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COMPARISON BETWEEN CROPWAT AND YIELD-STRESS MODELS IN PREDICTING SESAME YIELD AND CONSUMPTIVE USE UNDER WATER STRESS CONDITIONS

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ABSTRACT

Both CROPWAT and Yield-Stress models were validated using data from two field experiments conducted at Shandaweel Agriculture Research Station, Egypt in 2007 and 2008 growing seasons. The aim of the experiment was to study the effect of imposing water stress on sesame yield and consumptive use. Four sesame varieties namely Giza 32, Toshky 1, Shandaweel 3 and Sohag 3 were used, in addition to two different irrigation treatments (irrigation after depletion of 50% and 70% of total available soil moisture). The results indicated that both CROPWAT and Yield-Stress models predicted yield reduction and consumptive use as a result of water stress for both irrigation treatments over both growing seasons with high degree of accuracy. However, Yield-Stress model predicted values of sesame yield and consumptive use were more close to the measured values, compared with the values of CROPWAT model. This could be attributed to the method that Yield-Stress model uses to predict yield, compared with CROPWAT model method, which is percent reduction in the yield as a result of water stress. Furthermore, the highly accurate prediction of Yield-Stress of consumptive use could be attributed to using daily measurements of weather parameters, not monthly measurements that CROPWAT uses. Prediction results also indicated that if irrigation water was applied when 80% of total available water was depleted, CROPWAT predicted reduction in sesame yield by 13.8 and 13.3%, in both growing seasons, whereas Yield-Stress predicted 13.6 and 13.9% reduction. Therefore, under deficit irrigation procedure irrigation water should be applied when 70% of total available soil moisture was depleted to avoid high yield decrease.

Keyword: Soil water balance, irrigation scheduling models, total available water, evapotranspiration, sesame yield

INTRODUCTION

Achieving greater water use efficiency became the primary challenge for scientists in agriculture. This should include the employment of techniques and practices that deliver a more accurate supply of water to crops. Furthermore, there is a need to quantify the impact of the water limitation on crop productivity. Therefore, the necessity to develop a crop simulation model was arisen to use the existing knowledge of yield responses to water supply and quantify that in term of yield losses. Many crop simulation models have been developed with high degree of sophistication and significant data requirements. Among them, DSSAT, and CropSyst, which simulate potential production, and water and nitrogen-limited production as well. However, the considerable information needed on crop, soil, and environmental characteristics to run these models cause a limitation. For that purpose, a need was arisen to develop a simpler, mechanistic model that focuses on water-limited crop production to predict the potential yields for a given water supply.

Many simulation models, using soil water budget in the root zone, were developed over the past thirty years (Hill, et al., 1987; Keller, 1987; Camp et al., 1988; Choeng, 1992; Foroud et al., 1992; Prajamworng, 1994 and George et al., 2000). Of these models and the most important one is CROPWAT (Smith, 1991), which have been widely accepted. The CROPWAT model developed by the FAO Land and Water Development Division (FAO, 1992) includes a simple water balance model that allows the simulation of crop water stress conditions and estimations of yield reductions based on well established methodologies for determination of crop evapotranspiration (Allen et al., 1998) and yield responses to water (FAO, 1979). Smith et al. (2000) used CROPWAT model to predict yield reduction in cotton, sugar beet and potato under water stress. They stated that the CROPWAT model can adequately simulate yield reduction for such crops as a result of imposed water stress conditions. CROPWAT model accounted well for the relative sensitivity of different growth stages and was able to reproduce the negative impact of water stress on yield. CROPWAT model was used in the estimation of water requirements of paddy rice in Japan (Toda *et al*., 2005) and in Taiwan (Kuo *et al.,* 2001). Furthermore, the model was used in the estimating potential evapotranspiration in Iran (Naijafi, 2007). However, in Egypt CROPWAT has been used mainly in irrigation scheduling not in assessing the impact of deficit irrigation on crop yield.

