SIMULATION OF THE EFFECT OF IRRIGATION WATER MANAGEMENT ON COTTON YIELD AT TWO LOCATIONS IN EGYPT

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ABSTRACT

Simulation of the effect of irrigation water management on cotton yield and its consumptive use was done using data of six years field trials planted at Beni Sweif and Demiatte locations. Cotton was planted at Beni Sweif for four growing season (1997, 1998, 2000 and 2001) and at Demiatte for two growing seasons (1999 and 2002). Cotton was irrigated with either fresh or drainage water at the two locations. Yield-Stress model was calibrated and validated using the yield and consumptive use of those field trials. Then, the model was used to predict cotton yield and consumptive use under deficit irrigation (80, 70, 60 and 50% of full irrigation). The results of the simulation showed that, at Beni Swief, there is a high potentiality for irrigation water saving corresponding to 30% of the applied full irrigation with only yield losses not exceeding the 2% under both fresh and drainage irrigation water. Whereas, at Demiatte, 20% saving in irrigation water reduced cotton yield by about 5% average over the two growing seasons under both fresh and drainage irrigation water. However, the point that should be clearly identified is to what extent the applied water can be reduced without exerting harmful effects on the cotton yield.

Keywords: Yield-Stress model, Cotton, Consumptive use, Fresh and drainage water irrigation

INTRODUCTION

Worldwide cotton represents about 50% of the fiber used in textile industry. Cotton is also a complex plant. It is a perennial plant with an indeterminate habit, but it is cultivated as an annual crop (Jallas et al. [1]). Water stress occurring during cotton growing season may reduce final lint yield. Numerous studies have reported that the effect of water stress on cotton yield depends on the timing and severity of the drought. Krieg [2] indicated that the period from square initiation to first flower represents the most critical development period in terms of water supply affecting yield components. Water stress affects lint quality in numerous ways, especially during fiber elongation period. It causes a decrease in fiber length and fiber immaturity

(Ritchie et al. [3]; McWilliams [4] and Mert [5]). Furthermore, the strength and elongation factors in cotton were well correlated with soil water (Johnson et al. [6]), where adequate soil water along with high ambient temperatures before and during boll development increased fiber maturity (Davidonis et al. [7]).

Irrigation water management becomes increasingly important in the presence of low water supplies. Irrigation management of cotton involves a balance between vegetative and reproductive growth. Excessive vegetative growth as a result of increasing irrigation amounts can delay maturity and reduce final yield (Davidonis et al. [7]). Excessive leaf area, which increases shading on lower parts of the plant and the incidence of boll rot, may lead to yield losses (Johnson et al. [6]). Furthermore, the over irrigation of the farmers results in high water losses and low water use efficiency, which create drainage and salinity problems. Thus, the expected limited availability of irrigation water requires fundamental changes in irrigation management to save irrigation water.

The increasing needs for more efficient management of crop production systems along with more consideration in environmental issues resulting from management decisions, has necessitated the use of crop simulation models as additional management tools for researchers and agricultural extension personnel. Crop growth/irrigation scheduling simulation models are becoming an integral part of crop management schemes, designed to maximize input use. Many simulation models using soil water budget in the root zone were developed over the past thirty years (Hill, et al. [8]; Camp et al. [9]; Smith [10]; Choeng [11]; Foroud et al. [12]; Prajamworng [13]; George et al. [14]). However, the selection of a particular model over others must be based on the model's performance under local conditions. In this context, Yield-Stress model (Ouda [15]) was tested to predict the yield and consumptive use of several crops under deficit irrigation, which proved its capability under the Egyptian conditions. The model was validated for several crops (Ouda et al. [16]; Ouda et al. [17]; Ouda et al., [18]; Ouda et al. [19]; and Ouda et al. [20]) and locations (Ouda et al. [21]; Tantawy et al. [22]; and Khalil et al. [23]). The model simulates soil water budgeting over the root zone to predict crop yield under different water stress conditions, which could be very helpful in the management of deficit irrigation applications.

