Modeling the Irrigation Schedule on Wheat under Climate Change Conditions

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Abstract; The effect of climate change on wheat grown under sprinkler irrigation was studied using previous data of two growing seasons (2008/09 and 2009/10); these data were used to calibrate CropSyst model. Furthermore, a field experiment was conducted at El-Giza Governorate in 2010/11 growing season; the data of this experiment (2010/11 season) was used to validate the CropSyst model. The treatments of the validation experiment composed of two wheat cultivars (Sakha 93 and Giza 168) and four irrigation treatments (0.6, 0.8, 1.0 and 1.2 of ETc). Two climate change scenarios (A2 and B2) were used to assess the consequences of climate change on wheat yield in 2060. A new irrigation schedule developed by Basic Irrigation Schedule (BIS) model was used to improve water productivity under climate change conditions. The results showed that CropSyst model was able to predict wheat yield with high degree of accuracy for both calibration and validation procedures. The results also indicated that, in general, the yield of both cultivars will be decrease under climate change; however the reduction was lower for Sakha 93, as compared with Giza 168. The application of the new irrigation schedule under climate change conditions increased water productivity under the two climate change scenarios, compared with irrigation amount resulted from 0.8, 1.0 and 1.2 of ETc, for both wheat cultivars. Moreover, Sakha 93 gave the highest water productivity. Our results suggested that if we want to reduce yield losses for wheat under climate change conditions and increase water productivity, Sakha 93 should be cultivated and BIS model should be used to schedule irrigation.

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1.Introduction

Climate variability has been and continues to be the principal source of fluctuations in global food production in the world. Climate change refers to the increase of earth temperature due to the release of green house gases into the earth's atmosphere (IPCC, 2007). Climate change presents a challenge for researchers attempting to quantify its local impact due to the global scale of likely impact and the diversity of agricultural system. Similarly, the effect of climate change on vegetation can be dramatic, due to variations in the amount of CO_2 available for photosynthesis. In addition, climatic factors such as temperature, precipitation, moisture and pressure affect the development of plants, either alone or by interacting with other factors (Cutforth *et al*.,, 2007).

Understanding the potential impacts of climate change is very important in developing both adaptation strategies and actions to reduce climate change risks. A range of valuable national studies have been carried out and published. However, assessing the impact of climate change is a challenge for scientists and it needs collaboration of multidiscipline. Unfortunately, the limitation in the information regarding to past and future climate change and its impacts on crops reduce the ability of policy makers in Egypt to adjust their plans to cope with the future.

Adaptation to climate change has received more attention compared with mitigation. Parry *et al*.,, (1998) indicated that adaptation seems more complicated than mitigation, emission sources are relatively few, but the array of adaptation is vast, yet to ignore adaptation is both unrealistic and perilous. Adaptation refers to efforts to reduce system's vulnerabilities to climate. According to IPCC (2007), adaptation is concerned with responses to both the negative and positive effects of climate change. It refers to any adjustments whether passive, reactive, or anticipatory that can respond to anticipated or actual consequences associated with climate change. Thus, it implicitly recognizes that future climate change will occur and must be accommodated in policy. A wide range of responses can be implemented exogenously by management or policy decisions at the regional or national level. These adjustments are adaptation strategies (Carter, 1996). Agricultural adaptation to climate change at the farm level depends on the technological potential, such as different varieties of crops, irrigation technologies, changing sowing dates and changing irrigation schedule. The capability of farmers to detect climate change and undertake any necessary actions will then be reflected on achieving higher crop water productivity.

Irrigation scheduling was defined by Jensen (1981) as "a planning and decision-making activity that the farm manager or operator of an irrigated farm is involved in before and during most of the growing season for each crop that is grown.

Irrigation scheduling is an important element in improving water productivity. The term water productivity is used exclusively to denote the amount or value of product over volume or value of water depleted or diverted (Renault and Wallender, 2000).

Crop simulation models can be used to assess the likely impact of climate change on grain yield and yield variability. These crop models must accurately predict several key characteristics over a wide range of climatic conditions, such as timing of flowering and physiological maturity, through correct descriptions of phenological responses to temperature and day length. Furthermore, accumulation of yield needs to be predicted by accurately predicting the development and loss of leaf area and, therefore, a crop's ability to intercept radiation, accumulate biomass, and partition it to harvestable parts such as grain. Crop water use is also needed to be accurately predicted by correctly predicting evapotranspiration and the extraction of soil water by plants roots (Richter and Semenov 2005). CropSyst (Stockle *et al.*,, 1994) is one of these models that could be used along with a set of daily weather data spanning a reasonable number of years to assess the impact of climate change on crops (Tubiello *et al.*,, 2000; Torriani *et al.*,, 2007). The application of such models allows the simulation of many possible climate change scenarios from only a few experiments for calibration.