Another model called Yield-Stress (Ouda, 2006) was developed using similar approach to that of CROPWAT in the estimation of soil water reserve in the root zone and the determination of crop evapotranspiration, with a different method in the calculation of yield reduction as a result of water stress. Basically, the Yield-Stress model assumes that there is a linear relationship between available soil water and yield, where the 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). The Yield-Stress model was design to predict the effect of deficit irrigation scheduling on the yield of several crops and their consumptive use. The model was used in irrigation management for several crops under different stress conditions and its performance was acceptable (Ouda *et al*., 2006a; Ouda *et al*., 2006b El-Mesiry *et al*., 2007; Khalil *et al*., 2007; Ouda *et al.*, 2007; Tantawy *et al.,* 2007 and Ouda *et al*., 2008a; Ouda *et al*., 2008b; Ouda *et al*., 2008c). Although the performance of Yield-Stress in predicting the yield and consumptive use of several crops was satisfactory, a comparison between it and CROPWAT model will increase its credibility.

The objective of this research were (i) to compare between CROPWAT and Yield-Stress model in predicting sesame yield and consumptive use under water stress; (ii) to use both models in predicting sesame yield reduction under more irrigation water saving.

MATERIALS AND METHODS

1. Field experiments

Two field experiments, under surface irrigation, were conducted at Shandaweel Agriculture Research Station, Egypt in 2007 and 2008 growing seasons to study the effect of imposing water stress on sesame yield and consumptive use and to use yield data in validating CROPWAT and Yield-Stress models. Four sesame varieties were used i.e. Giza 32, Toshky 1, Shandaweel 3 and Sohag 3 with two different irrigation treatments i.e. irrigation after depletion of 50% of total available soil moisture, which represent control treatment and irrigation after depletion of 70% of total available soil moisture, which represent water stress treatment. A split plot design was used with four replications, where the main plots were devoted to irrigation treatments and the sub plots were devoted to sesame varieties. Plot area was 100 m^2. Sowing was done on the 17^{th} and 18^{th} of May in 2007 and 2008 growing seasons, respectively. All agricultural practices, for sesame production in the area, were followed as recommended. Soil mechanical analysis of the experimental field, at the depth of 0-60 cm, was done according to Piper (1950) and shown in Table (1).

Table (1): Soil mechanical analysis of the experimental site

Soil fraction	Content (%)
Sand	30.5
Silt	25.3
Clay	39.4
Organic matter	1.6
$CaCO_3$	3.2

The soil water content was determined before irrigation to calculate the required amount of applied irrigation water to reach field capacity. The applied amount of irrigation water was measured using cutthroat flume for surface irrigation. Actual evapotranspiration was estimated by soil sampling method and calculated according to the Israelsen and Hansen (1962) using the following formula:

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

Where: CU= consumptive use (mm), Θ_2=soil moisture percentage, by weight , after irrigation, Θ_1=soil moisture percentage, by weight , before the next irrigation, Bd=bulk density (g/cm^3) and ERZ= effective root zone depth ,mm. Field capacity, wilting point and available soil water and bulk density (g/cm^3) values, in the depth of 0-60 cm ,are shown in Table (2).

Table (2): Some soil moisture constants and bulk density of the experimental field

Depth/cm	Field capacity, wt %	Wilting point, wt %	Available water, wt %	Bulk density (g/cm^3)
00 – 15	35.04	14.45	20.59	1.26
15 – 30	31.21	13.90	17.31	1.30
30 – 45	27.11	13.09	14.02	1.34
45 – 60	27.85	12.69	15.16	1.35

The yield (ton/ha) of each of the four sesame varieties under the two irrigation treatments was measured at harvest.

