Research Journal of Agriculture and Biological Sciences, 2(6): 323-327, 2006

Irrigation Optimization for Sunflower Grown under Saline Conditions

[1]S.A. Ouda, [2]M.S. Gaballah, [1]M.M. Tantawy and [2]T. El-Mesiry

[1]Water Requirements and Field Irrigation Research Department, Soil, Water and Environment Research Institute, Agricultural Research Center, Egypt
[2]Water Relations and Field Irrigation Department, National Research Centre, Cairo, Egypt.

Abstract: Two field experiments were conducted during the 2004 and 2005 growing seasons for sunflower planted in saline soil (EC = 4.68 dSm^{-1}). The experiment was designed to study the influence of soil salinity on the yield of two sunflower cultivars. The results were used to model the effect of reducing soil EC on sunflower yield and on irrigation water conservation using "Yield-Stress" model. Two scenarios were proposed to increase sunflower yield under saline soil and optimize irrigation water as follows: 1) To predict sunflower yield under the reduction of soil EC and $CaCO_3$ using actual irrigation amounts. 2) To predict sunflower yield under the reduction of soil EC, $CaCO_3$ and conserving irrigation water. The model showed good agreement between actual and predicted sunflower yield and water consumptive use for both cultivars. RMSE and Willmott index were 0.0214 and 0.9999 for yield, whereas it was 0.0403 and 0.9998 for water consumptive use. The results also showed that sunflower yield improvements would occurred as a result of reducing soil EC from 4.68 to 1.68 dSm^{-1} for both cultivars and for the two growing seasons. Yield improvements were also observed as a result of reducing soil EC from 4.68 to 1.68 dSm^{-1} and reducing the amount of applied irrigation water for both cultivars for the two growing seasons. The amount of irrigation water that could be saved were 1149 and 1179 m^3/ha or about 15% for 2004 and 2005 growing seasons, respectively.

Key words: Sunflower, irrigation, salinity, simulation model, "Yield-Stress" model.

INTRODUCTION

Increasing soil salinity in Egypt is a very alarming problem. Soil salinity inhibits plants growth as result of stomatal closure, which reduces the CO_2 to O_2 ratio in the leaves and inhibits CO_2 fixation[1], as a result the rate of leaf elongation, enlargement and cells division was reduced[2]. Furthermore, salts in the soil water solution can reduce evapotranspiration by making soil water less available for plant root extraction[3].

Sunflower is moderately sensitive to soil salinity, where it can tolerate salinity up to EC equals to 1.7 dSm^{-1}[2]. Sunflower yield was greatly reduced when plants were grown under salinity conditions[4]. Leaching salts from the soil by increasing irrigation amount is a practice used in Egypt to improve growth and yield of crops grown under saline conditions. However, conserving irrigation water became a concern these days, which could limit using this practice to reduce salinity stress. Instead, reducing both soil EC and $CaCO_3$ by using soil amendments could improve soil and increase final yield. Moreover, these soil amendments could lead to reduction in irrigation water application during the growing season.

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[5], evapotranspiration[6], and agricultural chemical movement[7]. 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[8] and RZWQ[9], which include the effect of salinity.[10] modified van Genuchten-Hanks[11] model to simulate crop yield under various irrigation management regimes including saline conditions. On the other hand, A model called "Wheat-Stress" was developed by Ouda[12] to predict wheat yield under water and salinity stresses. This model could be modified to predict yield and water consumptive use of sunflower grown under saline conditions.

The objectives of this research were (i) to modify "Wheat-Stress: model to predict sunflower yield under saline soil. (ii) to predict sunflower yield under reduced salinity stress. (iii) to predict sunflower yield under reduced salinity stress, in addition to saving of irrigation water.

Corresponding Author: S.A. Ouda, Agroclimatology and climate change unit, Department of Irrigation Research, Agriculture Research Centre, Egypt.
E.mail: samihaouda@yahoo.com.

MATERIALS AND METHODS

Two field experiments were conducted during the summer season of 2004 and 2005 for sunflower planted in saline soil (EC = 4.68 dSm^{-1}) at the experimental farm at Demo, 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 soil salinity on the yield of two sunflower cultivars i.e. Euroflour and Vidoc and the obtained results were used to model the effect of reducing soil EC on sunflower yield and on irrigation water conservation. Sowing was done on the 21st of May for the 1st season and on 20th of May in the 2nd season. Harvest was done on mid of September in both seasons. The experimental plots consisted of five rows; each was 5 m long and the 0.7 m width. The seeds were sown within the rows at 20 to 25 cm apart. Fertilization was accomplished using ammonium nitrate (33.5% N), calcium super phosphate (15.5% P_2O_2) and potassium sulfate (48.0 K_2O) at the rate of 480, 480, and 120 kg/ha, respectively. Irrigation was applied using after root zone depletion method. The recommended cultural practices for the growing sunflower plants were followed. Soil physical and chemical analyses were done according to Jackson[13] (Table 1).