The objectives of this paper were: (i) to calibrate CropSyst model for wheat grown at El-Giza governorates using previous field data; (ii) To validate CropSyst model for field data experiment of wheat in the same governorate; (iii) to determine yield losses under two climate change scenarios; and (iv) to use BIS model to develop new irrigation schedules under current climate and use it to run CropSyst model to manage water more efficiently.

2.Materials and Methods

Previous data for wheat yield and consumptive use was obtained for 2006/07 and 2007/08 growing seasons (Khalil *et al.*,, 2009). These data was used for calibrating the CropSyst model. In addition, a field experiment was conducted in 2010/11 to collect the data needed for validating the model.

1. The previous field data for calibration

Two field experiments were conducted in 2006/07 and 2007/08 growing seasons in Giza Agricultural Research Station, Egypt (Khalil *et al.*, 2009). Two wheat cultivars were planted, i.e. Sakha 93 and Giza 168 in a randomized complete block design with three replicates. Wheat was planted on the 15th and 17th of November in the first and second growing seasons, respectively. Nitrogen fertilizer was divided into 3 doses and added at sowing date, tillering stage and at booting stage in the form of Urea (180 kg/ha, 46% N). Phosphorus fertilizer was applied in the form of single super phosphate (36 kg/ha, 15% P_2O_5) and was incorporated into the soil during land preparation. Potassium in the form of potassium sulphate (57 kg/ha, 48% K_2O) was applied at booting stage. The applied amount of NPK fertilizer was sufficient to ensure optimum growth. Irrigation was applied using 1.2 pan evaporation coefficient, which is the optimum for wheat under Giza climate conditions. Evaporation data were collected on a daily basis from a standard Class-A-Pan located near the experimental field. Irrigation amounts were calculated with the following equation (Allen *et al.*,, 1998):

$$I= Epan*Kp \quad [1]$$

Where: I is the applied irrigation water amount (mm), Epan is the cumulative evaporation amount in the period of irrigation interval (mm), Kp is the pan evaporation coefficient. Soil mechanical analysis according to Piper, (1950) of the experimental field in the depth of 0-60 cm is shown in Table (1).

Table (1): Soil Mechanical analysis at Giza Agricultural Station

Soil fraction	Content (%)
Coarse sand	2.91
Fine sand	13.40
Silt	30.51
Clay	53.18
Texture class	Clay

The soil moisture constants (% per weight) and bulk density (g/cm^3) in the depth of 0-60 cm are shown in Table (2).

Table (2): Soil moisture constants of the experimental field at Giza Agricultural Research Station

Depth (cm)	Field capacity (%, w/w)	Wilting point (%, water)	Available water (mm)	Bulk density g/cm^3
0 – 15	41.85	18.61	40.0	1.15
15 – 30	33.68	17.50	30.1	1.24
30 - 45	28.36	16.92	20.6	1.20
45 – 60	28.05	16.54	22.1	1.28

Maximum leaf area index was measured. Harvest was done in the 3rd week of April during the two growing seasons. Wheat grain and biological yield were measured and harvest index was determined.

The field experiment for validation

A field experiment was conducted at El-Dokki Experimental Site, El-Giza governorate in 2010/11 growing season for two wheat cultivars, i.e. Sakha 93 and Giza 168. These two cultivars were sown on the 24th of November. Wheat was sown under sprinkler irrigation in four irrigation treatments, i.e. irrigation with 0.6, 0.8, 1.0 and 1.2 of ETc. The sprinkler system used in this experiment was a solid set sprinkler irrigation technique. The rotary sprinkler (Rc160) of 0.87-1.23 m^3/hr was used and its discharge was at 2.10 bars nozzle pressure, with spacing of 9*7 meters between laterals and sprinklers. A differential pressure tank was connected to the sprinkler irrigation system to inject fertilizer via irrigation water. The fertigation rate was determined according to irrigation system operation water supply, concentration of the fertilizer element in the stock solution and the discharge of the fertigator. Nitrogen fertilizer was added in the form of ammonium nitrate in the rate of 400 kg/ha. Potassium sulphate was added in the rate of 100 kg/ha. Phosphorus was added in the form of phosphoric acid (60%) in the rate of 125 kg/ha. Evaporation data were collected on a daily basis from a standard Class-A-Pan located near the experimental field. Irrigation amounts were calculated according to evaporation pan records (Allen *et al.*,, 1998).

Tables (3) and (4) showed the mechanical and chemical analysis of the experimental site.

Table (3): Mechanical analysis of the soil of the site of validation experiment.

