

Predicting the Effect of Water and Salinity Stresses on Yield and Water consumption of Wheat

Samiha Abou El-Fetouh OWF^{C1}

Water Requirements and field Irrigation Research Department; Soil, Water, and Environment Research Institute; Agriculture Research Center; Egypt
*****9 Gamaa Street, Giza, Egypt

Received : 07 August 2006

Accepted : 31 May 2006

Email address: samihaouda@yahoo.com

Abstract

A computer model was developed to predict wheat yield and its water consumptive use. The developed model called "Wheat-Stress". The model calculates water depletion from root zone using equations described at FAO publication N°56. The model was validated using two-year experimental data for wheat planted during growing seasons of 2003/04 and 2004/05 to study the impact of skipping the 5th or the 6th irrigation on the yield of two wheat cultivars i.e. Sakha 93 and Giza 168. "Wheat-Stress" model was also used to predict wheat yields under the following hypothetical situations: (1) Reducing the amount of irrigation water by 20 %. (2) Using saline water for irrigation. Results showed that the model prediction gave good agreement with actual yield, for both varieties over the two growing seasons. Results also indicated that the yield of both varieties was reduced under deducting 20 % of irrigation water by 8.62 and 8.76 % for Sakha 93 and Giza 168, respectively. Furthermore, using saline water for irrigation reduced wheat yield by 4.14 and 4.38 % for Sakha 93 and Giza 168, respectively. Water consumptive use under total irrigation was reduced by 18.54 and 11.64% for both growing seasons, respectively, under saving 20 % of total water irrigation. Whereas, under saline water irrigation, water consumptive use was reduced by 15.02 and 11.93 % for both growing seasons, respectively. The developed model could be modified to predict the yield of other crops using specific crop parameters presented at FAO publication N°56.

Key words: wheat, "Wheat-Stress" model, RMSE, yield prediction, water consumptive use.

INTRODUCTION

Recently, water scarcity became an alarming problem. Deficit irrigation may resulting in similar yield or low yield reduction, with the benefit that the amount of saved irrigation water can be assign to be used in irrigating new lands. Furthermore, using saline water for irrigation could also save a lot of fresh water. FAO publication N°56 [1] provided a very important guideline for calculating crop evapotranspiration under water and salinity stresses.

Wheat is a very important cereal crop in Egypt and it is characterized by being moderately tolerant to salinity [1]. Water stress in wheat changes patterns of plant growth and development. Depressed water potential suppresses cell division, organ growth, net photosynthesis, protein synthesis, and alters hormonal balances of major plant tissues [2]. During vegetative growth, phyllochron decreases in wheat under water stress (McMaster, 1997) [3] and leaves become smaller, which could reduce leaf area index [4], tillers/plant, as well as shoot dry weight [5, 6, 7]. Water stress could result in disturbance metabolites transportation to the grains [8], reduced the number of reproductive tillers which limit their contribution to grain yield [6] and caused pollen sterility [9]. Furthermore, water stress occurs during grain growth could have a sever effect on final yield compared with stress occurred during other stages [10]. The amount of wheat yield reduction as a result of water stress is affected by the stage of grain development, where early grain development stage is more vulnerable to water stress than latter grain development stage [11].

Salts in the soil water solution can reduce evapotranspiration by making soil water less available for plant root extraction [1]. 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 [1]. Shalhevet [12] reported that the effect of salinity and water stress are generally additive in their impacts on crop evapotranspiration. Under saline conditions, plant growth is usually reduced by reducing the rate of leaf elongation, enlargement and the division of the cells in the leave [1].

Drainage water irrigation is used widely in Egypt after blending it with fresh water, where its EC became equal to 1 dS/m. Furthermore, the direct use of drainage water (EC=3 dS/m) is also a familiar practice of some farmers in Egypt to plant several crops, such as wheat (Amer and Ridder, 1988) [13]. Mashli [14] reported that, at El-Fayoum, Egypt wheat yield resulted from irrigation with fresh water was similar to the one obtained under saline water with EC=2.8 dS/m. Pilot studies carried out in two Governorates in Egypt showed that by applying appropriate management practices, drainage water with EC of 2 to 2.5 dS/m can be safely used for irrigation without long term hazardous consequences to crops or soils [15].

