VULNERABILITY AND ADAPTATION OF WHEAT TO CLIMATE CHANGE IN MIDDLE EGYPT

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ABSTRACT

The effect of climate change on the yield of three wheat varieties (Sids1, Sakha 93 and Giza 168) and consumptive use was studied by implementing two-year field experiment in Giza Agricultural Station, Giza, Egypt in 2006/07 and 2007/08 growing seasons using CropSyst model with two climate change scenarios. These scenarios were A2 (temperature increase by 3.1°C and CO_2 concentration is 834 ppm) and B2 (temperature increase by 2.2°C and CO_2 concentration is 601 ppm) developed by Hadley Center for Climate Prediction and Research. CropSyst model was validated using the collected data of wheat yield and consumptive use. The scenarios were used to run the CropSyst model and to predict the expected yield in the year of 2038. Two early sowing dates were proposed as adaptation options, i.e. 1st of November and 21st of October to reduce the harm effect of climate change on wheat yield and a new irrigation schedule was used. The results indicated that CropSyst predictions for yield and consumptive use were highly accurate. Furthermore, A2 scenario predicted greater reduction in wheat yield, compared with B2 scenario in the year of 2038. Likewise, wheat yield losses were higher at the 1st growing season, compared with the 2nd growing season under the two scenarios. The results also revealed that under the 1st growing season for both climate change scenarios, Sakha 93 variety was found to be more tolerant to heat stress. Whereas, Sids 1 variety was found less vulnerable to climate change in the 2nd growing season. The results also showed that wheat yield improvement and irrigation water saving could be attained using the proposed adaptation strategies in the year of 2038. Under cultivation in November, 1st, a slight improvement in yield losses could be achieved with a slight increase in the amount of applied irrigation water. Whereas, under sowing in October, 21st, a decrease in yield losses could be achieved with a decrease in the amount of applied irrigation water. Under all cases, water use efficiency was increased, compared with its value under the two climate change scenarios.

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INTRODUCTION

Predictions of human induced global climate change are derived from increases in atmospheric level of carbon dioxide. One of its adverse effects is warmer temperatures and increasing episodes of very hot weather. Temperature is the primary factor driving wheat development (Wilhelm and McMaster, 1995), and consequently influence yield (McMaster, 1997). Numbers of tillers are usually decreased when wheat plants were exposed to high temperature (Friend 1965). In addition, temperature is the major variable controlling spikelet initiation and 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). At higher temperature, the duration of grain filling period was reduced (Sofield et al., 1977) as well as growth rates with a net effect of lower final kernel weight (Bagga and Rawson 1977; McMaster, 1997). Therefore, it is expected that climate change will have implications for possible fluctuation on wheat yield (Wrigley, 2006). Many studies have documented the effects of climate change on agriculture in Egypt and pose a reasonable concern that climate change is a threat to sustainable development. Climate change could do severe damage to agricultural productivity if no adaptation measures are taken (El-Shaer et al. 1997). Most of the previous research on the impact of climate change on agricultural sector used two scenarios, i.e. 1.5°C rise in temperature (MAGICC/SCENGEN results) and 3.6°C rise in temperature (GCM results) to predict the impact at the year 2050. These scenarios predicted reduction in wheat grain yield by up to 30% and increase in its water needs by up to 3% (Eid et al., 1992; Eid et al., 1993 and Eid et al., 1994) in the year of 2050. Thus, the effects of climate change on wheat production will determine the future of food security in Egypt, especially under the existence of large gap between wheat production and consumption. For that reason, adaptation strategies should be explored reduced the vulnerability of the system to climate change.

Pervious research suggested that increasing the applied irrigation water amount, increasing nitrogen fertilizers and delay sowing could be used to reduce the vulnerability of crops to climate change (Eid et al., 1995; El-Shaer et al., 1997; Eid and El-Mowelhi, 1998 and Eid and El-Marsafawy 2002). However, warming could also affect water resources and that will pose another problem, which is water scarcity.

Furthermore, increasing nitrogen fertilizer could increase the soil and ground water pollution. Whereas, delay sowing could expose the growing plants to higher temperature, which will negatively affecting the final yield. On the contrary, early sowing could help the growing plants to escape heat stress (Wrigley, 2006) and that could result in yield improvement.

The objectives of this research were: (i) To use CropSyst model to simulate wheat yield under two climate change scenarios; (ii) To use CropSyst model to test the effect of early sowing as an adaptation option on relieving the harm effect of climate change on wheat yield and water use efficiency.

