, Leonard et al., 1987). Nevertheless, they all do not consider soil salinity. Other models were developed to link a plant water uptake term to the soil system, such as LEACHM (Hutson and Wagenet, 1992) and RZWQ (Great Plains Systems Research, 1992), which include the effect of salinity. Cardon and Letey (1992) modified van Genuchten-Hanks (V-H, 1978) model to simulate crop yield under various irrigation management regimes including saline conditions. On the other hand, a model called Yield-Stress was developed by Ouda (2006) to predict wheat yield under water and salinity stresses. 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, 1958; Childs and Hanks, 1975; Bresler, 1987; and Shani and Dudley, 2001). Thus, 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 in irrigation optimization for sunflower grown under saline conditions (Ouda et al., 2006a) and was used to predict maize yield grown under water stress (Ouda et al., 2006b). Furthermore, the model was validated under skipping the last irrigation for barley and then the model was exploited in different irrigation management practices (Khalil et al., 2007). Similarly, the model was validated under deficit irrigation for sesame yield (Tantawy et al., 2007).

The objectives of this part were: (i) to validate Yield-Stress model for wheat grown under three salinity levels; (ii) to predict the potential wheat yield under irrigation scheduling and salinity stress.

MATERIALS AND METHODS

A field experiment was conducted for two growing seasons 2004-2005 and 2005-2006 of three different sites of soil salinity levels (4.72, 7.79 and 10.86 dS/m) at Demo experimental farm, Faculty of Agriculture, Fayoum University, Egypt. A randomized complete block design was used with three replications. The experiment was designed to study the influence of these three salinity levels of soil in addition to biofertilizer application on two wheat cultivars (Sakha 93 and 94). Applied amount of irrigation was measured during experimentation (m^3/ha) under the different soil salinity sites in addition to comparison between biofertilizer application and absence of biofertilization (inoculated and uninoculated) biofertilization, the yield of Sakha 93 and 94 cultivars were calculated (ton/ha) under previously mentioned conditions. The biofertilization treatment was yeast (Candida tropicalis) and was applied before cultivation where wheat seeds were inoculated with the biofertilizer yeast loaded on sterilized peatmoss. Firstly, wheat seeds were mixed with the Arabic gum (4%), then spread in a shadow place for 15 minutes. Wheat seeds were mixed carefully with the tested inoculum that kindly supported by Department of Agricultural Microbiology, NRC.

Yield-Stress Model Description

Yield-Stress model (Ouda 2006) calculates crop evapotranspiration (ET_{crop}) using Penman-Monteith equation (Allen et al., 1998). Furthermore, the model calculates readily available water at root zone using equations described in FAO publication N°56. Root zone depletion is calculated by accumulating ET_{crop} and the model compare it with readily available water on a daily basis. If root zone depletion is higher than readily available water, a water stress coefficient (K_{ws}) is calculated and used to calculate ET_{crop} adjusted (Allen et al., 1998). Under water stress, yield is predicted by multiplying Ks by accumulated yield on a daily basis. The model also calculates a salinity stress coefficient (K_{ss}) when the value of EC is higher than the EC threshold, which is used to calculate ET_{crop} adjusted and yield. Yield-Stress model predicts dry matter accumulation using solar radiation level on a daily basis, as the limiting factor. The method was cited after Gardner et al., (1985) from Loomis and Williams, (1963). This method converts total solar radiation to micro-Einstein. Then, it assumed that 82% of the visible light was intercepted by chloroplasts with maximum quantum efficiency equals to 10% (10 photons reduces one CO_2 molecule). Furthermore, the method subtracts 33% of gross photosynthesis as respiration cost to calculate net photosynthesis, and then the model convert it from µmoles/cm^2 to g/m^2 dry matter produced per day. The model predicts seed yield through multiplying the amount of produced biomass at harvest by harvest index.

"Yield-Stress" requires two types of input data. Input data by the user and input data file. The model asks the user to input planting and harvesting date and harvest index. The model also asks the user to input soil characteristics i.e. clay, silt, sand, organic matter, and $CaCO_3$ percentages. The other input data source is a file represent the whole growing season, starts with sowing month and day, and ends with harvesting month and day. The file contain maximum, minimum and mean temperature, relative humidity, solar radiation, wind speed, crop coefficient and the date and the amount of each irrigation. Seasonal weather parameters for the two growing seasons were collected and means are included in Table (1).

Table (1): Seasonal weather parameters for wheat planted in 2004/05 and 2005/06 growing seasons

Growing season	Mean temperature (°C)	Relative humidity (%)	Solar radiation (Mj/m^2/day)	Wind speed (m/sec)
2004/05	16.9	53	16.82	1.68
2005/06	17.0	54	16.83	1.73
Mean	16.9	54	16.83	1.71

Methodology

Yield-Stress model was validated using measured wheat yield grown under the three salinity levels for each growing season. For more testing of the model prediction, the model predicted wheat yield without the application of bio-fertilizer and with the application of bio-fertilizer. Furthermore, by studying the depletion of readily available water from root zone, the model was used in irrigation management to save irrigation water and to increase yield. To test the accuracy of the model in predicting wheat yield, percent reduction between measured and predicted values for each growing season was calculated. Furthermore, regression analysis was done to test the strength of the relationship between measured and predicted yield. Coefficient of determination (R^2) and root mean squared error (RMSE) were also calculated.