Soil depth	Clay %	Silt %	Fine sand %	Coarse sand %
10-30	35.2	50.4	10.7	3.7
30-60	36.2	38.9	19.6	5.3
60-90	37.4	50.5	8.7	3.4

Table (4): Chemical analysis of the soil of the site of validation experiment.

Depth	SP	pH	ECe (dS/m)	meq/l							
				Cations				Anions			
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	CO_3^{--}	HCO_3^{-}	SO_4^{--}
10-20	43	7.75	0.6	2.2	1.71	1.83	0.27	1.35	-	2.09	2.57
20-30	45	7.7	0.7	3.0	2.37	1.3	0.37	1.35	-	1.9	3.79
30-40	48	7.70	0.5	2.0	1.00	1.76	0.27	1.35	-	0.95	2.73

Maximum leaf area index (at anthesis) was measured. The date of phenological stages was measured in the field. At harvest, grain and biological yield were measured and harvest index was calculated.

2. CropSyst model

2.1. Model description

The CropSyst (Cropping Systems Simulation Model) objective is to serve as an analytical tool to study the effect of cropping systems management on crop productivity and the environment. For this purpose, CropSyst simulates the soil water budget, soil-plant nitrogen budget, crop phenology, crop canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water, and pesticide fate. These are affected by weather, soil characteristics, crop characteristics, and cropping system management options including crop rotation, variety selection, irrigation, nitrogen fertilization, pesticide applications, soil and irrigation water salinity, tillage operations, and residue management (Stockle and Nelson, 1994).

The water budget in the model includes rainfall, irrigation, runoff, interception, water infiltration and redistribution in the soil profile, crop transpiration, and evaporation. The nitrogen budget in CropSyst includes nitrogen application, nitrogen transport, nitrogen transformations, ammonium absorption and crop nitrogen uptake. The calculation of daily crop growth, expressed as biomass increase per unit area, is based on a minimum of four limiting factors, namely light, temperature, water, and nitrogen (Stockle *et al.*,, 1994).

Pala *et al.*, (1996) suggested that minor adjustments of some of these parameters, accounting for cultivar-specific differences, are desirable whenever suitable experimental information is available. Details on the technical aspects and use of the CropSyst model have been reported elsewhere (Stockle *et al.*,, 1994; Stockle and Nelson, 1994).

2.2. Model calibration

Input files required by CropSyst model for El-Giza location and wheat crop were prepared and used to run the model. For each treatment one management file was prepared represent each irrigation treatment. The date of each phenological stage was used to calculate growing degree days for that stage. Total biomass, grain yield, total and seasonal evapotranspiration, computed from the soil-moisture measurements from all the treatments, were used for model calibration. The values of the crop input parameters were either taken from the CropSyst manual (Stockle and Nelson, 1994) or set to the values observed in the experiments. The calibration consisted of slight adjustments of selected crop input parameters to reflect reasonable simulations. These adjustments were around values that were either typical for the crop species or known from previous experiences with the model.

2.3. Model validation

The CropSyst model was validated using the field experiment data conducted in 2010/11 growing season. It was validated for grain and biological yield.

2.4. Goodness of fit

To test the goodness of fit between the measured and predicted data, percentage of difference between measured and predicted values of grain and biological yield in each growing season were calculated. In addition, root mean square error (Jamieson *et al.*,, 1998), which describes the average difference between measured and predicted values, was calculated. Furthermore, Willmott index of agreement was calculated, which take a value between 0.0-1.0 and 1.0 means perfect fit (Willmott, 1981).

3. Climate change scenarios

Two climate change scenarios, i.e. A2 and B2 were used (Wigley *et al.*,, 2000) to predict the effect of climate change in 2060. A2 and B2 supposed heterogeneous world, where A2 assumed regionally oriented economic development and B2 assumed local environmental sustainability. A2 assumed an annual average of mean temperature increase by 2.5 ºC and B2 assumed 1.9 ºC increase in average annual temperature in 2060 (Table 5).

Table (5): Increase in monthly mean temperature (ºC) under A2 and B2 climate change scenarios in 2060.

Month	A2	B2
January	2.3	1.8
February	2.3	1.6
March	2.2	1.7
April	2.0	1.6
May	2.1	1.7
June	2.8	2.2
July	3.2	2.5
August	2.5	1.9
September	3.1	2.4
October	2.7	2.1
November	2.1	1.7
December	2.2	1.7
Average	2.5	1.9

4. Irrigation water management under climate change

Irrigation was rescheduled using an irrigation scheduling model called BISm (Snyder *et al.*,, 2004). The BIS model (The Basic Irrigation Scheduling) application was written using MS Excel to help plan irrigation management of crops. The BISm program and a pdf version and its documentation can be downloaded from: http://www.waterplan.water.ca.gov/landwateruse/wateruse/Ag/CUP/California_Climate_Data_010804.xls. The model uses weather data or evapotranspiration data, kc of the crop at each growth stage, soil moisture constants and depletion of soil water from root zone to determine the amount of water needed to be applied for individual irrigation and the time of its application. The model was run for wheat planted in 2010/11 growing season under current weather conditions. A new irrigation schedule was developed. CropSyst model was run using the new schedule and the effect of it on water productivity was assessed under climate change.