MATERIALS AND METHODS

1. Field experiments

Two field experiments were conducted in 2006/07 and 2007/08 growing seasons in Giza Agricultural Research Station, Egypt to collect data on wheat grain and biological yield. These collected data was used to validate CropSyst model and to run it under two climate change scenarios. CropSyst model was also used in assessing the effect of early sowing and increasing number of irrigations on wheat yield and water use efficiency under the two climate change scenarios. Three wheat varieties were planted, i.e. sids 1, sakha 69 and Giza 128 in a randomize complete plot design with three replicates. Wheat was planed on the 15^{th} and 17^{th} of November in the first and second growing seasons, respectively. Nitrogen fertilizer was divided into 3 doses (at sowing date, tillering stage and at boating 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 boating 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 one 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):

$$I = Epan*Kp \tag{1}$$

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. The total number of irrigations was 7 irrigations. 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

Metrological data were collected for Giza Agricultural Research Station and are included in Table (3).

Table (3): Meteorological data for Giza region in 2006/07 and 2007/08 growing seasons

2006/07 growing season							
Month	Tmax (ºC)	Tmin (ºC)	WS (m/s)	RH (%)	SS (h)	SR ($cal/cm^2/day$)	Epan (mm/day)
November	23.9	14.2	3.6	67	8.2	326	2.5
December	20.8	11.2	3.0	69	7.0	268	2.0
January	19.5	9.0	3.4	70	7.0	280	2.0
February	21.6	11.6	3.4	62	7.9	453	3.4
March	24.6	13.2	4.4	59	8.6	441	4.2
April	27.8	16.1	5.2	27.8	9.6	519	5.3
2007/08 growing season							
Month	Tmax (ºC)	Tmin (ºC)	WS (m/s)	RH (%)	SS (h)	SR ($cal/cm^2/day$)	Epan (mm/day)
November	26.8	15.7	3.6	62	8.2	326	3.2
December	22.7	11.2	3.0	66	7.0	268	2.0
January	18.0	7.2	3.4	62	7.0	280	2.2
February	20.6	8.1	3.4	53	7.9	453	3.3
March	27.4	13.1	4.4	47	8.6	441	3.5
April	30.4	15.7	5.2	44	9.6	519	5.7

Tmax=Maximum temperature; TMin=Minimum temperature; WS=Wind speed; RH=Relative humidity; SS=Actual sunshine duration; SR= Solar radiation; Epan=Evaporation pan.

Consumptive water use was calculated using soil sampling. Consumptive water use was estimated by the following equation (Israelsen and Hansen, 1962):

$$CWU = (\Theta_2 - \Theta_1) * Bd * ERZ \qquad (2)$$

Where: CWU=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 in g/cm^3, ERZ= effective root zone.

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. Water use efficiency (kg/m^3) values for the three varieties were calculated by the following equation (Vites, 1965):

$$WUE = \text{Grain yield (kg/ha)}/\text{Consumptive use } (m^3/ha) \quad (3)$$

2. CropSyst model calibration and validation

CropSyst (Cropping Systems Simulation Model) is a multi-year, multi-crop, daily time step crop growth simulation model, developed with emphasis on a friendly user interface, and with a link to GIS software and a weather generator (Stockle, 1994). The model's 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.

After each growing season, input files required by CropSyst model for Giza location and wheat crop were prepared and use to run the model. A few variety-specific parameters were calibrated within a reasonable range of fluctuation set in CropSyst manual. After calibration, the model was validated using the measured data of the three varieties for grain and biological yield and consumptive use. To test the goodness of fit between the measured and predicted data, percent difference between measured and predicted values for each variety in each growing season were calculated, in addition to root mean squared error (Jamieson, et al., 1998) and Willmott index of agreement (Willmott, 1981). Furthermore, regression analysis was done to test the strength of the relationship between measured and predicted yield and consumptive water use values.

3. Climate change scenarios

In this work, the HadCM3 which is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre for Climate Prediction and Research (United Kingdom) was used (Gordon et al., 2000 and Pope et al., 2000) and considered as significantly and more sophisticated than earlier versions (Hulme et al., 1998). This model has a spatial resolution of 2.5 x 3.75 (latitude by longitude). HadCM3 provide information about climate change all over the entire world during the 21st century and present information about three times slices: 2020s, 2050s, and 2080s. In order to provide information on possible changes in the world climate, the climate change

models are forced to consider future scenarios. The IPCC (Nakicenvic et al., 2000) has developed emission scenarios known as SRES (Special Report on Emission Scenarios). The four SRES scenarios combined two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization (IPCC-TGCIA, 1999). Two climate change scenarios were considered in this study: A2 and B2. These selected two scenarios: A2 and B2 consider a rise in global annual mean temperature by 3.09 and 2.16°C, respectively, CO_2 concentration 834 and 601 ppmv, respectively and global mean sea level rise 62 and 52 cm, respectively. As the resolution of the model is too big, using simple interpolation techniques of these percentages have been applied to fit the station site. Data were downloaded in GRIB format from the IPCC Data Distribution Centre web site, and the GRBCONV program source code is found at the following web site:
[http://www/dkrz.de/ipcc/ddc/html/HadleyCM3/hadcm3. html].