RESULTS AND DISCUSSION

1. Applied Irrigation Amounts and Measured Wheat Yield

The applied irrigation amounts for wheat in 2004/05 and 2005/06 growing seasons for the two varieties are included in Table (2) and Table (3). As it shown in these two tables, the amounts of applied irrigation water for wheat were similar under salinity level EC = 4.7 dS/m or EC = 7.8 dS/m. However, the amount of applied irrigation was higher under salinity level EC = 10.9 and its corresponding wheat yield value is very low. Results in both tables also indicated that the application of bio-fertilizer improved wheat yield of the two varieties under the three salinity levels. Moreover, results also showed that Sakha 93 variety yield was higher that Sakha 94 variety under the three salinity levels, as an indication of being more tolerant to salinity than Sakha 94 variety. Therefore, to obtained higher yield under the three salinity levels, it is recommended to plant Sakha 93 variety and to apply bio-fertilizer. Wheat yield under the three salinity levels for both varieties and without the application of bio-fertilizer were significantly differed (one sided t-test, $P < 0.01$) in both growing seasons. Furthermore, under the application of bio-fertilizer, wheat yield under the three salinity levels for both varieties were significantly differed (one sided t-test, $P < 0.01$) in both growing seasons.

Table (2): Applied irrigation amounts and corresponded yield values for wheat grown in 2004/05 season under three salinity levels

Salinity Level	Irrigation amounts (m^3/ha)				Yield (ton/ha)			
	Sakha 93		Sakha 94		Sakha 93		Sakha 94	
	Without bio	With bio	Without bio	With bio	Without bio	With bio	Without bio	With bio
S1	5370	5442	5360	5489	5.42	7.50	4.90	7.11
S2	5395	5459	5510	5616	3.45	6.88	3.27	5.85
S3	6039	6389	6079	6188	0.31	1.16	0.11	0.38

S1=EC equals to 4.7 dS/m; S2=EC equals to 7.8 dS/m; S3=EC equals to 10.9 dS/m; Without bio =without bio-fertilizer; With bio =with bio-fertilizer.

Table (3): Applied irrigation amounts and corresponded yield values for wheat grown in 2005/06 season under three salinity levels

Salinity Level	Irrigation amounts (m^3/ha)				Yield (ton/ha)			
	Sakha 93		Sakha 94		Sakha 93		Sakha 94	
	Without bio	With bio	Without bio	With bio	Without bio	With bio	Without bio	With bio
S1	5379	5436	5366	5481	5.41	7.53	4.91	7.09
S2	5385	5452	5500	5606	3.46	6.85	3.26	5.88
S3	6031	6381	6071	6181	0.30	1.14	0.10	0.37

S1=EC equals to 4.7 dS/m; S2=EC equals to 7.8 dS/m; S3=EC equals to 10.9 dS/m; Without bio =without bio-fertilizer; With bio =with bio-fertilizer.

2. Yield-Stress Model Validation without the Application of Bio-Fertilizer

Regarding to the prediction of wheat yield without the application of bio-fertilizer, the model accurately predicted wheat yield under the first two salinity levels, where percent reduction between measured and predicted yield was less than 1% for both varieties. However, under the third salinity level (EC = 10.9 dS/m), the model fail to accurately predict wheat yield for both varieties because the measured yield was very low (Table 4).

Table (4): Measured versus predicted wheat yield (ton/ha) without the application of bio-fertilizer for both varieties in 2004/05 growing season

Salinity Level	Sakha 93			Sakha 94		
	Measured Yield	Predicted Yield	% difference	Measured Yield	Predicted Yield	% difference
S1	5.42	5.37	0.92	4.9	4.86	0.82
S2	3.45	3.42	0.87	3.27	3.24	0.92
S3	0.31	0.3	3.23	0.11	0.1	9.09

S1=EC equals to 4.7 dS/m; S2=EC equals to 7.8 dS/m; S3=EC equals to 10.9 dS/m.

Results in Fig. (1) implied that all predicted wheat yield value under the three salinity levels lies within 95% confidence interval (95% CI). A statistically significant linear relationship ($P < 0.01$) between measured and predicted wheat yield for both varieties under the three salinity levels was found with equation $y = 0.008 + 1.007x$ ($R^2 = 0.999$, RMSE = 0.003 ton/ha). Lobell and Ortiz-Monasterio (2006) stated that CERES-Wheat model was able to predict crop yield under different irrigation trials quite well with a root mean squared error of 0.23 ton/ha.

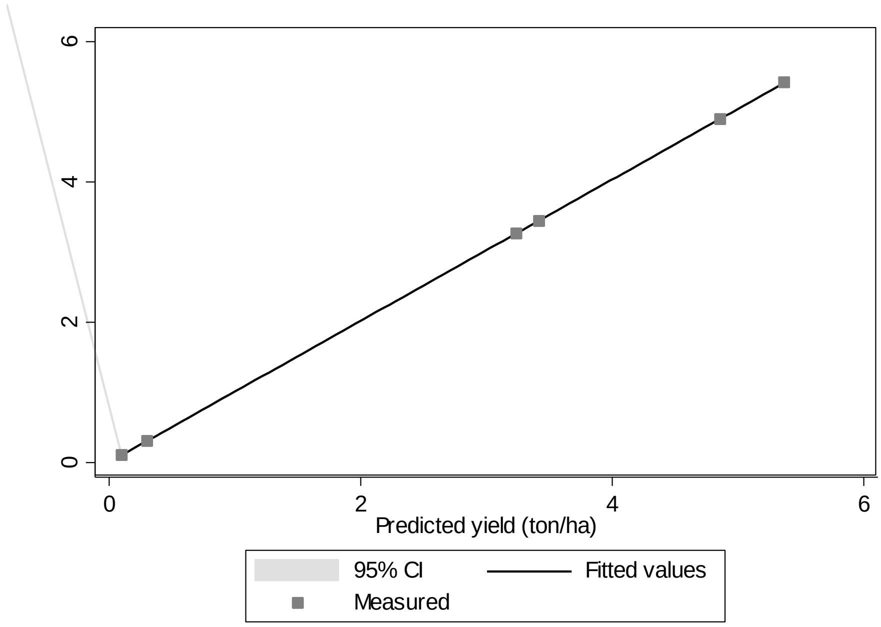

Fig. (1): Measured versus predicted wheat yield grown under three salinity levels in 2004/05 growing season

Furthermore, in 2005/06 growing season, the model accurately predicted wheat yield under the three salinity levels, where percent reduction between measured and predicted yield was also less than 1% (Table 5).