2.7. Crop water productivity

Crop water productivity (CWP) was defined according to Moulden (1997) as "the physical mass of production or the economic value of production measured against gross inflows, net inflow, depleted water, process depleted water, or available water". Thus, it is calculated according to the following equation:

CWP= Wheat yield (kg)/applied irrigation water (mm)

Water productivity was calculated for wheat cultivars planted in 2010/11 growing season under the four irrigation treatments. Furthermore, it was calculated under climate change scenarios and under using the new irrigation schedule.

3.Results and Discussion

1. CropSyst calibration

1.1. Wheat grain yield

Table (6) showed measured versus predicted wheat yield in the two growing seasons. Results in that table implied that CropSyst model predicted wheat yield with high degree of accuracy. Percent difference between measured and predicted wheat yield was less than 1%. RMSE was 0.05 ton/ha and Willmott index of agreement was 0.99. Several publications highlighted the accuracy of the model, such as Benli *et al.*, (2007) and Singh *et al.*, (2008). Both papers indicated that the model prediction showed low RMSE. Furthermore, Benli *et al.*, (2007) stated that high Willmott index of agreement was obtained with a value of 0.98, which is similar to what is shown in Table (6).

Table (6): Measured versus predicted wheat grains yield (ton/ha) in the two growing seasons

Variety	2006/07 growing season			2007/08 growing season		
	Measured yield	Predicted yield	PD (%)	Measured yield	Predicted yield	PD (%)
Sakha 93	5.86	5.82	0.64	5.39	5.36	0.61
Giza 168	5.52	5.51	0.16	5.38	5.38	0.01
RMSE	0.05					
WI	0.99					

RMSE= Root mean square error; WI= Willmott index of agreement; PD(%)= percentage of difference between measured and predicted values.

1.2. Wheat biological yield

Similar results were obtained for the prediction of wheat biological yield (Table 7), where percentage of difference between measured and predicted wheat biological yield was less than 1.5%. Results in that table also indicated that RMSE was 0.17 ton/ha and Willmott index of agreement was 0.98. These results showed the highly accurate performance of CropSyst model. Likewise, Singh *et al.*, (2008) reported that RMSE between observed and predicted biomass by CropSyst was 1.27 ton/ha as compared to 1.94 ton/ha between observed and predicted biomass by CERES-Wheat.

Table (7): Measured versus predicted wheat biological yield (ton/ha) in the two growing seasons

Variety	2006/07 growing season			2007/08 growing season		
	Measured yield	Predicted yield	PD (%)	Measured yield	Predicted yield	PD (%)
Sakha 93	19.25	19.38	0.68	18.98	19.12	0.74
Giza 168	17.69	17.76	0.41	18.77	18.56	1.12
RMSE	0.17					
WI	0.98					

RMSE= Root mean square error; WI= Willmott index of agreement; PD(%)= percentage of difference between measured and predicted values.

2. CropSyst validation

Validation of CropSyst model for the two cultivars showed good agreement between measured and predicted grain and biological wheat yield under the four irrigation treatments. This agreement was reflected by low percentage of difference between measured and predicted values of grain and biological yield, low mean square error and high Willmott index of agreement (Tables 8 and 9).

With respect to Sakha 93, the root mean square error was low, i.e. 0.16 and 0.20 ton/ha for grain and biological yield, respectively. Willmott index of agreement was 0.99 for both grain and biological yield (Table 8).

Table (8): Measured versus predicted wheat grain yield and biology yield for the cultivar Sakha 93 at 2010/11 growing season

Irrigation treatment	Grain yield (ton/ha)			Biology Yield (ton/ha)		
	Measured	Predicted	PD %	Measured	Predicted	PD %
I_1	6.90	6.82	1.16	22.01	22.14	0.58
I_2	8.76	8.61	1.71	27.94	28.07	0.44
I_3	9.66	9.55	1.14	30.82	31.06	0.80
I_4	10.26	10.07	1.85	32.73	32.90	0.53
RMSE	0.16			0.20		
WI	0.99			0.99		

I_1= irrigation with 0.6 of ETc; I_2=irrigation with 0.8 of ETc; I_3= irrigation with 1.0 of ETc; I_4= irrigation with 1.2 of ETc; RMSE= Root mean square error; WI= Willmott index of agreement; PD% = percent difference between measured and predicted values.