The objectives of this research are (i) to develop a computer model to predict wheat yield under the application of total irrigation or under water stress. (ii) to validate the model using field data for wheat. (iii) To use the developed model to predict wheat yield under high level of saline water irrigation.

MATERIALS AND METHODS

Model Description

A computer model was developed to predict wheat yield and water consumptive use. The developed model called "Wheat-Stress". The model is written in Pascal (computer language). "Wheat-Stress" requires two types of input data. Input data by the user and input data file. The model ask the user to input planting and harvesting date, the length of the

growing season, crop yield, total irrigation amount, and the EC of soil. The model also asks the user to input soil characteristics i.e. clay, silt, sand, organic matter, and CaCO₃ percentages.

The other input data source is a file represent the whole growing season, starts with sowing month and date, and

ends with harvesting month and date. The file contains daily mean temperature, percentage of monthly sunshine hours, monthly crop coefficient (Kc) (Table 1) and the date and the amount of each irrigation

Table 1. Mean temperature, percentage of monthly sunshine hours, monthly wheat coefficient (Kc) over the two growing season

Month	Mean temperature (°C)		percentage of monthly sunshine hours	Kc
	2003/04	2004/05		
December	16.1	16.5	9.80	0.60
January	14.5	14.5	9.69	0.50
February	15.8	14.5	8.33	0.70
March	18.2	16.2	8.63	0.75
April	21.4	19.1	7.75	0.70
May	25.4	23.1	7.43	0.69
Average	18.57	17.32	8.61	0.66

The developed model is designed to predict wheat yield and water consumptive use under the application of total irrigation amounts and under water stress and/or salinity stress. Therefore, several parameters were included in the model to be used in calculating water balance. These parameters were obtained from Allen et al [1] and included in Table 2.

Table 2. Wheat parameters needed to run "Wheat-Stress" as indicated by FAO publication N^o65.

Parameters	Wheat
P	0.55
Ky	1.15
B	7.1
Eces	6.0

p = Depletion fraction; Ky = yield response factor; b = reduction in yield per increase on mean EC of the saturation extract for root zone (ECe, %/(dS/m)); ECes = EC of the saturation extract at the threshold of ECe when crop yield is reduced.

The model is divided into three principle procedures. The first one called "WaterBalance". The second procedure called "SalinityEffect". The third procedure called "YieldAccumulation".

Procedure "Water-Balance"

Procedure "WaterBalance" calculates, on a daily basis, ETc, readily available water at root zone and root zone water depletion. ETc, (mm/day) is calculated using Blaney-Criddle method as followed:

$$[1] ETc = ((MeanTemp * SSHH * Kc) / 100)$$

where:

MeanTemp = Mean temperature (° C).

SSHH = % of monthly sunshine hours

Kc = monthly crop coefficient

Readily available water (RAW, mm) is calculated from total available water (TAW, mm) at root zone and soil water depletion fraction under no stress (p), which is a crop specific coefficient [1]. Total available water is the amount of water that a crop can extract from its root zone, which depends on the type of soil and rooting depth. Whereas, readily available water is the fraction of total available water that a crop can extract from root zone without suffering water stress.

$$[2] TAW = (WaterFieldC - WaterWiltingP) * Z$$

$$[3] RAW = TAW * p$$

where:

WaterFieldC = Water at field capacity (mm)

WaterWiltingP = Water at wilting point (mm)

Z = rooting depth (cm)

Root zone depletion (Dr) is calculated next by accumulating ETc and compare it with readily available water on a daily basis. If root zone depletion is higher than readily available water, a water stress coefficient (Ks) is calculated and used to calculate ETc adjusted (ETcadj, mm) [1].

$$[4] Ks = (TAW - Dr) / ((1 - p) * TAW)$$

$$[5] ETcadj = ETc * Ks$$

Procedure "Salinity-Effect"