Table (5): Measured versus predicted wheat yield (ton/ha) without the application of bio-fertilizer for both varieties in 2005/06 growing season

Salinity Level	Sakha 93			Sakha 94		
	Measured Yield	Predicted Yield	% difference	Measured Yield	Predicted Yield	% difference
S1	5.41	5.36	0.92	4.91	4.83	1.54
S2	3.46	3.49	0.84	3.26	3.26	0
S3	0.30	0.30	0	0.10	0.10	0

S1=EC equals to 4.7 dS/m; S2=EC equals to 7.8 dS/m; S3=EC equals to 10.9 dS/m.

Figure (2) showed that all predicted wheat yield value under the three salinity levels lies within 95% confidence interval (95% CI). Regression analysis between measured and predicted wheat yield for both varieties under the three salinity levels revealed that a statistically significant linear relationship ($P < 0.01$) was found with equation $y = 0.014 + 0.989x$ ($R^2 = 0.999$, RMSE = 0.036 ton/ha).

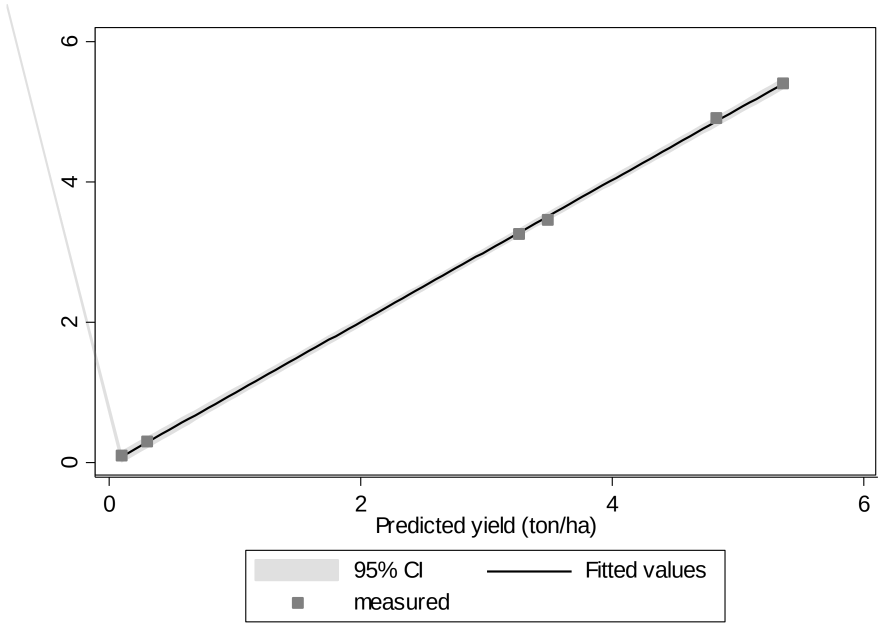

Fig. (2): Measured versus predicted wheat yield grown under three salinity levels in 2005/06 growing season

3. Yield-Stress Model Validation under the Application of Bio-Fertilizer

Testing the model under the application of bio-fertilizer revealed that the model prediction of wheat yield under the three salinity levels was accurate, where percent difference between measured and predicted yield was less than 1% in 2004/05 growing season, except for the third salinity level (EC = 10.9 dS/m), where the difference between measured and predicted yield of variety Sakha 94 was 2.70% (Table 6).

Table (6): Measured versus predicted wheat yield (ton/ha) with the application of bio-fertilizer for both varieties in 2004/05 growing season

Salinity Level	Sakha 93			Sakha 94		
	Measured Yield	Predicted Yield	% difference	Measured Yield	Predicted Yield	% difference
S1	7.50	7.45	0.67	7.09	7.05	0.56
S2	6.88	6.82	0.87	5.88	5.85	0.51
S3	1.16	1.15	0.86	0.37	0.36	2.70

S1=EC equals to 4.7 dS/m; S2=EC equals to 7.8 dS/m; S3=EC equals to 10.9 dS/m.

Results in Fig. (3) implied that all predicted wheat yield value under the three salinity levels lies within 95% confidence interval (95% CI). Regression analysis revealed that there was a statistically significant linear relationship ($P < 0.01$) between measured and predicted wheat yield for both varieties under the three salinity levels with equation $y = -0.005 + 0.994x$ ($R^2 = 0.999$, RMSE = 0.009 ton/ha). Panda et al. (2002)

indicated that a reasonably good agreement was found between simulated wheat yield values by CERES-Wheat model and measured values under deficit irrigation treatments, with $R^2 = 0.970$.