Similar trend was observed for Giza 168, where root mean square error was 0.12 and 0.17 ton/ha for grain and biological yield, respectively. Willmott index of agreement was 0.99 for both grain and biological yield (Table 9). Lobell and Ortiz-Monasterio (2006) stated that CERES-Wheat model was able to predict wheat yield for the different irrigation trials quite well with a RMSE of 0.23 ton/ha. Furthermore, Singh *et al.*, (2008) reported that RMSE between observed and predicted biomass by CropSyst was 1.27 ton/ha as compared to 1.94 ton/ha between observed and predicted biomass by CERES-Wheat.

Table (9): Measured versus predicted wheat grain yield and biology yield for the cultivar Giza 168 at 2010/11 growing season

Irrigation treatment	Grain yield (ton/ha)			Biology Yield (ton/ha)		
	Measured	Predicted	PD %	Measured	Predicted	PD %
I_1	3.60	3.53	1.94	11.48	11.51	0.24
I_2	6.06	5.98	1.32	19.33	19.53	1.03
I_3	7.08	6.99	1.27	22.59	22.72	0.58
I_4	8.04	7.89	1.87	25.65	25.81	0.65
RMSE	0.12			0.17		
WI	0.99			0.99		

I_1= irrigation with 0.6 of ETc; I_2=irrigation with 0.8 of ETc; I_3= irrigation with 1.0 of ETc; I_4= irrigation with 1.2 of ETc; RMSE= Root mean square error; WI= Willmott index of agreement; PD% = percent difference between measured and predicted values.

Our results showed that CropSyst model was cable of predicting grains and biological yield of wheat. One of the benefits of using CropSyst model is it can give an insight to processes happened during the growing season of wheat, which was difficult to measure in the field. The good agreement between measured and predicted values of wheat grain and biological yield and implied that the model worked sufficiently well to warrant the exploration of the effect climate change scenarios.

3. Effect of A2 climate change scenario

The results in Table (10) indicated that under both climate change scenarios, yield reduction will be the highest under irrigation with 0.6 of ETc and it will be the lowest under irrigation with 1.2 of ETc for both cultivars. Furthermore, yield losses for Giza 168 was higher, compared to Sakha 93. Table (10) also showed that A2 climate change scenario was more stressful than B2 climate change scenario, where yield losses was higher for A2 compared to B2. Ouda *et al.*, (2010) incorporated A2 scenario in CropSyst model and reported that wheat yield could be reduce by 31% in the year of 2038.

Table (10): Percentage of yield reduction in wheat under A2 and B2 climate change scenarios

Scenario	Irrigation	Sakha 93	Giza 168
A2	I_1	- 33	-54
	I_2	-29	-47
	I_3	-27	-39
	I_4	-27	-32
B2	I_1	-25	-50
	I_2	-22	-34
	I_3	-21	-31
	I_4	-21	-28

I_1= irrigation with 0.6 of ETc; I_2=irrigation with 0.8 of ETc; I_3= irrigation with 1.0 of ETc; I_4= irrigation with 1.2 of ETc.

The result in Table (10) showed that under climate change scenarios, wheat yield was reduced. This result could be attributed to the aboitic stress, such as heat and water stresses that wheat plants exposed to. High temperature reduces numbers of tillers (Friend, 1965) and spikelet initiation, as well as development rates (McMaster, 1997). Furthermore, high temperature during anthesis causes pollen sterility (Saini and Aspinall, 1982) and reduces number of kernels per head, if it prevailed during early spike development (Kolderup, 1979). The duration of grain filling is also reduced under heat stress (Sofield *et al.*, 1977), as well as growth rates with a net effect of lower final kernel weight (Bagga and Rawson, 1977 and McMaster, 1997).

Furthermore, exposing wheat plants to high moisture stress depressed seasonal consumptive use and grain yield (El-Kalla *et al.*,, 1994 and Khater *et al.*,, 1997). During vegetative growth, phyllochron decreases in wheat under water stress (McMaster, 1997) and leaves become smaller, which could reduce leaf area index (Gardner *et al.*,, 1985) and reduce the number of reproductive tillers, in addition to limit their contribution to grain yield (Mosaad *et al.*,, 1995). Furthermore, water stress occurs during grain growth could have a sever effect on final yield compared with stress occurred during other stages (Hanson and Nelson, 1980).