2. Description of the crop models

2.1. CROPWAT model

CROPWAT is a computer program for irrigation planning and management. The calculation of reference evapotranspiration (ET_o) is based on the FAO Penman-Monteith method (Allen et al., 1998). Crop water requirements (ET_{crop}) over the growing season are determined from ET_o and estimates of crop evaporation rates, expressed as crop coefficients (K_c), based on well-established procedures (FAO, 1977). Stress conditions in the root zone are defined by the critical soil water content, expressed as the fraction of total available soil water between field capacity and wilting point, which is readily available for crop transpiration, and characterizes a soil moisture condition in which crop transpiration is not limited by any flow restrictions in the root zone. The effect of water stress on the yield is quantified by relating the relative yield decrease to the relative evapotranspiration deficit through an empirically derived yield response factor (K_y, FAO 1979). The input data required by the model include monthly temperature (maximum and minimum), relative humidity, sunshine hours, and wind-speed. The crop parameters used for the estimation of the crop evapotranspiration, water-balance calculations, and yield reductions due to water stress include crop coefficient (K_c), length of the growing season, critical depletion level (p), and yield response factor (K_y). The soil data include information on total available soil water content and the maximum infiltration rate for runoff estimates. In addition, the initial soil water content at the start of the season is needed. The impact of various levels of water supply on sesame yield is simulated by setting the dates and the application depth of irrigation. Through the soil moisture content and evapotranspiration rates, the soil water balance is determined on a daily basis. Output tables enable the assessment of the effects on yield reduction, for the various growth stages and efficiencies in water supply.

2.2. Yield-Stress model

Yield-Stress is a computer program calculates yield reduction as a result of water stress and can be used in irrigation planning and management. The model calculates daily reference evapotranspiration (ET_o), crop water requirements (ET_{crop}) over the growing season and the depletion of readily available water from the root zone using the same approach as CROPWAT model. However, the model uses the actual individual irrigation amount in the calculation of soil water balance. Furthermore, Yield-Stress model calculate dry matter production using solar energy level as the limiting factor (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, which is converted 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 by harvest index. Under water stress conditions, where the predicted readily available water is lower than predicted ET_{crop}, the model reduced the predicted yield in relation to the reduction in the daily water consumption. The input data required by the model include daily measurements of temperature (maximum and minimum), relative humidity, solar radiation, and wind speed. The FAO's crop coefficient (K_c) and critical depletion level (p) are used in the estimation of the crop evapotranspiration and water balance. The soil data required by the model include clay, silt, sand, organic matter, and $CaCO_3$ percentages. Furthermore, the amount of each individual irrigation is required for the estimation of water balance. The effect of different level of water stress on crop yield can be simulated by altering the amount of applied irrigation amounts. The depletion of soil water in the root zone can be graphed, which could help irrigation management process successfully.

3. Sesame yield and consumptive use prediction

The experimental data was used to validate both CROPWAT and Yield-Stress models. Furthermore, the two models were used to predict reduction in sesame yield as a result of saving more irrigation water.

3.1. CROPWAT model

CROPWAT was used to predict percent reduction in sesame yield as a result of applying irrigation when 70% of the total available water was depleted from the root zone for the four sesame varieties was also predicted. Consumptive use of sesame under application of irrigation when 50 and 70% of the total available water was depleted for the four sesame varieties was also predicted. Furthermore, the model was used to predict potential sesame yield reduction, if irrigation was applied when 80% of the total available water was depleted from the root zone**.**

3.2. Yield-Stress model

Yield-Stress was used to predict sesame yield and consumptive use under the application of the two irrigation treatments. The proposed irrigation amounts by CROPWAT under irrigation when 80% of total available water from root zone was used to run Yield-Stress model and predict potential sesame yield.

The results of the validation of the two models were compared to the measured data and to each others as well. Percent reduction between measured and predicted values of both models for each growing season was calculated; in addition to two goodness of fit measurements i.e. root mean squared error (Jamieson *et al.,* 1998) and Willmott index of agreement (Willmott, 1981).

RESULTS AND DISCUSSION

1. The field experiments

In 2007 growing season and under applying irrigation after 70% of total available water depletion, the average yield reduction was 4.9% over all the four sesame varieties. Whereas, the average percent reduction in the applied irrigation water to sesame was 20.1% for the four varieties and under the two irrigation treatments (Table 3). Sesame yield under the two irrigation treatments for the four varieties were significantly differed (one sided t-test, $P < 0.001$) in 2007 growing season.

Table (3): Measured sesame yield and the applied irrigation amounts in 2007 growing season.