The objectives of this research were: (i) To calibrate and validate Yield-Stress model for cotton yield and consumptive data at two locations; (ii) To use Yield-Stress model in predicting cotton yield under deficit irrigation.

MATERIALS AND METHODS

1. Cotton field trials

Data for cotton yield and consumptive use were available from four years farm trials conducted at Beni Sweif Governorate (Middle Egypt) in 1997, 1998, 2000 and 2001 growing seasons. Furthermore, data of two years farm trials were available from another location: Demiatte Governorate for two growing seasons (1999 and 2001). These data was obtained from a project called "Soil and Water Resource Management" done by Agricultural Research Center, Egypt in collaboration with ICARDA. Beni Sweif Governorate is classified as an old land, whereas Demiatte is classified by being salt affected soil. In both locations, sufficient NPK was applied to insure optimum plants growth. Irrigation was applied according to governmental enforced irrigation intervals. Applied irrigation amounts were measured through discharge from defined portable pump. Soil moisture sampling was collected before irrigation to calculate the needed amount of applied irrigation water to reach field capacity. Consumptive use was calculated using the following equation (Israelsen and Hansen [24]):

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

Where: CU = the amount of consumptive use (mm), Θ_2= soil moisture percentage after irrigation, Θ_1 = soil moisture percentage before the following irrigation, Bd = bulk density (g/cm^3) and ERZ = effective root zone. Irrigation treatments were two treatments of water quality, i.e. fresh and agricultural drainage irrigation. EC value of fresh water was equal to 0.48 dS/m, and it was equal to 0.9 dS/m for agricultural drainage water, which it did not impose any salinity stress on the growing plants. Season length and seasonal weather parameters in both locations are included in Table (1).

Table (1): Season length and seasonal weather parameters for cotton planted at two locations

Location	Growing season	Season length (days)	Mean temperature (°C)	Relative humidity (%)	Solar radiation (MJ/m^2/day)	Wind speed (m/sec)
Beni Swief	1997	177	30.7	55	24.30	1.42
	1998	180	34.3	56	24.32	1.50
	2000	167	37.6	57	24.80	1.50
	2001	172	38.7	57	24.60	1.50
Demiatte	1999	166	27.2	59	23.41	2.78
	2002	189	24.3	68	23.14	2.63

2. Yield-Stress model description

Yield-Stress model is a multi-year and a multi-crop simulation model. The model can be used by non-professionals, where the input of the model is easy to prepare and the output of the model is very descriptive of the process of the depletion of readily available water from root zone after the application of each single irrigation. Thus, the user can easily determine at which irrigation he could apply deficit irrigation. The Yield-Stress model uses a daily time step. The model requires weather data, management data and soil data. Weather data consist of maximum, minimum and mean temperature, relative humidity, solar radiation, wind speed. Management data composed of planting and harvest dates, season length, irrigation date and amount, FAO's crop coefficient at each growth stage (Allen et al. [25]). Soil data are consist of clay, silt, sand, organic matter, and $CaCO_3$ percentages. The model has three main components: soil water balance calculation routine, salinity stress routine and crop yield calculation routine.

3. Yield-Stress model calibration and validation

The model was calibrated for cotton yield and consumptive use, and then the model was validated using the field trials data. The goodness of fit between measured and predicted values by the model was tested by calculated percent difference between measured and predicted values of cotton yield and consumptive use, in addition to root mean squared error (RMSE) (Jamieson et al. [26]) and Willmott index of agreement (Willmott [27]).

4. Prediction of Cotton yield under deficit irrigation

Cotton yield was predicted under 80, 70, 60 and 50% of full irrigation with either fresh or drainage water irrigation amounts.