The second procedure "SalinityEffect" is called in the program to be executed if the value of irrigation water EC (ECe) is higher than the EC threshold (ECes). Under that condition, another water stress coefficient is calculated to account for salinity stress and new value of ETcadj is calculated [1] as followed:

$$[6] Ks = (1 - (b / (ky * 100)) * (ECe - ECes))$$

Procedure "Yield-Accumulation"

Procedure "YieldAccumulation" is called in the program to accumulate yield on a daily basis as a function of water consumptive use. The model calculates a mean value for the accumulated yield per day throughout the growing season. The model accumulate yield by choosing one of two

alternatives. On a daily basis, if there is no stress, the daily value of accumulated yield would equal to the calculated mean value. If stress exist (water and/or salinity), the mean value of the actual yield is reduced in relation to the reduction in daily water consumptive use.

Field experiments

Wheat yield data was obtained from two field experiments conducted at Shalkan, Kalubia Governorate, Egypt in the growing seasons of 2003/04 and 2004/05 to study the impact of skipping the 5th or the 6th irrigation on the yield of two wheat cultivars i.e. Sakha 93 and Giza 168. The experimental design was split plot design with three replications, where irrigation treatments were assigned to the main plots and wheat varieties were assigned to the sub plot. Sowing was done on 15th of December in the two growing seasons and harvest was done on 20th of May in the first season and on 23rd of May in the second season. Wheat plants received six irrigations with a total of 5832 m³/ha in the 1st season and 5969 m³/ha in the 2nd season. Soil type was clay loam with 7.5 % sand, 55.9 % silt, 33.6 % clay, 1.6

% organic matter and 2.4 % CaCO₃. The plants were subjected to water stress by skipping the 5th or the 6th irrigation. To test the accuracy of "Wheat-stress" model, wheat yield was predicted under applying the total irrigation amount and skipping either the 5th or the 6th irrigation. Both Percent error (PE) and root mean square error (RMSE) between actual and predicted yield were calculated. Low PE and RMSE between observed and predicted yields reflect the accuracy of the model. Furthermore, analysis of variance and R² were calculated between actual and predicted values.

Moreover, "Wheat-Stress" model was used to predict wheat yield the following hypothetical situations:

1. Reducing the amount of irrigation water by 20 %.
2. Using saline water for irrigation (EC = 9 dS/m).

Table 3 shows actual irrigation amounts (m³/ha) for the three treatments i.e. total irrigation, skipping the 5th or the 6th irrigation. Furthermore, the two hypothetical irrigation water amounts i.e. saving 20 % of total irrigation amount and irrigation with saline water are included in the same table

Table 3. Irrigation water amounts used to predict wheat yield under the two growing seasons.

Irrigation amount (m ³ /ha)	2003/04	2004/05
Total irrigation amount	5832	5969
Skipping the 5 th irrigation	4836	4973
Skipping the 6 th irrigation	4812	4949
Total irrigation amount less 20 %	4668	4776
Saline irrigation water amount	5832	5969

RESULTS

"Wheat-Stress" model verification

Predicted yield of Sakha 93 variety

Yield of Sakha 93 variety was predicted in the growing seasons of 2003/04 and 2004/05 (Table 4 and 5). The model prediction gave good agreement with actual yield, where both the values of PE and RMSE were low.

Table 4 . Actual and predicted yield of Sakha 93 variety planted in 2003/04 growing season.

Irrigation (m ³ /ha)	Actual yield (ton/ha)	Predicted yield (ton/ha)	PE %	RMSE (ton/ha)
Application of total irrigation	6.94	6.94	0	0
Skipping the 5 th irrigation	6.02	6.12	1.59	0.10
Skipping the 6 th irrigation	6.17	6.02	2.33	0.14

Table 5. Actual and predicted yield of Sakha 93 variety planted in 2004/05 growing season.

Irrigation (m ³ /ha)	Actual yield (ton/ha)	Predicted yield (ton/ha)	PE %	RMSE (ton/ha)
Application of total irrigation	6.98	6.98	0	0
Skipping the 5 th irrigation	6.41	6.26	2.25	0.12
Skipping the 6 th irrigation	6.48	6.31	2.59	0.17

Predicted yield of Giza 168 variety

Similarly, yield of Giza 168 variety was predicted in the growing seasons of 2003/04 and 2004/05 (Table 6 and 7). The model prediction gave good agreement with actual yield, where both the values of PE and RMSE were low.