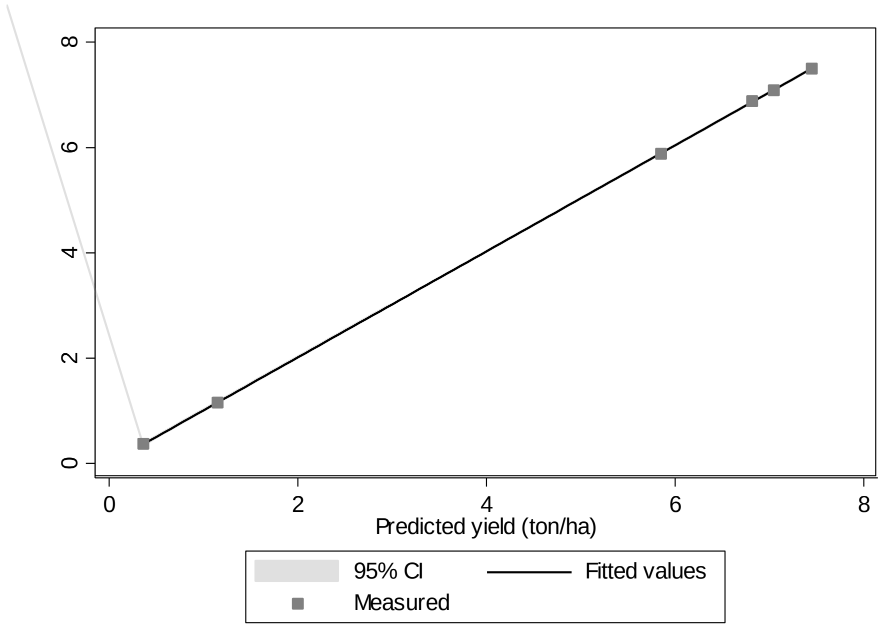

Fig. (3): Measured versus predicted wheat yield grown under three salinity levels and bio-fertilizer in 2004/05 growing season

In 2005/06 growing season, the model performance was also acceptable, where percent difference between measured and predicted wheat yield under the three salinity levels was also less than 1%, except for the third salinity level (EC = 10.9 dS/m), where the difference between measured and predicted yield of variety Sakha 94 was 2.60% (Table 7).

Table (7): Measured versus predicted wheat yield (ton/ha) with the application of bio-fertilizer for both varieties in 2005/06 growing season

Salinity Level	Sakha 93			Sakha 94		
	Measured Yield	Predicted Yield	% difference	Measured Yield	Predicted Yield	% difference
S1	7.53	7.49	0.48	7.09	7.15	0.85
S2	6.85	6.79	0.94	5.88	5.89	0.17
S3	1.14	1.15	0.67	0.37	0.36	2.60

S1=EC equals to 4.7 dS/m; S2=EC equals to 7.8 dS/m; S3=EC equals to 10.9 dS/m.

Results in Fig. (4) showed that all predicted wheat yield value under the three salinity levels lies within 95% confidence interval (95% CI). A statistically significant linear relationship ($P < 0.01$) between measured and predicted wheat yield for both varieties under the three salinity levels was found with equation y = 0.005 + 0.994x (R^2 = 0.999, RMSE = 0.009 ton/ha).

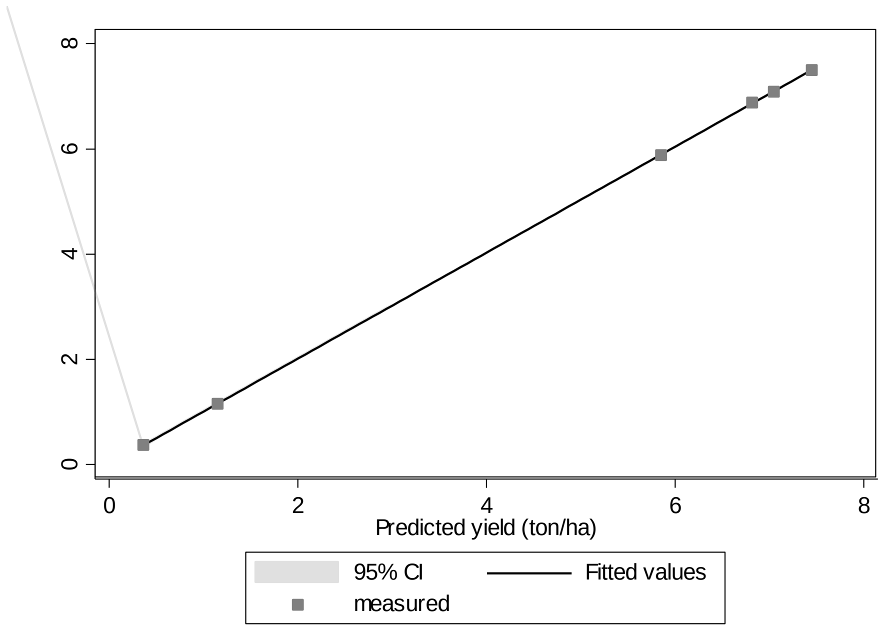

Fig. (4): Measured versus predicted wheat yield grown under three salinity levels and bio-fertilizer in 2005/06 growing season

The accurate results of obtained from running the model under the three salinity levels and under the application of bio-fertilizer implied that the model can be explored in irrigation management to save irrigation water. Although the above situation provides only a limited evaluation of the model, the model should be further tested as more data from more treatments in different locations and years become available. However, for the purposes of this study we felt that the model worked sufficiently well to warrant the exploration under irrigation water saving.