RESULTS AND DISCUSSION

1. Cotton field trials

The measured amounts of applied irrigation water and its corresponding measured yield values in the six growing seasons at the two locations are shown in Table (2). Cotton yields were significantly differed (one sided t-test, $P < 0.05$) under the application of fresh and drainage irrigation amounts at both locations. Regarding to Beni Sweif location, the results in that Table (2) also showed that cotton yield was low in 1998 and 2001 growing seasons, compared with the rest of the growing seasons under both irrigation water treatments. This could be attributed to higher seasonal mean temperature and relative humidity in these growing seasons (Table 1), compared with the rest of the growing seasons, which could had its negative effect on the growing cotton plants and consequently reduced final cotton yield. Similar situation was observed at Demiatte location, where cotton yield was lower in 2002, compared to 1999 growing seasons under both irrigation water treatments (Table 2).

Table (2): Irrigation amounts and corresponded cotton yield values for both fresh and drainage irrigation at the two locations

Location	Growing season	Fresh water irrigation		Drainage water irrigation	
		Irrigation amounts (m^3/ha)	Yield (ton/ha)	Irrigation amounts (m^3/ha)	Yield (ton/ha)
Beni Swief	1997	8669	3.80	9677	4.33
	1998	8218	2.10	8585	2.20
	2000	7597	3.25	8124	3.16
	2001	8335	2.72	8530	2.81
Demiatte	1999	7901	3.12	8009	3.36
	2002	9914	1.71	10447	2.07

2. Yield-Stress model validation for cotton yield and consumptive use

2.1. Prediction of cotton yield

Yield-Stress model predicted cotton yield with high degree of precision under both fresh and drainage irrigation amounts. Percent difference between measured and predicted values was less than 1% for both irrigation treatments, Willmott index of agreement was the highest and root mean square error per observation was 0.0002 and 0.0102 ton/ha for both fresh and drainage water irrigation amounts (Table 3). Zhange et al. [28] used SUCROS model to predict cotton yield with RMSE equal to 0.066 ton/ha.

Table (3): Measured versus predicted cotton yield planted at Beni Swief and Demiatte locations

Location	Growing season	Fresh water irrigation			Drainage water irrigation		
		Yield (ton/ha)		PR %	Yield (ton/ha)		PR %
		Measured	Predicted		Measured	Predicted	
Beni Swief	1997	3.80	3.78	0.53	4.33	4.32	0.23
	1998	2.10	2.08	0.95	2.20	2.18	0.91
	2000	3.25	3.24	0.31	3.16	3.14	0.63
	2001	2.72	2.71	0.37	2.81	2.79	0.71
Demiatte	1999	3.12	3.11	0.32	3.36	3.35	0.30
	2002	1.71	1.7	0.58	2.07	2.05	0.97
RMSE WI	0.0002 0.9999				0.0102 0.9999		

PR%= percent reduction between measured and predicted yield; RMSE= root mean square error; WI= Willmott index of agreement.

2.2. Prediction of cotton consumptive use

Regarding to cotton consumptive use prediction under both fresh and drainage water irrigation amounts, there was good agreement between measured and predicted consumptive use. RMSE was 0.0343 and 0.0780 cm for both fresh and drainage water irrigation, respectively. Willmott index of agreement was 0.9798 and 0.9692 for fresh and drainage water irrigation, respectively (Table 4).

Table (4): Measured versus predicted consumptive use for cotton planted at two locations

Location	Growing season	Fresh water irrigation			Drainage water irrigation		
		CU (cm)		PR %	CU (cm)		PR %
		Measured	Predicted		Measured	Predicted	
Beni Swief	1997	52.02	50.61	2.71	59.41	57.61	3.03
	1998	69.57	67.92	2.37	71.10	68.4	3.80
	2000	68.62	68.46	0.23	73.93	70.84	4.18
	2001	72.93	70.49	3.35	74.38	72.61	2.38
Demiatte	1999	57.50	56.32	2.05	53.90	55.94	3.78
	2002	58.80	58.89	0.15	56.70	58.89	3.86
RMSE WI	0.0343 0.9798				0.0780 0.9622		

CU= consumptive use (cm); PR%= percent reduction between measured and predicted yield; RMSE= root mean square error; WI= Willmott index of agreement.