Table 6. Actual and predicted yield of Giza 168 variety planted in 2003/04 growing season.

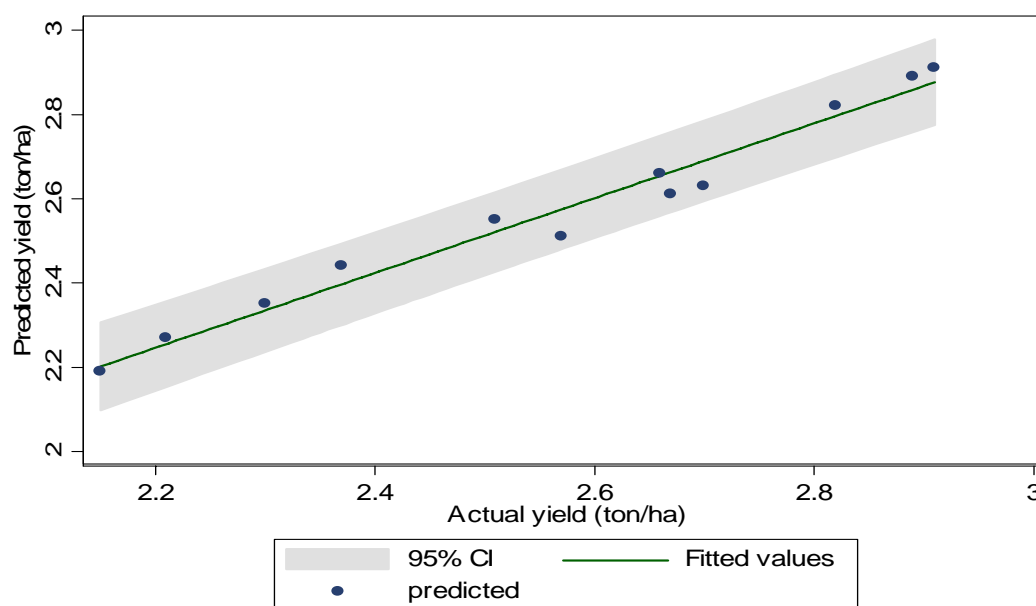
Irrigation (m ³ /ha)	Actual yield (ton/ha)	Predicted yield (ton/ha)	PE %	RMSE (ton/ha)
Application of total irrigation	6.77	6.77	0	0
Skipping the 5 th irrigation	5.52	5.64	2.17	0.14
Skipping the 6 th irrigation	5.69	5.86	2.95	0.17

Table 7. Actual and predicted yield of Giza 168 variety planted in 2004/05 growing season.

Irrigation (m ³ /ha)	Actual yield (ton/ha)	Predicted yield (ton/ha)	PE %	RMSE (ton/ha)
Application of total irrigation	6.38	6.38	0	0
Skipping the 5 th irrigation	5.16	5.26	1.86	0.10
Skipping the 6 th irrigation	5.30	5.45	2.71	0.14

Figure 1 shows the agreement between predicted and actual wheat yield for both varieties under application of total irrigation amount, skipping the 5th or the 6th irrigation overall the two growing seasons. The figure implied that all predicted values of wheat yield lied within a 95% confidence interval. Analysis of variance showed a significant relationship between actual and predicted yield. Furthermore, R^2 was found to be 0.9723 and the value of RMSE was found to be 0.10.

Figure 1. Actual versus predicted wheat yield for both varieties over the two growing seasons under total irrigation, skipping the 5th or the 6th irrigation.



Wheat yield prediction under water stress

The potential impact of reducing irrigation water by 20 % on wheat yield is presented in Table 8. Results indicated that the yield of both varieties was reduced under deducting 20 % of irrigation water by 8.62 and 8.76 % for Sakha 93 and Giza 168, respectively. This result was in agreement with what was reported by Kramer [8] that low soil moisture conditions caused losses of tissue water, which inhibit cell division and enlargement, and reduced number of reproductive tillers and limit their contribution to grain yield.