Sesame variety	Yield (ton/ha)			Irrigation amounts (m^3/ha)		
	I_1	I_2	PR %	I_1	I_2	PR %
V_1	1.1	1.0	5.5	8532	6286	26.3
V_2	1.3	1.3	4.5	8584	6708	21.9
V_3	1.6	1.5	5.2	8276	6766	18.2
V_4	1.4	1.3	4.4	7918	6806	14.1
Average	1.3	1.3	4.9	8328	6642	20.1

I_1= irrigation after the depletion of 50% of the total available water, I_2= irrigation after the depletion of 70% of the total available water, PR%= percent reduction, V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3 and V_4=Sohag 3.

The average sesame yield and irrigation amounts reductions as a result of irrigation application after the depletion of 70% of the total available water in 2008 growing season are presented in Table (4). These results implied that 22.2% reduction in the applied irrigation water reduced sesame yield by 5.4% average over the four varieties. Sesame yield under the two irrigation treatments for the four varieties were also significantly differed (one sided t-test, $P < 0.001$) in 2008 growing season.

Table (4): Measured sesame yield and the applied irrigation amounts in 2008 growing season.

Sesame variety	Yield (ton/ha)			Irrigation amounts (m^3/ha)		
	I_1	I_2	PR %	I_1	I_2	PR %
V_1	1.3	1.2	3.8	7734	6327	18.2
V_2	1.6	1.5	6.6	8007	6555	18.1
V_3	1.8	1.7	6.5	9010	6560	27.2
V_4	1.6	1.5	4.7	8379	6263	25.3
Average	1.5	1.6	5.4	8283	6426	22.2

I_1= irrigation after the depletion of 50% of the total available water, I_2= irrigation after the depletion of 70% of the total available water, V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3, V_4=Sohag 3 and PR%= percent reduction.

2. Validation of the CROPWAT model

2.1. Sesame yield prediction

The prediction of percent of sesame yield reduction as a result of applying irrigation after 70% depletion of total available water are included in Table (5). The results showed that CROPWAT over predicted sesame yield reduction as a result of water stress by as an average over the four varieties. Root mean square error was 0.34 and 0.41 %, whereas Willmott index of agreement was 0.97 and 0.95 for 2007 and 2008 growing seasons, respectively.

Table (5): Measured versus predicted sesame yield percent reduction by CROPWAT model.

Sesame variety	2007 growing season		2008 growing season	
	Actual yield reduction	CROPWAT prediction	Actual yield reduction	CROPWAT prediction
V_1	5.5	5.5	3.8	6.0
V_2	4.5	6.1	6.6	5.3
V_3	5.2	6.1	6.5	5.6
V_4	4.4	6.6	4.7	7.4
Average	4.9	6.1	5.4	6.1
RMSE	0.34		0.41	
WI	0.97		0.95	

V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3, V_4=Sohag 3, RMSE=Root Mean Square Error and WI=Willmott Index of agreement.

2.2. Prediction of sesame consumptive use

CROPWAT model prediction of consumptive use of sesame for both irrigation treatments in 2007 growing season was lower than the measured values (Table 6). Regarding to irrigation after the depletion of 50% of total available water at the root zone, the model prediction was higher by an average of 1.6% over the four varieties. Whereas, percent difference between measured and predicted consumptive use values was 4.5% under irrigation after the depletion of 70% of total available water at the root zone. Root mean square error was 0.3 and 0.5 mm for both irrigation treatments, respectively. Willmott index of agreement was 0.99 for both irrigation treatments (Table 6).

Table (6): Measured versus predicted consumptive use (cm) of sesame by CROPWAT model in 2007 growing season.

Sesame variety	I_1			I_2		
	Measured	Predicted	% difference	Measured	Predicted	% difference
V_1	489.0	488.2	0.2	443.8	435.9	1.8
V_2	451.8	449.6	0.5	410.2	385.7	6.0
V_3	455.6	433.9	4.8	414.0	389.8	5.9
V_4	466.8	462.7	0.9	416.4	398.2	4.4
Average	465.8	458.6	1.6	421.1	402.4	4.5
RMSE	0.03			0.05		
WI	0.99			0.99		

I_1=irrigation after the depletion of 50% of total available soil water, I_2=irrigation after the depletion of 70% of total available soil water, V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3, V_4=Sohag 3, RMSE=Root Mean Square Error and WI=Willmott index of agreement.