The GRBCONV program was used to convert the data files from GRIB format to the more conventional ASCII. The download site does not offer the option to subset the data based on an area of interest, so a custom program was used to extract the data for the region of interest. HadCM3 variables were monthly precipitation, solar radiation, minimum and maximum temperatures.

A2 and B2 climate change scenarios were used to run the CropSyst model to predict wheat yield and consumptive use in the year of 2038. The reason for choosing that year to predict potential wheat yield is to perceive how wheat productivity will be affected after 30 years. The effect of climate change on each of the two growing season will be discussed separately as if each season could be a representation of the growing season of the year of 2038.

4. Adaptation strategies

The effect of two early sowing dates and irrigation rescheduling on wheat yield was tested under the two climate change scenarios was investigated using CropSyst model. The proposed sowing dates were planting in the 1st of November and on 21st of October. The proposed irrigation scenario suggested to increase the number of irrigation from 7 irrigations to 8 irrigations and to apply irrigation every 21 days to refill plant available water to prevent the occurrence of water stress. Furthermore, Table (4) showed actual irrigation schedule in the two growing seasons and proposed irrigation schedule.

Table (4): days after planting for each actual single irrigation for the two growing seasons and for the proposed irrigation schedule

Irrigation number	Actual irrigation date		Proposed irrigation date
	2006/07 growing season	2007/08 growing season	
1st	Planting day	Planting day	Planting day
2nd	30	30	21
3rd	51	58	42
4th	75	77	63
5th	98	94	84
6th	121	112	105
7th	142	134	126
8th	---	---	147
Harvest	159	157	150-157

RESULTS

1. CropSyst model validation

1.1. Wheat grain yield prediction

Table (5) shows 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 0.0157 ton/ha and Willmott index of agreement was 0.9999.

Table (5): Measured versus predicted wheat grain yield (ton/ha) in the two growing seasons

Variety	2006/07 growing season			2007/08 growing season		
	Measured yield	Predicted yield	Percent reduction	Measured yield	Predicted yield	Percent reduction
Sids 1	5.92	5.91	0.20	5.40	5.39	0.19
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
RMSE	0.0157					
WI	0.9999					

RMSE= root means square error; WI= Willmott index of agreement.

Results in Figure (1) imply that all predicted wheat values lies within 95% confidence interval (95% CI). Regression analysis of the measured and predicted wheat yield values indicated a significant relationship ($P<0.001$) of $y = 0.1048 + 0.9782\, x$, with R^2 value of 0.9966 over the two growing seasons.

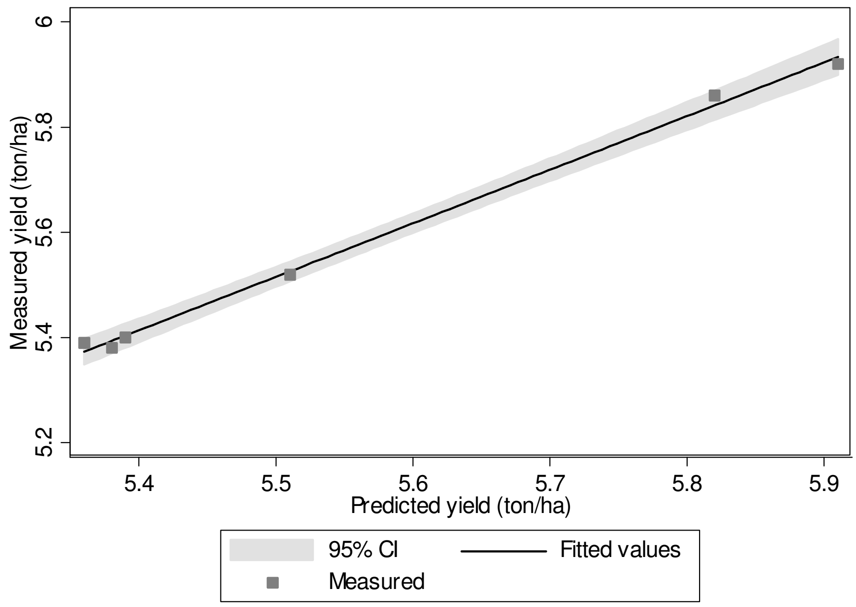

Figure (1): Measured versus predicted wheat yield over the two growing seasons

Singh et al. (2008) indicated that CropSyst model is more appropriate than CERES-Wheat in predicting growth and yield of wheat under different N and irrigation application situations in this study, where RMSE was 0.36 ton/ha compared with 0.63 ton/ha for CERES-Wheat. Whereas, 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.