"Wheat-Stress" model: "Wheat-Stress" is a computer model calculates crop evapotranspiration and water depletion from root zone using equations described in FAO publication Nº56[2]. The model employs the value of actual yield under no stress to predict the yield if water or salinity stresses occurred. Therefore, "Wheat-Stress" is capable of accurately predicting crop yield and water consumptive use under the application of total irrigation amount, under water and salinity stresses. The model contains two stress coefficients one for water stress and one for salinity stress. Under stress, the model predict crop yield in relation to either one or both of these coefficients. The model does not require calibration for each site. However, FAO's crop coefficient (Kc) should be adjusted to the local weather conditions.

Model Description: 1."Wheat-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, the length of the growing season, crop yield, and total irrigation amount. 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 date, and ends with harvesting month and date. 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.

Table 1: Physical and chemical analyses of the soil of the experiments

Property	Value
Physical analysis	
Clay %	29.50
Silt%	20.50
Sand %	50.00
Soil texture	Sandy clay loam
Chemical analysis	
EC (dSm^{-1})	4.68
Organic matter %	1.70
$CaCO_3$	6.45

Table 2: Seasonal weather parameters for sunflower planted in 2004 and 2005 growing seasons.

Growing season	Mean temperature (ºC)	Relative humidity (%)	Solar radiation ($Mj/m^2/day$)	Wind speed (m/sec)
2004	28.35	51.83	2.66	25.41
2005	29.18	51.49	2.66	25.38
Mean	28.77	51.66	2.66	25.4

Table 3: Actual and proposed values for soil EC and $CaCo_3$

Soil property	Actual	Scenario 1	Scenario 2	Scenario 3
EC (dSm^{-1})	4.68	3.68	2.68	1.68
$CaCO_3$	6.45	5.07	3.69	2.32

Table 4: Actual and proposed amounts of irrigation water (m^3/ha) for both growing seasons.

Scenario	Irrigation amounts (2004 growing season)	Irrigation amounts (2005 growing season)
Actual	7663	7863
Scenario 1	7280	7470
Scenario 2	6897	7077
Scenario 3	6514	6684

Prediction of sunflower yield and water consumptive use: "Wheat-Stress" was modified to predict sunflower yield and water consumption using parameters included in FAO publication N º56[2]. The model was renamed to "Yield-Stress" instead of "Wheat-Stress". A control value of yield was used for the two growing seasons. These values were obtained from Agricultural Statistical Yearbook for 2004 and 2005 growing seasons. Weather parameters for the two growing seasons were collected and means are presented in Table (2).

The model was used to predict sunflower yield and water consumption in both growing seasons. Furthermore, two scenarios were proposed to increase sunflower yield under saline soil and optimize irrigation water as follows:

- Predict sunflower yield under the reduction of soil EC and $CaCO_3$ using actual irrigation amounts.
- Predict sunflower yield under the reduction of soil EC and $CaCO_3$ and conserving irrigation water.

Table (3) included the above mentioned scenarios of soil EC, and $CaCo_3$. Actual irrigation amounts and proposed amounts are included in Table (4).

To test the accuracy of the model, percent difference between actual and predicted yield, root mean square error (RMSE) and Willmott index of agreement (Willmott, 1981) [14] were calculated.

RESULTS AND DISCUSSIONS

1. Sunflower yield and water consumptive use prediction: Results in Table (5) implied that there is good agreement between actual and predicted sunflower yield, where percent difference between actual and predicted yield were less than 2% for the both cultivars under the two growing seasons. Similarly, good agreement between actual and predicted water consumptive use were observed, where percent difference between actual and predicted were less than 3 % for the both cultivars under the two growing seasons. RMSE and Willmott index were 0.0214 and 0.9999 for yield, whereas it was 0.0403 and 0.9998 for water consumptive use. This is an indication of the accuracy of the model, which facilitate using it for further yield predictions with management practices. These results were similar with what was obtained by Ouda[12], when the model was used to predict wheat yield and water consumptive use.

Figure (1) showed the agreement between predicted and actual sunflower yield for both cultivars overall the two growing seasons. The figure showed that all predicted values of sunflower 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 0.9707.

2. Predicting sunflower yield under amended saline soil: In 2004 growing season, reducing soil EC from 4.68 to 3.68 dSm^{-1} (scenario 1) reduce sunflower yield losses from 30.49 and 32.43% to 15.70 and 15.44% for Euroflour and Vidoc cultivars, respectively (Table 6). Similarly, sunflower yield improvements were observed as result of reducing soil EC from 4.68 to 1.68 dSm^{-1} (scenario 3), where yield losses decreased to 3.59 and 3.47% for Euroflour and Vidoc cultivars, respectively.These results were similar to what was obtained by Francois[15], where under soil EC = 6 dSm^{-1} sunflower yield was reduced by 36.71%. Whereas, under soil EC = 2 dSm^{-1} sunflower yield was reduced by 16.03%.