Similar trend was observed in 2008 growing season, where percent difference between measured and predicted consumptive use was 3.3 and 4.5% for irrigation after 50 and 70% of available soil water, respectively. Root mean squared error and Willmott index of agreement were 0.04 mm and 0.99 for irrigation after the depletion of 50% of total available soil water, whereas it was 0.05 mm and 0.99 for irrigation after the depletion of 70% of total available soil water (Table 7).

Table (7): Measured versus predicted consumptive use of sesame by CROPWAT model in 2008 growing season.

Sesame variety	I_1			I_2		
	Measured	Predicted	% difference	Measured	Predicted	% difference
V_1	484.5	483.5	0.2	422.4	411.4	2.6
V_2	458.7	436.3	4.9	405.7	371.6	8.4
V_3	464.5	443.8	4.5	411.0	393.9	4.2
V_4	486.8	469.9	3.5	431.4	419.6	2.7
Average	473.6	458.4	3.3	417.6	399.1	4.5
RMSE	0.04			0.05		
WI	0.99			0.99		

I_1=irrigation after the depletion of 50% of total available soil water, I_2=irrigation after the depletion of 70% of total available soil water, V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3, V_4=Sohag 3, RMSE=Root Mean Square Error and WI=Willmott Index of agreement.

3. Validation of the Yield-Stress model

3.1. Prediction of sesame yield

The results of the validation of Yield-Stress model showed that in 2007 rowing season, the average difference between measured and predicted sesame yield values was low, where it was 0.1 and 0.2% for irrigation after the depletion of 50 and 70% of total available water at root zone (Table 8).

Table (8): Measured versus predicted sesame yield by Yield-Stress model in 2007 growing season.

Sesame variety	I_1			I_2		
	Measured	Predicted	% difference	Measured	Predicted	% difference
V_1	1.1	1.1	0.9	1.0	1.0	1.0
V_2	1.3	1.3	0.8	1.3	1.3	0
V_3	1.6	1.6	0	1.5	1.5	0
V_4	1.4	1.4	0.7	1.3	1.3	0
Average	1.3	1.3	0.1	1.3	1.3	0.2

I_1=irrigation after the depletion of 50% of total available soil water, I_2=irrigation after the depletion of 70% of total available soil water, V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3 and V_4=Sohag 3.

Likewise, similar results were obtained in 2008 growing season, where the average difference between measured and predicted yield values were 0.1 and 0.3% for irrigation after the depletion of 50 and 70% of total available water at root zone (Table 9).

Table (9): Measured versus predicted sesame yield by Yield-Stress model 2008 growing season.

Sesame variety	I_1			I_2		
	Measured	**Predicted**	**% difference**	**Measured**	**Predicted**	**% difference**
V_1	1.3	1.3	0	1.2	1.2	0
V_2	1.6	1.6	0	1.5	1.5	0.7
V_3	1.8	1.8	0.3	1.7	1.6	0.6
V_4	1.6	1.6	0	1.5	1.5	0
Average	1.5	1.5	0.1	1.5	1.5	0.3

I_1=irrigation after the depletion of 50% of total available soil water, I_2=irrigation after the depletion of 70% of total available soil water, V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3 and V_4=Sohag 3.

Results in Table (10) indicated that Yield-Stress model over predicted sesame yield reduction as a result of irrigation after the depletion of 70% of total available water by low percentage in both 2007 and 2008 growing seasons. Root mean square error was 0.18 and 0.09 %, whereas Willmott index of agreement was 0.99 for 2007 and 2008 growing seasons, respectively.

Table (10): Measured versus predicted sesame yield percent reduction by Yield-Stress model.

Sesame variety	2007 growing season		2008 growing season	
	Actual yield reduction	**Yield-Stress prediction**	**Actual reduction**	**Yield-Stress prediction**
V_1	5.5	5.6	3.8	3.9
V_2	4.5	5.3	6.6	7.0
V_3	5.2	5.2	6.5	7.3
V_4	4.4	5.7	4.7	4.5
Average	4.9	5.4	5.4	5.7
RMSE	0.18		0.09	
WI	0.99		0.99	

I_1=irrigation after the depletion of 50% of total available soil water, I_2=irrigation after the depletion of 70% of total available soil water, V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3, V_4=Sohag 3, RMSE=Root Mean Square Error and WI=Willmott Index of agreement.