Table 8. Actual and predicted yield of Sakha 93 and Giza 168 under water stress averaged over the two growing seasons.

Variety	Actual yield (ton/ha)	Predicted yield (ton/ha)	PE %
Sakha 93	6.96	6.36	8.62
Giza 168	6.58	6.00	8.76

Wheat yield prediction under irrigation with saline water

Wheat can tolerate EC up to 6 dS/m. Therefore, the potential impact of using saline water irrigation with EC=9 dS/m on wheat yield was assessed by "Wheat-Stress". Replacing fresh water with saline water for irrigation reduced wheat yield by 4.14 and 4.38 % for Sakha 93 and Giza 168, respectively (Table 9). This result in agreement with what was reported by Allen et al [1] that under saline conditions, plant growth is usually reduced by reducing the rate of leaf elongation, enlargement and the division of the cells in the leave, which is expected to reduce yield.

Table 9. Actual and predicted yield of Sakha 93 and Giza 168 under saline water stress averaged over the two growing seasons.

Variety	Actual yield (ton/ha)	Predicted yield (ton/ha)	PE %
Sakha 93	6.96	6.67	4.14
Giza 168	6.58	6.29	4.38

Water consumption of wheat

Wheat-Stress" is also capable of calculating water consumptive use under total irrigation amounts and under varying degree of water and salinity stress. Results in Table (10) revealed that water consumptive use under total irrigation amount was lower in the 2nd growing season, compared with the 1st growing season as a result lower mean temperature during the 2nd growing season (Table 1).

Regarding to water stress, results in Table (10) indicated that reducing the amount of applied irrigation water, reduced water consumptive use as a result of quick water depletion from root zone, which reduced the daily evapotranspiration by the value of the stress factor (Ks, calculated by the mo-

del). Water consumptive use of wheat under total irrigation was reduced by 18.54 % in the 1st season, and by 11.64 % in the 2nd season under saving 20 % of total water irrigation. Under these conditions, the corresponding value of yields was also reduced as indicated in Table (8).

Regarding to saline water irrigation, water consumptive use was reduced by 15.02 % in the 1st season and by 11.93 % in the 2nd season, although plants did received the total amount of irrigation water (Table 10). This is an indication of the role that salts in the soil water solution can do in reducing evapotranspiration by making soil water less available for plant root extraction [1].

Table 10. Water consumptive use of wheat grown under different amounts of irrigation water.

Water consumptive use (mm/season)	2003/04	2004/05
Total irrigation amount	426	419
Skipping the 5 th irrigation	363	367
Skipping the 6 th irrigation	359	352
Total irrigation amount less 20 %	347	371
Saline irrigation water amount	362	369

DISCUSSION

Because saving irrigation water became a necessity recently, different water management practices should be explored. However, that could be expensive to perform. Therefore, using simulation model to predict the effect of applying different irrigation amounts on yield could be the ultimate solution.

Over the last two decades, modeling has become a major research tool in agriculture for resource management. 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.

Wheat-Stress model employed soil water depletion equations to instantly predict potential wheat yield under different irrigation intervals. The good agreement between actual and predicted yield strongly suggested that the model can be used with confidence in simulating wheat yield under different water stress levels.

Using saline water for irrigation could help in saving fresh water. Several models were developed in the recent years dealing with plant growth, evapotranspiration, and agricultural chemical movement. Nevertheless, they all do not consider soil salinity. On the other hand, Wheat-Stress contained a procedure to predicted wheat yield under salinity stress. Therefore, the model was successful in predicting potential yield reduction as a result of using saline water for irrigation.

CONCLUSION

Wheat-stress model employed the soil water depletion equations to instantly predict potential wheat yield under varying degree of stress, which could partially replacing expensive field experiments. The good agreement between actual and predicted yield implied that the model is capable of investigating radical alternatives of deficit fresh water irrigation and/or deficit saline water irrigation.