3. Prediction of cotton yield and consumptive use under deficit irrigation

3.1. Beni Sweif location

The results representing the predicted yield (ton/ha) and the percentages of reduction in the yield under the different deficit irrigation treatments using fresh water are given in Table (5). The presented results indicated clearly that under deficit irrigation, the gradual reduction in the volumes of applied water up to 50% did not result in any significant differences in the predicted yield, compared with the same values obtained under full irrigation in 1997 growing season. In addition, such data clearly showed that around 50% of the applied water could be saved in the area with only a reduction in the predicted yield not exceeding 2%. The same percent of yield reduction could be obtained in 1998 growing season, when 30% of the full irrigation was saved (Table 5). Contrary to that was the situation regarding to 2000 growing season, where the presented results indicated that irrigation with water volume not lower than 70% of the full irrigation could reduce yield by 7.38%. Whereas, saving 20% of the applied fresh irrigation water did not result in any significant reduction in the predicted yield, being only 2% lower than that value where irrigation was practiced in full (Table 5). This was quite evident concerning the results obtained during the growing season of 2001, where nearly 40% of the water applied under full irrigation treatment could be saved with only a reduction in the cotton yield around the 3%.

Thus, at Beni Sweif and in view of the presented data, it could be safely concluded that there is a high potentiality for water saving corresponding to nearly 30% of the applied full irrigation with only yield losses not exceeding the 2%.

Table (5): Predicted cotton yield and its reduction percentages under the investigated deficit irrigation treatments using fresh water irrigation

Irrigation	1997		1998		2000		2001	
	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %
FI	3.8	--	2.1	--	3.25	--	2.71	--
80% of FI	3.8	0	2.07	1.43	3.19	1.85	2.71	0
70% of FI	3.8	0	2.06	1.90	3.01	7.38	2.71	0
60% of FI	3.79	0.26	1.86	11.43	2.75	15.38	2.62	3.32
50% of FI	3.73	1.84	1.55	26.19	2.41	25.85	2.40	11.44

FI= full irrigation (m^3/ha); 80% of FI= 80% of full irrigation; 70% of FI= 70% of full irrigation; 60% of FI= 60% of full irrigation; 50% of FI= 50% of full irrigation; PR%= percent reduction between measured and predicted yield.

Similar trend could be observed under drainage water irrigation, where saving 50, 30, 20 and 40% of the full drainage irrigation water in 1997, 1998, 2000 and 2001 growing seasons, respectively resulted in an average reduction of cotton yield by 2% at Beni Swief (Table 6).

Table (6): Predicted cotton yield and its reduction percentages under the investigated deficit irrigation treatments using drainage water irrigation

Irrigation	1997		1998		2000		2001	
	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %
FI	4.33	--	2.20	--	3.11	--	2.79	--
80% of FI	4.33	0	2.19	0.45	3.08	0.96	2.79	0
70% of FI	4.33	0	2.17	1.36	2.92	6.11	2.79	0
60% of FI	4.32	0.23	2.04	7.27	2.68	13.83	2.70	3.23
50% of FI	4.29	0.92	1.75	20.45	2.34	24.76	2.49	10.75

FI= full irrigation (m^3/ha); 80% of FI= 80% of full irrigation; 70% of FI= 70% of full irrigation; 60% of FI= 60% of full irrigation; 50% of FI= 50% of full irrigation; PR%= percent reduction between measured and predicted yield.

It was of special interest to calculate the predicted change percentage in consumptive use under deficit irrigation treatments during the four growing at Beni Sweif location (Table 7). The presented results indicated that the reduction in consumptive use of the cotton crop followed a trend similar to that concerning the predicted yield reduction. The reduction in both studied parameters was subjected to a gradual increase with the reduction in the applied water volume of full irrigation. However, the changes in both yield and consumptive use were not of similar values but varied greatly from one growing season to the other. In addition, the results declared that under the different deficit irrigation treatments, the action of irrigation with less water volume than full irrigation was more pronounced on consumptive use, where reduction percentage values always exceeding those of the predicted yield (Table 7).