3.2. Prediction of sesame consumptive use

With respect to consumptive use of sesame, the difference between measured and the predicted values of consumptive use by Yield-Stress model was an average of 2.0 and 3.1 % under irrigation after the depletion of 50 and 70% of total available water, respectively in 2007 growing season. Root mean square error was 0.02 and 0.03 mm for both irrigation treatments, respectively, whereas Willmott Index of agreement was 0.99 for both irrigation treatments (Table 11).

Table (11): Measured versus predicted consumptive use of sesame by Yield-Stress in 2007 growing season.

Sesame variety	I_1			I_2		
	Measured	Predicted	% difference	Measured	Predicted	% difference
V_1	489.0	478.5	2.2	443.8	428.0	3.6
V_2	451.8	444.0	1.7	410.2	400.2	2.4
V_3	455.6	443.5	2.7	414.0	400.5	3.3
V_4	466.8	459.3	1.6	416.4	403.3	3.2
Average	465.8	456.3	2.0	421.1	408.0	3.1
RMSE	0.02			0.03		
WI	0.99			0.99		

I_1=irrigation after the depletion of 50% of total available soil water, I_2=irrigation after the depletion of 70% of total available soil water, V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3, V_4=Sohag 3, RMSE=Root Mean Square Error and WI=Willmott Index of agreement.

Furthermore, the difference between measured and predicted values of consumptive use in 2008 growing season was 1.2 and 3.0% for irrigation after the depletion of 50 and 70% of total available soil water, respectively. Root mean square error was 0.01 and 0.04 for both irrigation treatments, respectively. Willmott index of agreement was 0.99 for both irrigation treatments (Table 12).

Table (12): Measured versus predicted consumptive use of sesame by Yield-Stress in 2008 growing season.

Sesame variety	I_1			I_2		
	Measured	Predicted	% difference	Measured	Predicted	% difference
V_1	484.5	497.6	2.7	422.4	426.0	0.9
V_2	458.7	457.0	0.4	405.7	382.1	5.8
V_3	464.5	463.1	0.3	411.0	392.7	4.5
V_4	486.8	480.6	1.3	431.4	434.8	0.8
Average	473.6	474.6	1.2	417.6	408.9	3.0
RMSE	0.01			0.04		
WI	0.99			0.99		

I1=irrigation after the depletion of 50% of total available soil water, I2=irrigation after the depletion of 70% of total available soil water, V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3, V_4=Sohag 3, RMSE=Root Mean Square Error and WI=Willmott Index of agreement.

4. Comparison between CROPWAT and Yield-Stress models

4.1. Prediction of sesame yield

Actual percent of sesame yield reduction as a result of irrigation after the depletion of 70% of available soil moisture and predicted percent of yield reduction by CROPWAT and Yield-Stress models are presented in Table (13). Comparing the average values of actual percent yield reduction with the predicted values by either Yield-Stress or CROPWAT, Yield-Stress predicted values were closer to the actual values than CROPWAT predicted values.

Table (13): Comparison of actual percent reduction in sesame yield and predicted percent reduction by both models.

Sesame variety	2007 growing season			2008 growing season		
	Actual yield reduction	CROPWAT yield reduction	Yield-Stress yield reduction	Actual yield reduction	CROPWAT yield reduction	Yield-Stress yield reduction
V_1	5.5	5.5	5.6	3.8	6.0	3.9
V_2	4.5	6.1	5.3	6.6	5.3	7.0
V_3	5.2	6.1	5.2	6.5	5.6	7.3
V_4	4.4	6.6	5.7	4.7	7.4	4.5
Average	4.9	6.1	5.4	5.4	6.1	5.7

V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3and V_4=Sohag 3.