1.2. Wheat biological yield prediction

Similar results were obtained for the prediction of wheat biological yield (Table 6), where percent difference between measured and predicted wheat biological yield was less than 1.5%. Results in that table also indicated that RMSE was 0.1907 ton/ha and Willmott index of agreement was 0.9999. 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 (6): 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	Percent reduction	Measured yield	Predicted yield	Percent reduction
Sids 1	21.38	21.10	1.30	19.54	19.25	1.46
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	0.1907					
WI	0.9998					

RMSE= root means square error; WI= willmott index of agreement.

The results also showed that all predicted wheat biological yield values lies within 95% confidence interval (95% CI) (Figure 2). Regression analysis between measured and predicted wheat biological yield had a significant linear relationship ($P < 0.001$), with equation $y = 1.8090 + 0.9023\ x$ ($R^2 = 0.9763$).

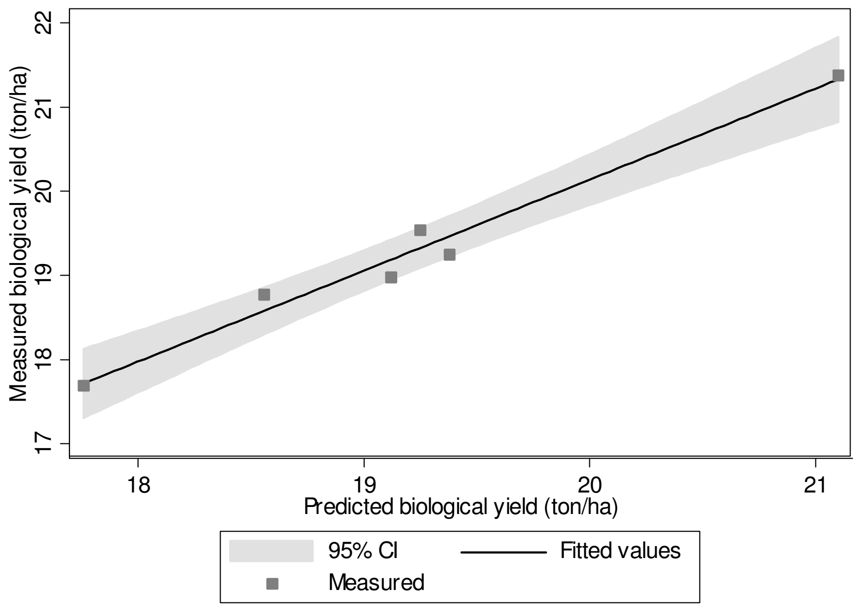

Figure (2): Measured versus predicted wheat biological yield over the two growing seasons

1.3. Wheat consumptive use prediction

Regarding to consumptive use prediction, the model prediction was highly accurate too. Percent difference between measured and predicted wheat consumptive use was less than 1%. RMSE was 0.5692 mm and Willmott index of agreement was 0.9999 (Table 7). Similar results were obtained by Wang et al., (2006), where RMSE was 0.07 mm for evapotranspiration and Punnkuk et al., (1998), where it was 0.05 mm when CropSyst was used to predict evapotranspiration.

Table (7): Measured versus predicted wheat consumptive use (mm) in the two growing seasons

Variety	2006/07 growing season			2007/08 growing season		
	Measured CU	Predicted CU	Percent reduction	Predicted CU	Measured CU	Percent reduction
Sids 1	380.95	379.80	0.30	400.95	400.82	0.03
Sakha 93	362.86	361.88	0.27	366.90	366.09	0.22
Giza 168	358.10	355.64	0.69	367.14	365.64	0.41
RMSE	0.5692					
WI	0.9999					

Figure (3) shows that all predicted wheat consumptive use values lies within 95% confidence interval (95% CI) A statistically significant relationship ($P < 0.001$) was found between measured and predicted consumptive use value, with equation $y = -15.0726 + 1.0372\ x$ ($R^2 = 0.9990$).