Table (7): Percent reduction in predicted yield and consumptive use for cotton under different fresh deficit irrigation treatments at Beni Sweif

Irrigation	1997		1998		2000		2001	
	PY %	PCU %	PY %	PCU %	PY %	PCU %	PY %	PCU %
80% of FI	0	0	1.43	1.71	1.85	5.49	0	1.44
70% of FI	0	0	1.90	5.58	7.38	13.73	0	5.58
60% of FI	0.26	0.18	11.43	19.58	15.38	24.45	3.32	15.14
50% of FI	1.84	8.86	26.19	38.86	25.85	39.04	11.44	28.97

FI= full irrigation (m^3/ha); 80% of FI= 80% of full irrigation; 70% of FI= 70% of full irrigation; 60% of FI= 60% of full irrigation; 50% of FI= 70% of full irrigation; PY%= percent reduction between measured and predicted yield; PCU= percent reduction between measured and predicted consumptive use.

The situation was similar under deficit drainage water irrigation (Table 8). However, comparing the reduction in the two studied parameters (yield and consumptive use) under the different deficit drainage irrigation, it can be noticed that the percent reduction in both parameters was relatively lower than those found under irrigation with fresh water.

Table (8): Percent reduction in predicted yield and consumptive use for cotton under different drainage deficit irrigation treatments at Beni Sweif

Irrigation	1997		1998		2000		2001	
	PY %	PCU %	PY %	PCU %	PY %	PCU %	PY %	PCU %
80% of FI	0	0	0.45	0.21	0.96	5.75	0	1.43
70% of FI	0	0	1.36	4.94	6.11	12.86	0	4.38
60% of FI	0.23	0.11	7.27	15.24	13.83	22.31	3.23	13.89
50% of FI	0.92	5.27	20.45	34.12	24.67	35.55	10.75	26.40

FI= full irrigation (m^3/ha); 80% of FI= 80% of full irrigation; 70% of FI= 70% of full irrigation; 60% of FI= 60% of full irrigation; 50% of FI= 70% of full irrigation; PY%= percent reduction between measured and predicted yield; PCU= percent reduction between measured and predicted consumptive use.

Such variations in the obtained values being of higher values under fresh water irrigation than drainage irrigation water could be attributed to the negative effect of drainage water on the vegetative growth, which diminishing its growth and development and, thereby, reducing the consumptive water use. This is quite apparent when irrigation was practiced with volumes corresponding to 50% of the full irrigation.

3.2. Demiatte location

Regarding the cotton planted at Demiatte location in 1999 growing season (Table 9), the yield under deficit irrigation treatment behaved in a manner completely different than that obtained under Beni Sweif location. The presented results revealed that under deficit irrigation, the lower is the volume of applied water; the greater is the reduction in the predicted yield. Irrigation with a volume of water amounting to 50% of the full irrigation, seriously affected the yield, showing losses reached 58.65 and 56.42% of the yield obtained under the full irrigation either with fresh or drainage water, respectively (Table 9). Reducing the applied water by only 20% of that of the full irrigation affected the predicted yield, but with a relatively lower rate, representing only the 6.73 and 4.78% of that under full irrigation of fresh and drainage irrigation. This result implied that reducing the volumes of applied water to values exceeding the 20% of that of full irrigation is not recommended for cotton production in Demiatte location.

Comparing the results representing the growing season of 1999 with those of 2002 growing season (Table 9), in the latter growing season the results indicated that 30% of the applied water could be saved without any significant deterioration in the yield showing only around 3% losses of that of full fresh water irrigation and no yield losses under drainage water irrigation.

Therefore, this situation can be attributed to the fact that Demiatte is characterized by being salt affected soil, where reducing the amount of applied irrigation water reduced surface salt leaching, which increased soil salinity and decrease cotton yield at that location.