4.2. Prediction of consumptive use

Regarding to predicted values of consumptive use, the average percent difference between measured and predicted value by Yield-Stress model was lower than the average predicted value of CROPWAT for both irrigation treatments over the two growing seasons, except for irrigation after the depletion of 50% of total available soil water in 2007 growing season (Table 14 and 15).

Table (14): Percent difference between measured and predicted consumptive use by CROPWAT and Yield-Stress in 2007 growing season.

Sesame variety	I_1		I_2	
	CROPWAT	Yield-Stress	CROPWAT	Yield-Stress
V_1	0.2	2.2	1.8	3.6
V_2	0.5	1.7	6.0	2.4
V_3	4.8	2.7	5.9	3.3
V_4	0.9	1.6	4.4	3.2
Average	1.6	2.0	4.5	3.1

I_1=irrigation after the depletion of 50% of total available soil water, I_2=irrigation after the depletion of 70% of total available soil water, V1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3 and V_4=Sohag 3.

Table (15): Percent difference between measured and predicted consumptive use by CROPWAT and Yield-Stress in 2008 growing season.

Sesame variety	I_1		I_2	
	CROPWAT	Yield-Stress	CROPWAT	Yield-Stress
V_1	0.2	2.7	2.6	0.9
V_2	4.9	0.4	8.4	5.8
V_3	4.5	0.3	4.2	4.5
V_4	3.5	1.3	2.7	0.8
Average	3.3	1.2	4.5	3.0

I_1=irrigation after the depletion of 50% of total available soil water, I_2=irrigation after the depletion of 70% of total available soil water, V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3, and V_4=Sohag 3.

5. Sesame yield prediction under deficit irrigation

Both models were used to predict potential sesame yield reduction if irrigation was applied if 80% of the total available water was depleted. CROPWAT predicted 13.8 and 13.3% in 2007 and 2008 growing seasons, respectively. Similar values were predicted by Yield-Stress model i.e. 13.6 and 13.9% reduction in sesame yield (Table 16).

Table (16): Predicted percent of sesame yield reduction under irrigation when 80% depletion of total available water

Sesame variety	2007 growing season		2008 growing season	
	CROPWAT prediction	Yield-Stress prediction	CROPWAT prediction	Yield-Stress prediction
V_1	12.8	12.8	13.8	15.5
V_2	13.7	14.3	11.9	13.5
V_3	14.9	15.5	13.3	13.8
V_4	13.7	11.8	14.0	16.9
Average	13.8	13.6	13.3	13.9

V_1=Giza 32, V_2=Toshky 1, V_3=Shandaweel 3 and V_4=Sohag 3.

Discussion and Conclusion

Water scarcity is a major cause of crops yield reduction in many parts of the world. For that reason, a more rational use of irrigation water should be adapted and deficit irrigation principles should be accepted with a certain level of reduction in yield level. Our results showed that applying irrigation water when 70% of total available water was depleted, which could save 20.1 and 22.2% in irrigation water, resulted in 4.9 and 5.4% reduction in sesame yield for 2007 and 2008 growing seasons, respectively (Table 3 and 4).

Modeling has become a major research tool in agriculture for resource management, which could help in extending findings and conclusions to conditions not tested in the field. Both CROPWAT and Yield-Stress models are soil water balance based irrigation scheduling models, which use soil water budgeting over the root zone. Several simulation models for crop water requirements have been developed using this approach. These models have been widely accepted and used by irrigation researchers and other professionals, but their adoption by extension personnel has been very slow. That may be attributed to that these models are written for large computers not readily accessible to extension personnel. Another reason could be that these models are not user friendly. For that reason, there was a need to develop a user-friendly irrigation scheduling model that can be readily used by non professionals. Thus, Yield-Stress model was developed to be used as an easy irrigation management tool. Our results indicated that both CROPWAT and Yield-Stress models predicted sesame yield reduction as a result of water stress and consumptive use for both irrigation treatments over both growing seasons with high degree of accuracy. Goodness of fit measurements i.e. root mean square error was very low and Willmott index of agreement was high (Tables 5, 6, 7, 10, 11 and 12). Therefore, it can be concluded that the Yield-Stress model is comparable to CROPWAT.