4. Predicting Wheat Yield under Irrigation Water Management

4.1. Readily available water depletion from root zone

The depletion of readily available water from root zone was studied in 2005/06 growing season for the first two salinity level. The third salinity level was excluded from the analysis because wheat yield was very low and the model was not able to successfully predict the yield. Figure (5) illustrated the depletion of readily available water from root zone for variety Sakha 93 under the first salinity level (EC = 4.7 dS/m). The figure indicated that there are six hills, each top of these hills represent irrigation day and the amount of readily available water at root zone. The figure also showed that there was a plenty of readily available water at the root zone after the 1st, 2nd and the 3rd irrigations. However, readily available water was completely depleted after the 3rd and the 4th irrigations, where water stress was prevailing for 12 days. In that case, salinity stress was not exist because wheat can tolerate up to EC = 6 dS/m.

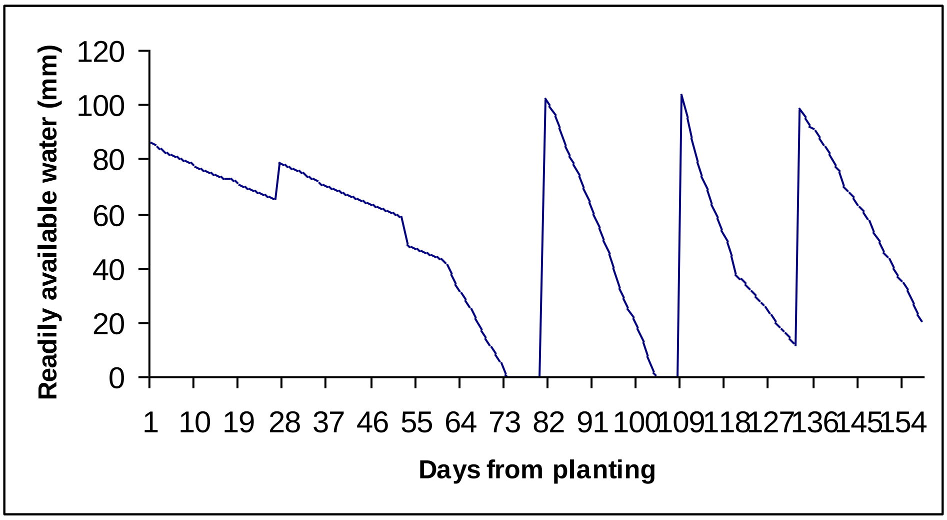

Fig. (5): Readily available water depletion from root zone for variety Sakha 93 grown under the (EC = 4.7 dS/m) in 2005/06 growing season.

Figure (6) illustrated the depletion of readily available water from root zone for variety Sakha 93 increased as a result of increasing soil salinity level to EC = 7.8 dS/m). Under these circumstances, the additive effect of both water and salinity stresses was prevailed and the number of stressed days was increased to 25 days.

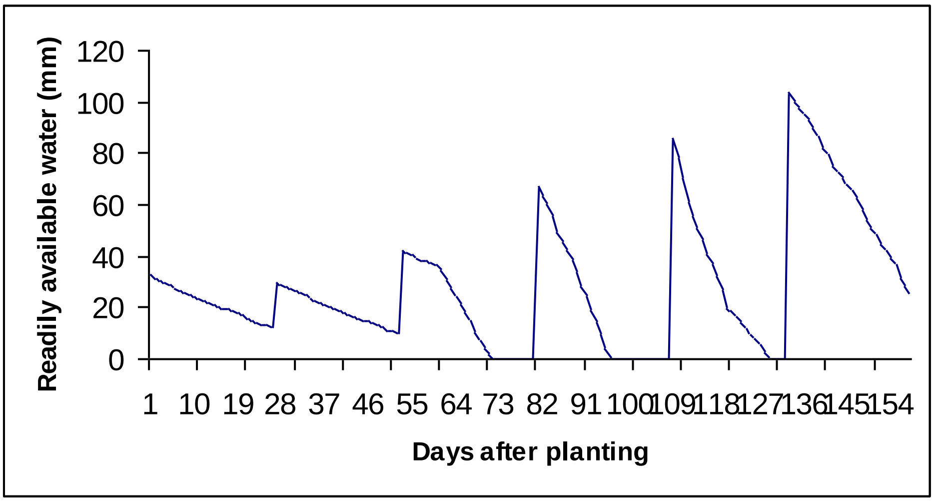

Fig. (6): Readily available water depletion from root zone for variety Sakha 93 grown under the (EC = 7.8 dS/m) in 2005/06 growing season.

Similar trend was observed for variety Sakha 94, where plenty of readily available water at root zone existed after the first three irrigations and the complete depletion of readily available water after the 3rd and the 4th irrigations under the first salinity level (EC = 4.7 dS/m). Water stress prevailed for 9 days (Fig. 7).

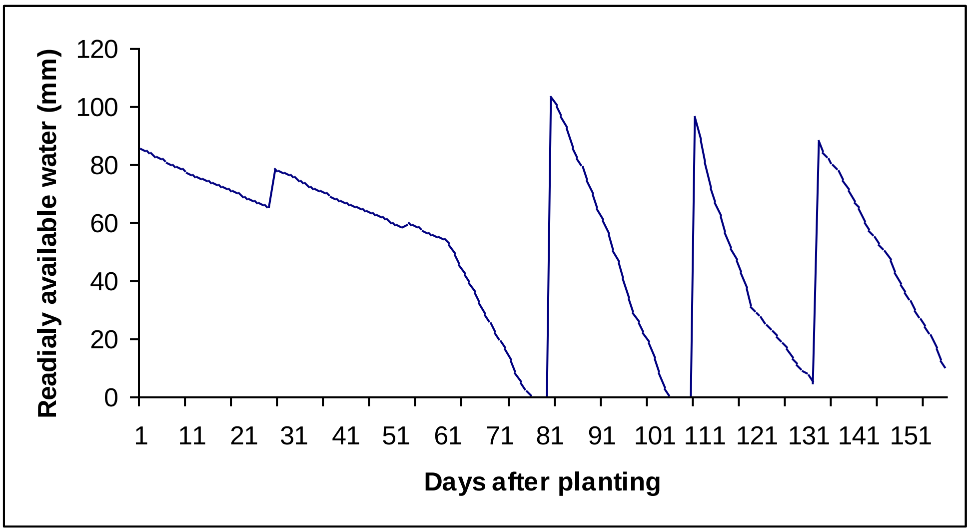

Fig. (7): Readily available water depletion from root zone for variety Sakha 94 grown under the (EC = 4.7 dS/m) in 2005/06 growing season.