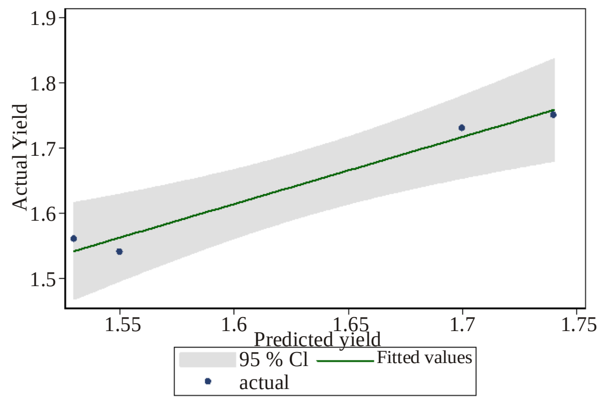

Fig. 1: Actual versus predicted sunflower yield for both cultivars over the two growing seasons.

Table 5: Actual and predicted sunflower yield and water consumptive use grown under saline soil.

		Yield (ton/ha)			WCU (cm)		
Growing season	Variety	Actual	Predicted	Percent difference	Actual	Predicted	Percent difference
2004	Euroflour	1.54	1.55	0.91	53.22	54.36	2.15
	Vidoc	1.73	1.7	1.5	53.54	54.67	2.11
2005	Euroflour	1.56	1.53	1.92	56.75	55.12	2.87
	Vidoc	1.75	1.74	0.57	57.15	55.77	2.42
RMSE		0.0214			0.04		
Willmott index		0.9999			0.9998		

Table 6: Actual and predicted sunflower yield under proposed different soil salinity levels in 2004 growing season.

	Euroflour			Vidoc		
	Yield (ton/ha)			Yield (ton/ha)		
Scenario	Actual	Predicted	Percent difference	Actual	predicted	Percent difference
Actual	2.23	1.55	30.49	2.59	1.74	32.43
Scenario 1	2.23	1.88	15.7	2.59	2.19	15.44
Scenario 2	2.23	2.09	6.28	2.59	2.43	6.18
Scenario 3	2.23	2.15	3.59	2.59	2.5	3.47

Table 7: Actual and predicted sunflower yield under proposed different soil salinity levels in 2005 growing season.

	Euroflour			Vidoc		
	Yield (ton/ha)			Yield (ton/ha)		
Scenario	Actual	Predicted	Percent difference	Actual	predicted	Percent difference
Actual	2.26	1.53	32.3	2.61	1.74	32.95
Scenario 1	2.26	1.9	15.93	2.61	2.18	16.48
Scenario 2	2.26	2.14	5.31	2.61	2.42	7.28
Scenario 3	2.26	2.19	3.1	2.61	2.48	4.98

Table 8: Actual and predicted sunflower yield under proposed different soil salinity levels and reduced irrigation amounts in 2004 growing season.

	Euroflour			Vidoc		
	Yield (ton/ha)			Yield (ton/ha)		
	Actual	predicted	Percent difference	Actual	predicted	Percent difference
Actual	2.23	1.55	30.49	2.59	1.74	32.43
Scenario 1	2.23	1.83	17.94	2.59	2.13	17.76
Scenario 2	2.23	2.02	9.42	2.59	2.34	9.65
Scenario 3	2.23	2.1	5.83	2.59	2.44	5.79

Table 9: Actual and predicted sunflower yield under proposed different soil salinity levels and reduced irrigation amounts in 2005 growing season.

	Euroflour			Vidoc		
	Yield (ton/ha)			Yield (ton/ha)		
Scenario	Actual	predicted	Percent difference	Actual	Predicted	Percent difference
Actual	2.26	1.53	32.3	2.61	1.74	32.95
Scenario 1	2.26	1.83	19.03	2.61	2.13	18.39
Scenario 2	2.26	2.06	8.85	2.61	2.38	8.81
Scenario 3	2.26	2.12	6.19	2.61	2.45	6.13

Table 10: Saved irrigation amounts (m^3/ha) for each scenario averaged over the two cultivars for 2004 growing season.

	Irrigation (m^3/ha)		Yield losses (ton/ha) under		
Scenario	Actual	Proposed	EC reduction	EC reduction+less irrigation	Saved amount
Scenario 1	7663	7280	17.85	15.57	383
Scenario 2	7663	6897	9.54	6.23	766
Scenario 3	7663	6514	5.81	3.53	1149

Table 11: Saved irrigation amounts (m^3/ha) for each scenario averaged over the two cultivars for 2004 growing season.