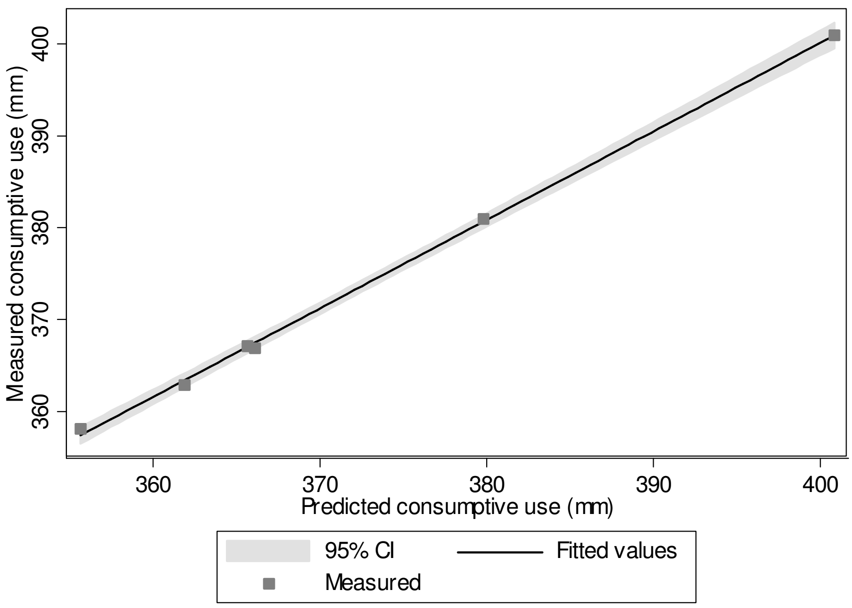

Figure (3): Measured versus predicted wheat consumptive use over the two growing seasons

The accurate results that obtained from running the model for the three wheat varieties implied that the model can be used in simulating wheat yield under environmental stresses. Although the above situation provides only a limited evaluation of the model, the model should be further tested as more data from more treatments in different locations and years become available. However, for the purposes of this study we felt that the model worked sufficiently well to warrant the exploration of the effect of climate change on wheat yield and water requirements.

2. Prediction of wheat yield under climate change scenarios

As it was stated before, the effect of climate change on each growing season could be a representation of the growing season of the year of 2038. Therefore, the results of each growing season will be presented separately.

Regarding to 2006/07 growing season, the expected reduction in grain and biological wheat yield was higher under A2 scenario, compared with B2 scenario (Table 8). Under both scenarios, the most vulnerable variety for climate change was Giza 168 and the less vulnerable variety was Sakha 93. Under both scenarios, water consumption was increased for the three varieties between 5.04-7.14%.

Table (8): Percent reduction in grain and biological wheat yield and percent increase in wheat consumptive use as a result of the two scenarios for 2006/07 growing season

Variety	Climate scenario	Grain (ton/ha)	PR %	Biological (ton/ha)	PR %	Consumptive use (mm)	PI %
Sids1	Current	5.91	---	21.10	---	379.80	---
	A2	3.2	45.85	11.44	45.34	398.94	5.04
	B2	3.61	38.92	12.89	38.91	402.81	6.06
Sakha 93	Current	5.82	---	19.38	---	361.88	---
	A2	3.22	44.67	10.74	44.58	386.31	6.75
	B2	3.63	37.63	12.10	37.56	387.71	7.14
Giza 168	Current	5.51	---	17.76	---	355.64	---
	A2	2.90	47.37	9.35	47.35	375.65	5.63
	B2	3.32	39.75	10.71	39.70	375.80	5.67

A2 and B2= two climate change scenarios; PR= percent reduction between measured and predicted values; PI= percent increase between measured and predicted values.

With respect to 2007/08 growing season and under A2 scenario, the three varieties were similar in their response to heat stress, where percent reduction for the three varieties was around 36% by the year 2038. The situation was different for B2 scenario, where the less vulnerable variety was Sids 1, where its yield reduction was 30.00% (Table 9). Water consumptive was also increased for the three varieties between 4.81-6.27% by the year 2038.

Table (9): Percent reduction in grain and biological wheat yield and percent increase in wheat consumptive use as a result of the two scenarios for 2007/08 growing season

Variety	Climate scenario	Grain (ton/ha)	PR %	Biological (ton/ha)	PR %	Consumptive use (cm)	PI %
Sids1	Current	5.39	---	19.25	---	400.82	---
	A2	3.42	36.67	12.22	37.45	420.25	4.81
	B2	3.78	30.00	13.51	30.85	427.45	6.61
Sakha 93	Current	5.36	---	19.12	---	366.09	---
	A2	3.41	36.38	12.17	36.35	388.22	6.04
	B2	3.47	35.26	12.40	35.15	389.05	6.27
Giza 168	Current	5.38	---	18.56	---	365.64	---
	A2	3.40	36.83	11.73	36.80	386.77	5.78
	B2	3.47	35.53	11.95	35.61	386.88	5.81

A2 and B2= two climate change scenarios; PR= percent reduction between measured and predicted values; PI= percent increase between measured and predicted values.