Under EC = 7.9 dS/m, the additive effect of both water and salinity stresses was prevailed and the number of stressed days was increased to 21 days (Fig. 8).

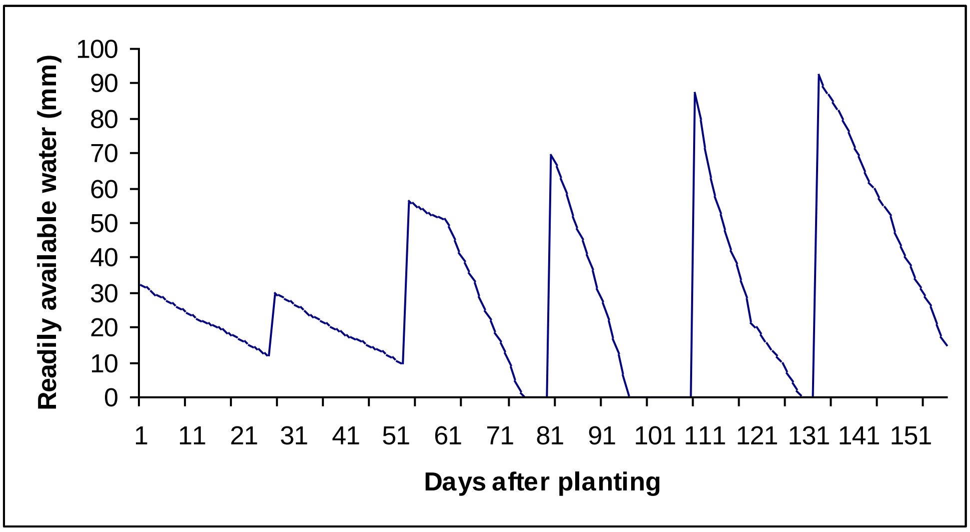

Fig. (8): Readily available water depletion from root zone for variety Sakha 94 grown under the (EC = 7.8 dS/m) in 2005/06 growing season.

4.2. Proposed scenario for irrigation

After studying the depletion of readily available water from root zone, a new irrigation schedule was proposed for the two varieties and under the two salinity levels. The proposed scenario was to reduce the amount of applied irrigation on the first three irrigations and to increase the amount of applied irrigation on the last three irrigations. This scenario resulted in saving about 5% of the total applied irrigation for both varieties under the 1st salinity level and saved about 2% of the total applied irrigation for both varieties under the 2nd salinity level. Results in Table (7) indicted that using the proposed irrigation schedule resulted in an increase in the yield of variety Sakha 93 by 0.19 and 1.71% under the two salinity levels, respectively. Furthermore, for variety Sakha 94, the yield was reduced by 0.93% under the 1st salinity level (EC = 4.7 dS/m) and was increased by 0.64% under the 2nd salinity level (EC = 7.8 dS/m)

Table (7): Predicted wheat yield under irrigation scheduling for both varieties and under two salinity levels

Salinity Level	Sakha 93			Sakha 94		
	Measured Yield	Predicted Yield	% difference	Measured Yield	Predicted Yield	% difference
S1	5.41	5.42	+0.19	4.91	4.86	-0.93
S2	3.46	3.52	+1.71	3.26	3.28	+0.64

S1=EC equals to 4.7 dS/m; S2=EC equals to 7.8 dS/m.

For variety Sakha 93 grown under the 1st salinity level (EC = 4.7 dS/m), Fig (9) showed that readily available water in the root zone was reduced after the first three irrigations and was increased after the last three irrigations compared with Fig. (5). Readily available water was completely depleted after the 5th and the 6th irrigations (Fig. 6). The number of water stress days was reduced to 8 days and yield was increased by 0.19% (Table 7).

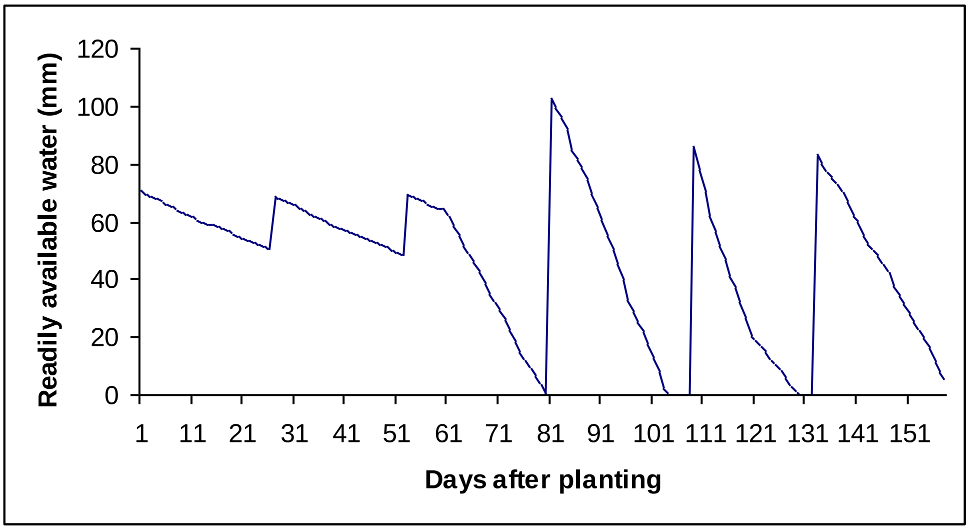

Fig. (9): Readily available water depletion from root zone for variety Sakha 93 grown under the (EC = 4.7 dS/m) after irrigation scheduling in 2005/06 growing season.