	Irrigation (m^3/ha)		Yield losses (ton/ha) under		
Scenario	Actual	Proposed	EC reduction	EC reduction+less irrigation	Saved amount
Scenario 1	7863	7470	16.21	18.71	393
Scenario 2	7863	7077	6.3	8.83	786
Scenario 3	7863	6684	4.04	6.16	1179

Similar results were observed in 2005 growing season, were reducing soil EC from 4.68 to 1.68 dSm^{-1} (scenario 3) reduced yield losses from 32.30 and 32.95% to 3.10 and 4.98% for Euroflour and Vidoc cultivars, respectively (Table 7).

3. Predicting sunflower yield under amended saline soil and conserving irrigation water: Regarding to 2004 growing season, yield losses were reduced from 30.49 and 32.43% to 5.83 and 5.79% for the both cultivars, respectively under using soil amendment, in addition to reducing the amount of applied irrigation water (Table 8).

Similarly, results in Table (9) indicated that in 2005 growing season and under EC = 1.68 dSm^{-1} (scenario 3), yield losses were reduced to 6.19 and 6.13% for the both cultivars, respectively.

Results in Table (10) implied that using soil amendments to reduce EC from 4.68 to 1.68 dSm^{-1} (scenario 3) could save 1149 m^3/ha or about 15% of the total applied water in 2004 growing season.

Whereas, 1179 m^3/ha of the applied irrigation water could be saved (about 15%) if soil EC was reduced to 1.68 dSm^{-1} (Table 11). Gaballah *et al*.,[4] stated that up to 600 m^3/ha of irrigation water applied to sunflower planted under saline soil could be save if soil pH was reduced by 0.3.

Conclusion: Modeling is a mathematical representation of a system, which could be time and money conserving tool. Yield-Stress model employed the soil water depletion equations to instantly predict potential sunflower yield under different soil salinity levels, which could partially replacing expensive field experiments. The good agreement between actual and predicted yield strongly suggested that the model can be used with confidence in simulating sunflower yield under different soil salinity conditions. Furthermore, the model does not require calibration or curve-fitting parameter adjustments. However, a value of yield grown under no stress conditions is required to run the model.

Sunflower yield improvements were obtained when soil EC was reduced to 1.68 dSm^{-1}. Furthermore, up to 15% of the total irrigation could be saved, with a considerable yield losses reduction.

REFERENCES

1. Epstein, E., 1989. Salt tolerance crops origin, development and prospects of the concept. Plant and soil., 89: 187-193.
2. Allen, R.G., L.S. Pereira, D. Raes and M. Smith, 1998. Crop evapotranspiration: Guideline for computing crop water requirements. FAO N^{o}56.
3. Shalhevet, J., 1994. Using water of marginal quality for crop production: Major issues – Review article. Agricultural Water Management. 25: 233-269.
4. Gaballah, M.S, S.A. Ouda, M.S. Mendour and M.M. Rady, 2006. Predicting the role of antoxidant and irrigation on sunflower yield grown under saline conditions. Proceeding of International Conference: Environmentally Sound Technology in Water resources management. pp: 30-35.
5. 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.
6. FAO., 1992. CROPWAT C A Computer Program for Irrigation Planning and Management. FAO Irrigation and Drainage Paper No. 46. Rome : Food and Agriculture Organization.
7. Leonard, R.A., W.G. Knisel and D.A. Still, 1987. GLEAMS: Groundwater loading effects of agricultural management systems. Trans. ASAE 30: 1403–1418.
8. Hutson, J.L. and A. Cass, 1987. A retentively functions for use in soil-water simulation models. J. Soil Sci., 38: 105-113.
9. Great Plains Systems Research. 1992. Root zone water quality model. Version 1.0. GPSR Tech. Rep. No. 2. USDA-ARS-GPSR, Fort Collins, CO.
10. Cardon, G.E. and J.1 Letey, 1992. Soil-based irrigation and salinity management model: I. Plant water uptake calculations. Soil Sci. Soc. Am. J. 56: 1881-1887.
11. 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.
12. Ouda, S.A., 2006. Predicting the effect of water and salinity stresses on wheat yield and water needs. J. Appl. Bio. Sci. Accepted for publication.
13. Jackson, M.L., 1969. Soil Chemical Analysis. New Delhi. Prentice Hall of India Private Limited. New Delhi., pp.144-197 and 326-338.
14. Willmott, C.J., 1981. On the validation of models. Phys. Geogr. 2: 184–194.
15. Francois, L.E., 1996. Salinity effects on four sunflower hybrids. Agron. J. 88: 215-219.