3. Effect of adaptation strategies

As it was previously mentioned, two early sowing dates i.e. sowing in the 1st of November and sowing on the 21st of October were tested to reduce yield vulnerability under the two climate change scenarios in the year of 2038.

Although both early sowing dates did not reduce yield losses for Sids 1 variety in 2006/07 growing season, sowing in the 21st of October reduced the amount of applied irrigation water by 4.09 and 2.05% under A2 and B2, respectively (Table 10). Furthermore, water use efficiency was the highest under B2 scenario when Sids 1 variety was planted on the 21st of October, compared with the one under current climate conditions.

Table (10): Percent decrease in predicted wheat grain yield, corresponded percent of predicted irrigation amount and water use efficiency for Sids 1 variety in both growing seasons

Climate scenario	2006/07 growing season			2007/08 growing season		
	% decrease in yield	% change in irrigation	WUE (kg/m^3)	% decrease in yield	% change in irrigation	WUE (kg/m^3)
Current	---	---	1.34	---	---	1.21
A2	45.85	-1.59	0.74	36.67	+0.67	0.76
A2SD1	42.30	+2.50	0.76	33.33	+6.26	0.76
A2SD2	45.85	-4.09	0.76	37.59	-3.13	0.78
B2	38.92	+2.50	0.80	30.00	+4.92	0.81
B2SD1	38.07	+2.27	0.81	28.70	+6.26	0.81
B2SD2	38.75	-2.05	0.84	28.33	+1.68	0.85

A2 and B2= two climate change scenarios; A2SD1and B2SD1= sowing in the 1st of November under the two climate change scenarios A2 and B2; A2SD2and B2SD2= sowing in the 21st of October under the two climate change scenarios A2 and B2; WUE= water use efficiency.

Regarding to 2007/08 growing season and under A2 scenario, yield losses could be reduced from 36.67% when wheat was planted on the 15th of November to 33.33% with planting occurred on the 1st of November. However, this yield reduction required to increase irrigation amount by 6.26%. Furthermore, percent of wheat yield reduction could be lessen from 30.00% under A2 scenario and planting on 15th of November to 28.33% under planting on the 21st of October, with 1.68% increase in irrigation amount (Table 11). Therefore, it could be recommended to plant wheat on October 21st to reduce wheat yield losses and to increase water use efficiency, regardless of the slight increase in the amount of applied irrigation water.

Regarding to Sakha 93 variety in 2006/07 growing season, irrigation water saving by 2.6% and yield improvement from 37.63% to 35.57% could be occurred under B2 scenario when wheat was planted on the 21st of October, which achieved higher water use efficiency (Table 11).

With respect to 2007/08 growing season, large percent of yield improvement from 35.26% to 27.24% could be occurred under B2 scenario with planting take place in 21st of October and less than 1% increase in irrigation water, which attained higher water use efficiency (Table 11). Therefore, for Sakha 93 variety, it is recommended to plant it on October, 21st to reduce yield losses under climate change scenarios.

Table (11): Percent decrease in predicted wheat grain yield, corresponded percent of predicted irrigation amount and water use efficiency for Sakha 93 variety in both growing seasons

Climate scenario	2006/07 growing season			2007/08 growing season		
	% decrease in yield	% change in irrigation	WUE (kg/m^3)	% decrease in yield	% change in irrigation	WUE (kg/m^3)
Current	---	---	1.38	---	---	1.27
A2	44.67	+1.23	0.75	36.38	+0.71	0.80
A2SD1	43.30	+1.89	0.77	33.21	+4.99	0.81
A2SD2	51.20	-2.84	0.69	37.69	-1.19	0.80
B2	37.63	+0.71	0.85	35.26	+4.04	0.79
B2SD1	36.94	-0.71	0.87	30.41	+4.99	0.84
B2SD2	35.57	-2.60	0.91	27.24	+0.95	0.92

A2 and B2= two climate change scenarios; A2SD1and B2SD1= sowing in the 1st of November under the two climate change scenarios A2 and B2; A2SD2and B2SD2= sowing in the 21st of October under the two climate change scenarios A2 and B2; WUE= water use efficiency.

Similar trends was obtained for Giza 168 variety in 2006/07 growing season under B2 scenario, where 2.69% of irrigation water could be saved with yield improvement from 39.75% to 37.39% when wheat was planted on the 21st of October to achieve higher water use efficiency (Table 12). The same trend was observed in 2007/08 growing season, where large percent improvement in wheat yield from 35.53% to 27.54% could be occurred under B2 scenario with planting take place in 21st of October with less than 1% increase in irrigation water, which achieved higher water use efficiency (Table 12). Therefore, to reduce yield losses under climate change scenarios for Giza 168 variety, it is recommended to plant it on October, 21st.