Table (9): Predicted cotton yield and its reduction percentages under the investigate deficit irrigation treatments using fresh and drainage water irrigation at Demiatte

Irrigation	Fresh water irrigation				Drainage water irrigation			
	1998		2002		1998		2002	
	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %	Predicted yield (ton/ha)	PR %
FI	3.12	--	1.71	--	3.35	--	2.07	--
80% of FI	2.91	6.73	1.71	0	3.19	4.78	2.07	0
70% of FI	2.50	19.87	1.66	2.92	2.74	18.21	2.07	0
60% of FI	1.88	39.74	1.43	16.37	2.11	37.01	1.85	10.63
50% of FI	1.29	58.65	1.06	38.01	1.46	56.42	1.40	32.37

FI= full irrigation (m^3/ha); 80% of FI= 80% of full irrigation; 70% of FI= 70% of full irrigation; 60% of FI= 60% of full irrigation; 50% of FI= 70% of full irrigation; PR%= percent reduction between measured and predicted yield.

Similar to Beni Swief location, the presented results for Demiatte site indicated that the reduction in consumptive use of the cotton crop followed a trend similar to that concerning the predicted yield reduction under fresh and drainage water deficit irrigation (Table 10).

Table (10): Percent reduction in predicted cotton yield and consumptive use under different deficit irrigation treatments at Demiatte site

Irrigation	Fresh water irrigation				Drainage water irrigation			
	1998		2002		1998		2002	
	PY %	PCU %	PY %	PCU %	PY %	PCU %	PY %	PCU %
80% of FI	6.73	8.17	0	0.80	4.78	6.90	0	0.12
70% of FI	14.87	24.66	2.92	8.30	18.21	23.01	0	3.11
60% of FI	39.74	48.05	16.37	22.16	37.01	45.08	16.63	15.44
50% of FI	58.65	68.95	38.01	47.22	56.42	67.40	32.37	40.04

FI= full irrigation (m^3/ha); 80% of FI= 80% of full irrigation; 70% of FI= 70% of full irrigation; 60% of FI= 60% of full irrigation; 50% of FI= 70% of full irrigation; PY%= percent reduction between measured and predicted yield; PCU= percent reduction between measured and predicted consumptive use.

Comparing cotton consumptive use under the two investigated locations, it is quite clear that such parameter varies greatly with the variation in the growing season as well as that of the location. In the case of Beni Sweif location, the consumptive use showed values relatively higher than those obtained under Demiatte location. However, the reduction percent in consumptive use at Demiatte location showed values nearly two or three times greater than those representing the Beni Sweif location. This is quite evident under severe deficit irrigation treatments where irrigation was practiced with volumes of water amounting to 60 and 50% of the full irrigation volume. Furthermore, the results also showed that increasing the reduction in the volume of applied water, had its harm effect more in the growing season of 1999 than 2002 growing season. In the growing season of 1999, the percentages of reduction in both predicted parameters were greatly exceeding the ones obtained in the 2002 growing season. This holds true for the investigated deficit irrigation treatments under both fresh and drainage irrigation waters. The variation in the two studied parameters in Demiatte site could be attributed to the differences in the climatic parameters within the 1999 and 2002 growing season.

CONCLUSION

Water management is an important element of irrigated crops production. Irrigation water management requires timely application of the right amount of water. The traditional goal in irrigated agriculture is the achievement of the highest yield per unit land surface; only in relatively recent years it was realized that such a goal entails a wasteful use of water resources and the principles of deficit irrigation were developed (English [29]) aiming to obtain the highest yield per unit of water. Although an appreciable progress was made towards more rational use of water, adopting deficit irrigation principles implies the acceptance of a certain level of yield reduction (Hamdy et al.[30]). As long as that certain level of yield reduction is low, there is a good chance that farmers will adopt deficit irrigation.

Our results showed that deficit irrigation technique could be practiced successfully at Beni Sweif and Demiatte locations for cotton production, without any appreciable losses in the yield, using 30 and 20% less water than the ones already used for irrigation at Beni Sweif and Demiatte locations, respectively under either fresh or drainage water. However, the point that should be clearly identified is to what extent the applied water can be reduced without exerting harmful effects on the crop yield.

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