For the same variety grown under the 2nd salinity level (EC = 7.8 dS/m), Fig. (10) showed that readily available water in the root zone was reduced after the first three irrigations and was completely depleted after the 4th, and 5th irrigations. The number of water and salinity stresses days was reduced to 20 days and yield was increased by 1.17% (Table 7).

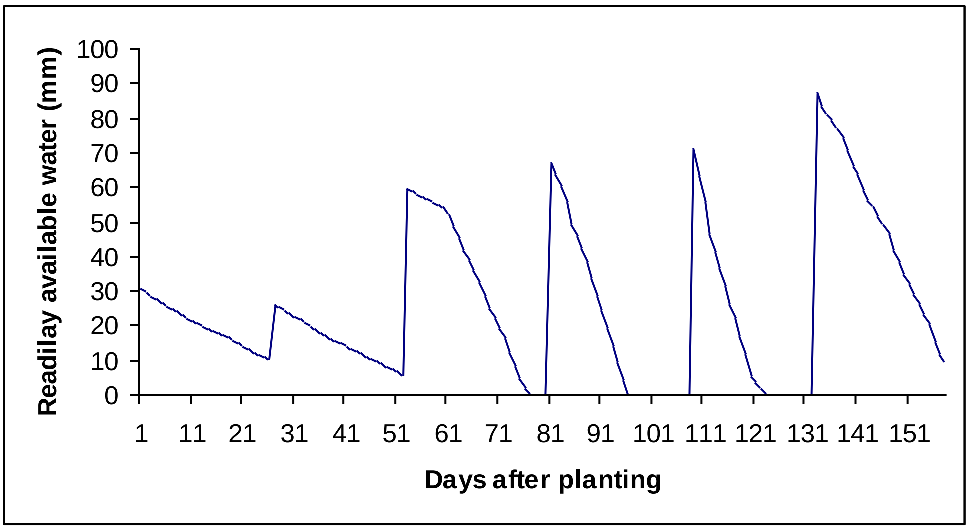

Fig. (10): Readily available water depletion from root zone for variety Sakha 93 grown under the (EC = 7.8 dS/m) after irrigation scheduling in 2005/06 growing season.

Similar trend was observed for variety Sakha 94 grown under the 1st salinity level (EC = 4.7 dS/m, Fig. (11), where the number of water stress days was reduced to 4 days and yield was decreased by 0.93% (Table 7).

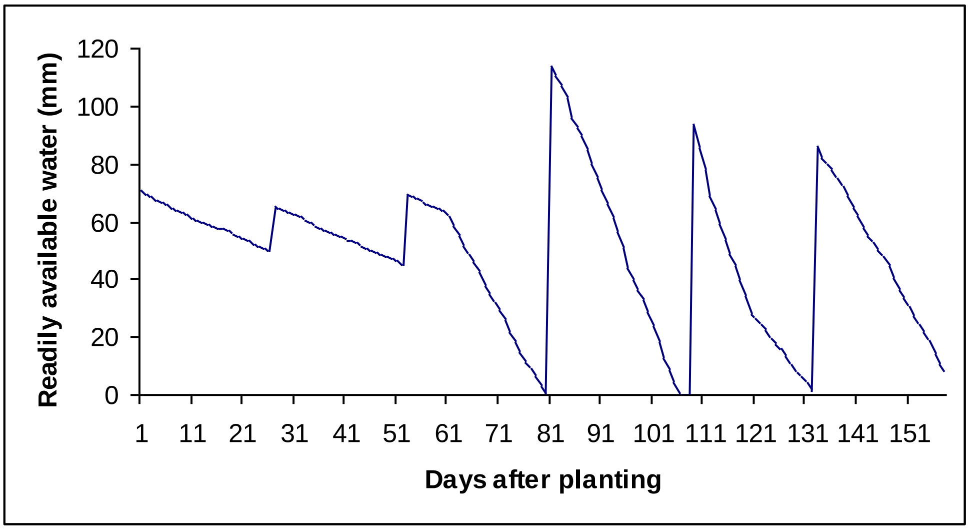

Fig. (11): Readily available water depletion from root zone for variety Sakha 94 grown under the (EC = 4.7 dS/m) after irrigation scheduling in 2005/06 growing season.

For variety Sakha 94 grown under the 2nd salinity level (EC=7.8 dS/m, Fig (12), similar trend was observed, where the number of water and salinity stresses days was reduced to 17 days and yield was increased by 0.64% (Table 7).