Table (12): Percent decrease in predicted wheat grain yield, corresponded percent of predicted irrigation amount and water use efficiency for Giza 168 variety in both growing seasons

Climate scenario	2006/07 growing season			2007/08 growing season		
	% decrease in yield	% change in irrigation	WUE (kg/m^3)	% decrease in yield	% change in irrigation	WUE (kg/m^3)
Current	---	---	1.33	---	----	1.28
A2	47.37	+1.06	0.69	36.83	+0.48	0.81
A2SD1	46.46	+1.69	0.70	33.67	+4.88	0.81
A2SD2	56.99	-2.96	0.59	42.40	-1.19	0.75
B2	39.75	+0.24	0.80	35.53	+3.89	0.80
B2SD1	38.48	-0.96	0.82	30.88	+4.91	0.84
B2SD2	37.39	-2.69	0.85	27.54	+0.95	0.92

A2 and B2= two climate change scenarios; A2SD1and B2SD1= sowing in the 1st of November under the two climate change scenarios A2 and B2; A2SD2and B2SD2= sowing in the 21st of October under the two climate change scenarios A2 and B2; WUE= water use efficiency.

DISCUSSION AND CONCLUSION

Simulation models can provide an alternative, less time-consuming and inexpensive means of determining the optimum management practices requirements under climate change conditions. CropSyst has been applied to several crops (corn, wheat, barley, soybean, sorghum, and lupines) and regions (Western US, Southern France, Northern and Southern Italy, Northern Syria, Northern Spain, and Western Australia), generally with good results (Stockle et al. 1994). Our results showed that CropSyst model is cable of predicting wheat yield and consumptive use under the Egyptian conditions (Tables 5, 6 and 7). 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, such as slight water stress and heat stress. CropSyst account for these two stresses conditions by calculating two stresses coefficients i.e. water stress coefficient and temperature stress coefficient. If these coefficients are higher than zero, dry matter production will be reduce in response to this type of stress.

In the 2006/07 growing season and under current climate conditions, the three varieties had higher yield, compared with its yield in 2007/08 growing season (Tables 5, and 6). The output of the model revealed that there was no detection of water stress in both growing season as it is reflected by zero value of water stress coefficient. However, heat stress was existed in 2007/08 growing season, where the value of the temperature stress coefficient was 0.48, 0.51 and 0.53 for Sids 1, Sakha 93 and Giza 168, respectively. This finding is supported by the actual weather data (Table 3), where temperature was higher in 2007/08 growing season, compared with 2006/07 growing season.

The response of wheat yield to the two climate scenarios was different. A2 (temperature increase by 3.1°C and CO_2 concentration is 834 ppm) predicted greater reduction in wheat yield, compared with B2 (temperature increase by 2.2°C and CO_2 concentration is 601 ppm) in the year of 2038. Gibson and Paulsen (1999) reported that high temperature is a major determinant of wheat development and growth, decreasing yields by 3 to 5% per every 1°C increase above 15°C under controlled conditions.

Furthermore, the two growing seasons responded differently to the effect of climate change, where yield losses were higher at the first growing season, compared with the second. Therefore, the effect of climate change on each growing season will be discussed separately.

In 2006/07 growing season and under both climate change scenarios, Sakha 93 variety was found to be more tolerant to heat stress, compared with the other two varieties. This tolerance is expressed by lower yield losses and higher consumptive use (Table 8). Under heat stress vegetative and reproductive growth of wheat is reduced (Gardner et al., 1985), which will be reflected on the final yield. Furthermore, heat stress increases the capacity of air to hold water, increases loss to the atmospheric demand; therefore it increases evapotranspiration (Gardner et al., 1985). However, the increase in consumptive use was higher under the B2 scenario (lower yield reduction), compared with A2 scenario (higher yield reduction). This could be attributed to the fact that under B2 scenario, slightly better vegetative growth was attained by wheat plants (expressed by lower yield reduction), which increased evapotranspiration (Table 8).

The situation was different in 2007/08 growing season, where under A2 scenario the three varieties were similar in their response to heat stress. However, under B2 scenario, Sids 1 variety was found less be vulnerable, compared with the other two varieties (Table 9).

The response of the three varieties to the interaction between early sowing and irrigation scheduling was different (Tables 10, 11 and 12). Early sowing could help the growing plants to avoid days with high stressful temperature. High temperature could also increase water depletion from root zone as result of increasing evapotranspiration. Therefore, scheduling irrigation to apply it every 21 days with total 8 irrigations, instead of applying 7 irrigations under current climate conditions helped in preventing water stress from occurring. In the mean time, it did not increase the total applied amount of irrigation by much. In fact, under some cases it saved a small percent of the applied irrigation water as a result of early sowing.