4. Irrigation water management under climate change

BIS model was run for wheat and a new irrigation schedule was developed. CropSyst model was run using the new irrigation schedule. The results revealed that wheat yield was not changed when the model was run using the new irrigation schedule under climate change. However, irrigation water saving was attained for I_2, I_3 and I_4 only. The saved irrigation amount was up to 5, 24 and 37% under I_2, I_3 and I_4, respectively when the new irrigation schedule was applied (Table 11).

Table (11): Amounts and percentage of change in irrigation developed by BIS model

Irrigation	I_1		I_2		I_3		I_4	
	Amount	%	Amount	%	Amount	%	Amount	%
Sakha 93	+226	+27	-59	-5	-342	-24	-623	-37
Giza 168	+226	+27	-59	-5	-342	-24	-623	-37

I_1= irrigation with 0.6 of ETc; I_2=irrigation with 0.8 of ETc; I_3= irrigation with 1.0 of ETc; I_4= irrigation with 1.2 of ETc; A2 and B2= two climate change scenarios.

4.1. Crop water productivity

CropSyst model was run using the new irrigation schedule under the two climate change scenarios. The simulation of the application of the new irrigation schedule revealed that the applied irrigation amount using BISm model increased water productivity under the two climate change scenarios, compared with irrigation with 0.8 of ETc for the two wheat cultivars. Sakha 93 gave higher water productivity, compared to Giza 168 (Table 12). This result implies that Sakha 93 posse trait of yield stability under the abiotic stress caused by climate change.

Table (12): Water productivity for wheat under irrigation with 0.8 of ETc versus the new irrigation schedule.

Scenario	Sakha 93		Giza 168	
	WP_{CC}	WP_{NS}	WP_{CC}	WP_{NS}
A2	6.19	6.83	4.06	4.48
	5.47	5.77	3.38	3.56
	4.69	4.94	2.58	2.72
	4.01	4.23	2.02	2.13
B2	6.38	7.04	4.23	4.66
	6.03	6.36	3.90	4.11
	5.60	5.91	3.52	3.71
	5.27	5.56	3.19	3.37

A2 and B2= two climate change scenarios; WP_{CC}= water productivity under climate change; WP_{NS}= water productivity under the new irrigation schedule.

Regarding to irrigation amount with 1.0 of ETc, water productivity will increase when the new irrigation schedule will be used under the two climate change scenarios for both cultivars (Table 13).

Table (13): Water productivity for wheat under irrigation with 1.0 of ETc versus the new irrigation schedule.

Scenario	Sakha 93		Giza 168	
	WP_{CC}	WP_{NS}	WP_{CC}	WP_{NS}
A2	5.55	7.64	3.91	5.39
	4.95	6.52	3.37	4.43
	4.48	5.90	2.94	3.87
	3.82	5.03	2.29	3.02
B2	5.69	7.84	4.03	5.56
	5.36	7.06	3.72	4.91
	5.05	6.65	3.47	4.57
	4.79	6.31	3.22	4.25

A2 and B2= two climate change scenarios; WP_{CC}= water productivity under climate change; WP_{NS}= water productivity under the new irrigation schedule.

Similar trend was observed under irrigation with 1.2 of ETc, where Sakha 93 gave the highest water productivity, compared to Giza 168 (Table 14).

Table (14): Water productivity for wheat under irrigation with 1.2 of ETc versus the new irrigation schedule.

Scenario	Sakha 93		Giza 168	
	WP_{CC}	WP_{NS}	WP_{CC}	WP_{NS}
A2	4.91	8.11	3.77	6.22
	4.43	7.00	3.34	5.27
	4.05	6.39	2.99	4.73
	3.60	5.69	2.59	4.09
B2	5.04	8.33	3.88	6.41
	4.80	7.58	3.66	5.78
	4.49	7.08	3.39	5.35
	4.30	6.79	3.22	5.09

A2 and B2= two climate change scenarios; WP_{CC}= water productivity under climate change; WP_{NS}= water productivity under the new irrigation schedule.

Conclusion

Rapid changes of climate may seriously inhibit the ability of some crops to survive or to achieve the desired yield in their current region. Sustainable land and water management combined with innovative agricultural technologies could mitigate climate change and help poor farmers adapt to its impacts. New knowledge, technology and policy for agriculture have never been more critical, and adaptation and mitigation strategies must urgently be applied to national and regional development programs. Our results showed that the lowest yield reduction under climate change was obtained for Sakha 93 using irrigation with either 1.0 or 1.2 of ETc. Our results also implied that Sakha 93 was tolerant to the aboitic stress of climate change compared with Giza 186 under the two climate change scenarios. The results also revealed that irrigation with 0.6 of ETc gave the highest yield reduction for both cultivars and under the two climate change scenarios.