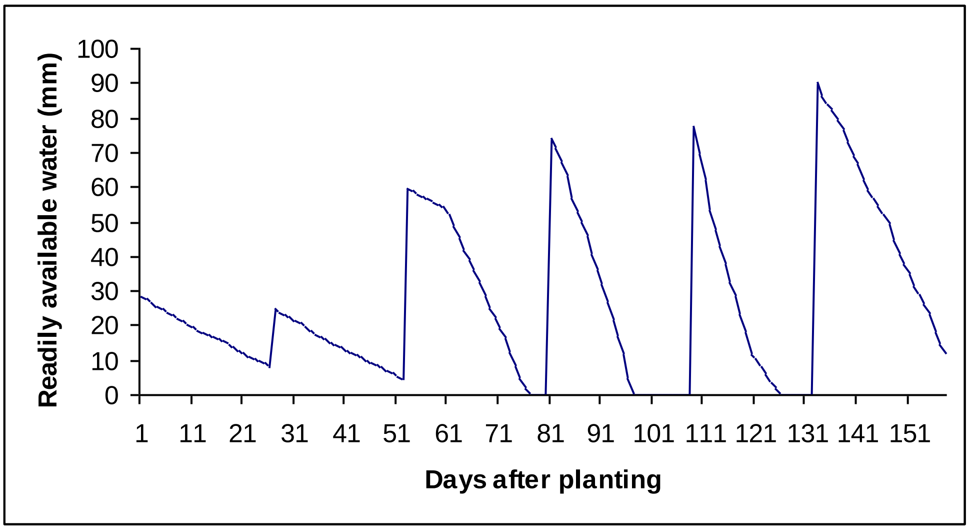

Fig. (12): Readily available water depletion from root zone for variety Sakha 94 grown under the (EC = 7.8 dS/m) after irrigation scheduling in 2005/06 growing season.

CONCLUSION

In the near future, the limitation of water resources will be increased. Therefore, it is important to study the effect of using irrigation water of poor quality in agriculture. The challenge of the future will be to maintain or even increase water productivity with less water or with water with poor quality. The ability of Yield-Stress model to calculate the effect of water and salinity stresses provide an appropriate irrigation management tool to maximize yield and to save irrigation water. The accurate prediction of the model for wheat yield under the three salinity levels for the both wheat varieties and under the application of bio-fertilizer implied that the model can be explored with confidence to predict wheat yield under irrigation water management. Using the model for irrigation scheduling under the first soil salinity level (EC = 4.7 dS/m) could result in saving 5% of the total applied irrigation water with 0.19 and 1.71% yield increase for variety Sakha 93 and Sakha 94, respectively. Whereas, under the second soil salinity level (EC = 7.8 dS/m) irrigation scheduling by the model could save 2% of the total applied irrigation water with 0.93% decrease in the yield of Sakha 93 and 0.64% yield increase for variety Sakha 94.

REFERENCES

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

Ayers, R.S., and Westcot, D.W. 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper 29, FAO, Rome.

Bresler, E. 1987. Application of conceptual model to irrigation water requirement and salt tolerance of crops. Soil Sci. Soc. Am. J. 51:788-793.

Cardon, G.E., and Letey, J. 1992. Soil-based irrigation and salinity management model: I. Plant water uptake calculations. Soil Sci. Soc. Am. J. 56:1881-1887.

Childs, S.W., and Hanks, R.J. 1975. Model of soil salinity effects in crop growth. Soil Sci. Soc. Am. Proc. 39:112-115.

de Wit, C.T. 1958. Transpiration and crop yield. Versl. Landbouwk. Onderz. 64.6 Inst. of Biol. Chem. Res. Field Crops Herbage, Wageningen, the Netherlands.

FAO. 1992. CROPWAT: A Computer Program for Irrigation Planning and Management. FAO Irrigation and Drainage Paper No. 46. Rome: Food and Agriculture Organization.

Gardner, F.P., Pearce, R.B., and Mitchell, R.L. 1985. Physiology of crop plants. Iowa State University Press. Ames.

Great Plains Systems Research. 1992. Root zone water quality model. Version 1.0. GPSR Tech. Rep. No. 2. USDA-ARS-GPSR, Fort Collins, CO.

Hutson, J.L., and Cass, A. 1987. A retentively functions for use in soil-water simulation models. J. Soil Sci. 38:105-113.

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

Leonard, R.A., Knisel, W.G., and Still, D.A. 1987. GLEAMS: Groundwater loading effects of agricultural management systems. Trans. ASAE 30:1403-1418.

Lobell, D.B., and Ortiz-Monasterio, J.I. 2006. Evaluating strategies for improved water use in spring wheat with CERES. Agric. Wat. Manag. 84:249-258.

Loomis, R.S., and Williams, W.M., 1963. Maximum crop productivity: an estimate. Crop Sci. 3, 67-72.

Ouda, S. A. 2006. Predicting the effect of water and salinity stresses on wheat yield and water needs. J. Appl. Sci. Res. 2(10):750-750.

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

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

Panda, R.K., Behera, S.K., and Kashyap, P.S. 2003. Effective management of irrigation water for wheat under stressed conditions. Agric. Wat. Mange. 63:37-56.

Shalhevet, J. 1994. Using water of marginal quality for crop production: Major issues – Review article. Agricultural Water Management. 25:233-269.

Shani, U., and Dudley, L. M. 2001. Field studies of crop response to water and salt stress. Soil Sci. Soc. Am. J. 65:1522-1528.

Steppuhn, H., van Genuchten, M.Th., and Grieve, C.M. 2005. Root-zone salinity: I. selecting a product–yield index and response function for crop tolerance. Crop Sci. 45:209-220.

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

Uehara, G. 1985. The International Benchmark Site Network for Agrotechnology Transfer. In W. Day and R.K. Atkin (eds.), Wheat Growth and Modeling, New York: Plenum Publishing, pp. 271-274.

Van Genuchten, M.Th. 1987. A numerical model for water and solute movement in and below the root zone. Res. Rep. 121. USDA-ARS, U.S. Salinity Lab., Riverside, CA.