However, Yield-Stress model predicted values of sesame yield, yield reduction and consumptive use were close to the measured values, compared with the predicted values of CROPWAT model (Tables 13, 14 and 15). Regarding to yield prediction, the method that Yield-Stress model uses, where it predicts a value of the yield of each irrigation treatment, resulted in more accurate prediction of percent of yield reduction, compared with the method that CROPWAT uses, which is percent reduction in the yield as a result of water stress. Furthermore, the more accurate prediction of Yield-Stress for consumptive use could be attributed to that the estimation method based on daily measurements of weather parameters, not monthly measurements that CROPWAT uses. Similar results were reported by George et al., (2000), where he stated that ISM model has an advantage over CROPWAT because it considers daily variations in weather data for predicting the soil moisture depletions, whereas CROPWAT uses average monthly evapotranspiration value which may result in under or over-prediction of irrigation depth if there is a large variation in daily weather. Toda et al., (2005) stated that CROPWAT model should be modified to include groundwater level to improve its accuracy in estimating dry season irrigation. Another advantage that Yield-Stress model have is that it requires the amount of applied individual irrigation to calculate soil water balance, which is easier to measure in the field than percent of water depletion that CROPWAT required in order to predict yield reduction as a result of water stress.

Both CROPWAT and Yield-Stress models were used in predicting sesame yield if irrigation was applied when 80% of total available water in the root zone was deleted. Our results showed that CROPWAT predicted reduction in sesame yield by 13.8 and 13.3%, whereas, Yield-Stress model predicted 13.6 and 13.9% reduction in yield. Therefore, under deficit irrigation procedure, irrigation water should be applied when 70% of total available soil moisture was depleted to avoid high yield losses.

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مقارنه بين نموذجى Yield-Stress و CROPWAT فى التنبؤ بمحصول السمسم و الاستهلاك المائى تحت ظروف الاجهاد الرطوبى

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قسم بحوث المقننات المائيه و الرى الحقلى - معهد بحوث الاراضى والمياه و البيئه – مركز البحوث الزراعيه.

استخدم نموذجى Yield-Stress وCROPWAT فى التنبؤ بمحصول السمسم والاستهلاك المائي فى موسمى 2007 و 2008 فى محطه بحوث شندويل . الهدف من هذه التجربه هو دراسه تأثيرتعرض نباتات السمسم للإجهاد الرطوبى على المحصول و الاستهلاك المائى . تم استخدام اربعة اصناف فى هذه الدراسه هم جيزة 32 ،توشكي 1 ، شندويل 3 ، سوهاج 3 مع معاملتين للرى (الرى عند استنفاذ 50% و 70% من الماء الارضى الميسر) . وقد اظهرت النتائج ان التنبؤ لكلا النموذجين كان على درجه جيده من الدقه للاربعة اصناف ومعاملتى الرى فى كلا من موسمى النمو . ولكن كانت دقة نموذج Yield-Stress أعلى فى التنبؤ بالمحصول من نموذج CROPWAT حيث ان النموذج الثانى يتنبأ بنسبة النقص فى المحصول نتيجة الاجهاد الرطوبى و لا يتنبأ بقيم فعليه للمحصول . ايضا كان تنبؤ نموذج Yield-Stress اكثر دقه من نموذج CROPWAT فى التنبؤ بالاستهلاك المائى و ذلك لان النموذج الاول يستخدم بيانات ارصاد يوميه بينما يستخدم النموذج الثانى بيانات ارصاد شهريه . و قد تنبأ نموذج CROPWAT بإنخفاض فى محصول السمسم بنسبة 13.8 % و 13.3% فى كلا من موسمى النمو و ذلك اذا تم اضافة مياه الرى عند استنفاذ 80% من الماء الارضى الميسر . بينما كانت قيم التنبؤ لنموذج Yield-Stress 13.6 % و 13.9 % . وعلى ذلك فإنه يمكن التوصيه بإضافة مياة الرى بعد استنفاذ 70% من الماء الارضى الميسر تحت ظروف الرى الناقص حتى لايقل محصول السمسم بنسبه كبيره .