Under climate change conditions, achieving greater water productivity is the primary challenge for scientists in agriculture. Therefore, changing irrigation schedule could provide a cheap and easy to implement irrigation management techniques to relief the harm effect of climate change, with no additional economic costs. Our results showed that the application of the new irrigation schedule increased water productivity (Tables 11-13).

In conclusion, to manage water more efficiently for wheat and to increase water productivity under climate change conditions, the following procedures **should be taken into account:**

1. Development of data base to classify the available wheat cultivars according to its ability to tolerate abiotic stress such as, heat and water stresses, in addition to document how efficient these cultivars in using irrigation water under climate change conditions. Our results showed that Sakha 93 is tolerant to heat and water stresses and use water more efficiently, compared to Giza 168.
2. Effect of adaptation strategy, such as changing irrigation schedule, on reducing the climate change risks should be taken into account during the management of irrigation water. Our results showed water productivity increased when irrigation was scheduled using BISm model.
3. Finally, our results suggested that if we want to reduce yield losses for wheat under climate change conditions and increase water productivity, Sakha 93 should be cultivated and BISm model should be used to schedule irrigation.

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References

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

Bagga, A. K. and I. M. Rawson. 1977. Contracting responses of morphologically similar wheat varieties to temperature appropriate to warm temperature climates with hot summers: A study in controlled environment. Aust. J. Agric. Res. 40:965-80.

Benli, B., M. Pala, C. Stockle, T. Oweis. 2007. Assessment of winter wheat production under early sowing with supplemental irrigation in a cold highland environment using CropSyst simulation model. Agric. Mang. Water. 3:45-54.

Carter, T. R. 1996. Assessing climate change adaptations: the IPCC Guidelines. In: J.B. Smith (ed.). Adapting to Climate Change: An International Perspective, 27-43.

Church, J. A. and N. J. White, 2006. A 20th century acceleration in global sea-level rise. Geophysical Research Letters, 33, L01602.

Cutforth, H.W., S.M. McGinn, E. McPhee and P.R. Miller, 2007. Adaptation of pulse crops to the changing climate of the Northern Great Plains. Agron. J., 99: 1684-1699.

Eid, H. M., N. A. Anton, and A. M. Tarrad 1994. Comparative study on Egyptian wheat varieties and their response to high temperatures. Annals of Agric. Sci. Moshtohor. 32 (1) 143-154.

Eid, H. M., N. G. Ainer, K. M. R. Yousef, M. A. M. Ibrahim, and G. M. Gad El-Rab. 1992. Climate change crop modeling study on wheat. 5th Egypt Bot. Conf. Siant Cather.

Eid, H. M., N. G. Ainer, M. A. Rady and W. M. Rizk. 1993. Impact of Climate change on simulated wheat yield and water needs. 1st. Conf. Egypt. Hung. Env. p.309-312.

El-Kalla, S.E., Leilah, A.A., Basiony, A.H., Hussien S.M. 1994. Effect of Irrigation and foliar nutrition treatments on growth and yield of some wheat cultivars under El-Arish area condition. 6th conf. Agron., Fac. Agric., Al-Azhar Uni., Egypt.

Friend, D. J. C. 1965. Ear length and spikelets number of wheat grown at different temperatures and light intensities. Cand. J. Bot. 43:343-353.

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

Hanson, A.D., Nelson E.C. 1980. The biology of crop production. New York Academic Press.

Hughes, T. P., A. H. Baird, D. R. Bellwood, M. Card, S. R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J. B. C. Jackson, J. Kleypas, J. M. Lough, P. Marshall, M. Nystrom, S. R. Palumbi, J. M. Pandolfi, B. Rosen, and J. Roughgarden, 2003: Climate Change, Human impacts, and the Resilience of Coral Reefs. Science, 301, 929-933.

IPCC, 2001: Summary for Policymakers: Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the 3rd Assessment Report of the Intergovernmental Panel on Climate Change. J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. Van Der Linden, and D. Xioaosu, Cambridge University Press, Cambridge, 944pp.

IPCC, 2007. New Assessment Methods and the Characterization of Future conditions: In Climate change 2007: Impacts, adaptation and vulnerability, pp: 976. Contribution of working group II to the fourth assessment report of the Intergovernmental panel on climate change. Cambridge university press, Cambridge, UK.

Jamieson, P.D., J. R. Porter, J. Goudriaan, J.T. Ritchie, H. van Keulen, and W. Stol. 1998. A comparison of the models AFRCWHEAT2, CERES-Wheat, Sirius, SUCROS2 and SWHEAT with measurements from wheat grown under drought. Field Crops Res. 55:23–44.