Saving 20% of irrigation water resulted in about 9% reduction in wheat yield and reduction in water consumptive use by about 15.09% for both growing seasons. Whereas,

using saline water to irrigate wheat resulted in about 4% reduction in yield and about 13.38 % reduction in water consumptive use for both growing seasons.

However, precaution should be taken into account when applying irrigation water with high salinity. Improving management practices, such as the use of soil amendments, deep ploughing, fertilization, applying minimum leaching requirements and organic manure application could overcome the harm effect of salts accumulation in the soil. Furthermore, mitigation of water stress [11] and salinity stress [16] through spraying chemical substances is another management practices to be done to relief the stress and increase yield. Lastly, breeding for water and salinity stress tolerance in wheat could be an important procedure to combat stress.

The developed model could be modified to predict the yield of other crops, such as maize, sunflower, or cotton using specific crop parameters presented in FAO publication No56.

REFERENCES

- [1]. Allen, R. G., L. S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration: Guideline for computing crop water requirements. FAO No56.
- [2]. Gusta, L.V., and T.H.H. Chen. 1987. The physiology of water and temperature stress. In E.G. Heyne (ed.) Wheat and wheat improvement. Agron. Monogr. 13, 2nd ed. ASA, CSSA, and SSSA, Madison, WI.
- [3]. McMaster, G.S. 1997. Phenology, development, and growth of wheat (*Triticum aestivum* L.) shoot apex: A review. *Advances in Agronomy*. 59:63-118.
- [4]. Gardner, F. P., R. B Pearce, R. L. Mitchell. 1985. *Physiology of Crop Plants*. Iowa State University Press. Ames.
- [5]. Abo El-Kheir, M.S.A. 2000. Antitranspirant effects on wheat plants grown under two levels of water supply. *Annals of Agricultural Science*. Moshtohor. 38 (2): 823-832.
- [6]. Mosaad, M.G.; G. Ortiz-Ferrara and V. Mahalak-Shmi 1995. Tiller development and contribution to yield under different moisture regimes in two *Triticum* species. *Journal of Agronomy*. 174: 173-180.

- [7]. Naceur, M.B.; M. Naily, and M. Selmi, 1999. Effect of water deficiency during different growth stages of wheat on soil different growth stages of wheat on soil humidity, plant physiology and yield components. *Medit.* 10 (2): 63-60 (c.f. *Soil and Fertilizer*, 1999, 62 (12), 13465).
- [8]. Kramer, P.J. 1995. *Water Relations of Plant and Soils*. Academic Press New York.
- [9]. Saini, H.S.; Sedgley, M. and Aspinall, D. 1984. Developmental anatomy in wheat of male sterility induced by heat stress, water deficit or abscisic acid. *Australian Journal of Plant Physiology*, (11), 243-254.
- [10]. Hanson A.D. and E.C. Nelson. 1980. *The biology of crop production*, ed. P. S. Carlson. New York Academic Press.
- [11]. El-Kholy, M. A., S. A. Ouda, M. S. Gaballah and M. Hozayn. 2005. Predicting the interaction between the effect of anti-transpirant and weather on productivity of wheat plant grown under water stress. *Journal of Agronomy*. 4(1):75-82.
- [12]. Shalhevet, J. 1994. Using water of marginal quality for crop production: Major issues – Review article. *Agricultural Water Management*. 25:233-269.
- [13]. Amer, M.H. and Ridder N.A. 1988. *Land drainage in Egypt*. Drainage Research Institute, Water Research Center, Cairo. 376 pp.
- [14]. Mashli A.M. 1985. Amelioration and development of deteriorated soils - Egypt. Technical Report, Project FAO/UNDP EGY/79/020. Cairo, Egypt. 1984-1985.
- [15]. Rhoades, J. D., A. Kandiah, and A. M. Mashli. 1992. *FAO irrigation and drainage No48*. Rome.
- [16]. Gaballah, M.S, S.A. Ouda, M.S. Mendour and M.M. Rady .2006. Predicting the role of antioxidant and irrigation on sunflower yield grown under saline condition. *International Journal of Natural and Engineering Science*. Accepted for publication.