Jensen, M.J. 1981. Summary and challenges. pp. 225-231. *In* Proc. of the ASAE's Irrigation Scheduling Conf., *Irrigation Scheduling for Water & Energy Conservation in the 80's*, ASAE Publ. 23-81, Am. Soc. Agric. Engr., St. Joseph, MI.

Jones, P. D. and A. Moberg, 2003: Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. J. Climate, 16, 206-223.

Khalil, F.A., H. Farag, G. El Afandi, and S. A. Ouda. 2009. Vulnerability and adaptation of wheat to climate change in Middle Egypt. 13th Conference on Water Technology. Hurghada, Egypt. 12-15 March.

Khater, A.N, Abdel Maksoud, H.H., Eid, H.M. 1997. Response of some wheat cultivars and their water relations to different irrigation level in Middle Delta. Egypt, J. Appl. Sci.11 (2):15-29.

Kolderup, I. 1979. Application of different temperatures in three growth phases of wheat. II. Effects on ear size and seed setting. Acta. Agric. Scand. 29:11-116.

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

McMaster, G.S. 1997. Phonology, development, and growth of wheat (Triticum aestivum L.) shoot apex: A review. Advaces in Agron. 59:63-118.

Molden, D. 1997. Accounting for water use and productivity. SWIM Paper 1. Colombo, Sri Lanka: International, Irrigation Management Institute.

Mosaad, M.G., Ortiz-Ferrara, G., Mahalak-Shmi, V. 1995. Tiller development and contribution to yield under different moisture regimes in two Triticum species. J. Agron. 174:173-180.

Ouda, S. A., M. Sayed, G. El Afandi and F.A. Khalil. 2010. Developing an adaptation strategy to reduce climate change risks on wheat grown in sandy soil in Egypt. 10th International Conference on Development of Dry lands. 12-15 December. Cairo, Egypt.

Pala, M., Stockle, C.S., Harris, H.C., 1996. Simulation of durum wheat (Triticum turgidum ssp Durum) growth under different water and nitrogen regimes in a Mediterranean environment using CropSyst. Agric. Sys. 51 (2), 147–163.

Parry, M., N. Arnell., M. Hulme., R. Nicholls and M. Livermore. 1998. Adapting to the inevitable. Nature, 395, 741.

Piper, C. S. 1950. Soil and plant analysis. Univ. of Adelaid. Australia.

Renault, D. & Wallender, W.W. 2000. Nutritional water productivity and diets: from 'crop per drop' towards 'nutrition per drop'. Ag. Wat. Man., 45: 275 - 296.

Richter, G. M. and Semenov, M. A. 2005. Modelling impacts of climate change on wheat yields in England and Wales: Assessing drought risks. Agricultural Systems 84(1):77-97.

Saini, H. S. and D. Aspinall. 1982. Sterility in wheat (Triticum aestivum L.) induced by water stress or high temperature: Possible mediation by abscisic acid. Aust. J. Plant Physio. 9:529-537.

Singh, A. K., R. Tripathy and U. K Chopra. 2008. Evaluation of CERES-Wheat and CropSyst models for water-nitrogen interactions in wheat crop. Agric. Wat. Mang. 95(7):776-786.

Snyder R.L., Organ, M., Bali, K. and Eching, S. 2004. Basic irrigation scheduling BIS.http://www.waterplan.water.ca.gov/landwateruse/wateruse/Ag/CUP/California_Climate_Data_010804.xls.

Sofield, I. L. T. Evans and I. F Wardlaw. 1977. The effect of temperature and light on grain filling in wheat. R. Soc. N. Z. Bull. 12:909-915.

Stockle, C. O., S. Martin and G. S. Campbell. 1994. CropSyst, a cropping systems model: water/nitrogen budgets and crop yield. Agricultural Systems. 46:335-359.

Stockle, C.O., Nelson, R., 1994. Cropping Systems Simulation: Model Users Manual (Version 1. 02. 00) Biological Systems Engineering Department, Washington State University, p. 167.

Torriani, D.S., P. Calanca, S. Schmid, M. Beniston, J. Fuhrer. 2007. Potential effects of changes in mean climate and climate variability on the yield of winter and spring crops in Switzerland. Clim Res 34:59–69

Tubiello, F.N., M. Donatelli, C. Rosenzweig, C.O. Stockle. 2000. Effects of climate change and elevated CO2 on cropping systems: model predictions at two Italian sites. Eur J Agron 13:179–189. University Press. Ames.

Wigley, T.M.L., S.C.B. Raper, M. Hulme and S.J. Smith, 2000. The Magicc/Scengen Climate Scenario Generator Version 2.4: Technical Manual. C.F: http://www.cru.uea.ac.uk.

Willmott, C. J., 1981: On the validation of models. Phys. Geog., 2, 184-194

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