Our results showed that wheat yield improvement and irrigation water saving were attained using the proposed adaptation strategies in the year of 2038. Under wheat cultivation in November, 1^{st}, almost in all cases, a slight improvement in yield losses were achieved with a slight increase in the amount of applied irrigation water. Whereas, under cultivation in October, 21st and in almost all cases, decrease in yield losses were achieve with decrease in the amount of applied irrigation water. This situation was valid under the two growing seasons. Under all cases, water use efficiency was increased, compared with its value under climate change scenarios (Tables 10, 11 and 12).

To conclude, this study is the first climate change study that explored the possibility of lowering yield reduction and saving irrigation water in the year of 2038. The real challenge under climate change conditions is to use adaptation strategies, which are improved agricultural management practices, to reduce the damage of climate change on the yield of the growing crops and in the mean time conserve a certain percent of the applied irrigation water. Furthermore, developing optimum nitrogen fertilizer regime could help in reducing the harm effect of climate change on crops yield and it may also help in conserving irrigation water. Thus, simulation model can be the ultimate solution for testing all these options.

Plant breeders could use the results of the application of the simulation models to help them in developing new varieties adapted to climate change. Wheat breeders will need to focus on overcoming heat stress rather than improving drought tolerance as a result of climate change. Moreover, breeding for varieties with higher water use efficiency is also very important goal to be achieved.

REFERENCES

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

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 Vol. 32 (1) 143-154.

Eid, H. M. and S. M. El-Marsafawy. 2002. Adaptation to climate change in Egyptian Agriculture and water resources. 3rd International Symposium on Sustainable Agro-environmental Systems: New Technologies and Applications. 26-29 October, Egypt.

Eid, H. M., and N. M. El-Mowelhi. 1998. Impact of climate change on field crops and water needs in Egypt. African International Environmental Conf. Oct, 1998 Egypt.

Eid, H. M., N. M. El-Mowelhi, M. A. Metwally, N. G. Ainer, F. A. Abbas, and M. A. Abd El-Ghaffar. 1995. Climate change and its expected impacts on yield and water needs of some major crops. Second ARC Field Irrigation and Agroclimatology Conference. Paper No.17.

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

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. 5^{th} Egypt. Botan.Conf. Siant Cather. Sianai, pp. 113-130.

El-Shaer, M. H., C. Rosenzweig, A. Iglesias, H. M. Eid and D. Hellil, 1997. Impact of climate change on possible scenarios for Egyptian agriculture in the future. Mitigation and Adaptation Strategies for Global Change.1: 233-250.

Gardner, F. P., R. B Pearce, R. L. Mitchell. 1985. Physiology of Crop Plants. Iowa State University Press. Ames. USA.

Gibson, L. R. and G. M. Paulsen. 1999. Yield components of wheat grown under high temperature stress during reproductive growth. Crop Sci. 39:1841–1846.

Gordon, C., C. Cooper, C.A. Senior, H. Banks, J. M. Gregory, T. C. Johns, J.F.B. Mitchell, and R.A. Wood. 2000. The simulation of sea surface temperature, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. Climate Dynamics (16):147-168

Hulme, M. and G.J. Jenkins, 1998. Climate change scenarios for the UK: Scientific Report. UKCIP Technical Report No. 1. Climate Research Unit, Norwich, UK.

Israelsen, O.W. and V.E. Hansen. 1962. Irrigation Principles and Practices. John Wiley & Sons, Inc. New York.

IPCC-TGCIA, 1999. Guidelines on the use of Scenario Data for Climate Impact and Adaptation Assessment, Version 1. Prepared by Carter, T.R., Hulme M., and Lal. M. Intergovernmental Panel on Climate Change, task Group on Scenarios for Climate Impact Assessment.

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.

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.

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

Nakicenovic, N., Alcamo, J., Davis, G., de Vries B.; Fenhann, J., Gaffin, S., Gregory, K., Grubler, A., Jung, T.Y., Kram, T., La Rovere, E. L., Michaelis, L.; Mori, S.; Morita, T.; Pepper, W.; Pitcher, H., Price, L., Raihi, K., Roehrl, A., Rogner, H., Sankovski, A., Schlesingger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., N. Victor and Z. Dadi. 2000. IPCC Special Report on Emission Scenarios Cambridge University Press. pp 599.

Pannkuk, C.D., C.O. Stockle, and R.I. Papendick. 1998. Evaluating CropSyst simulations of wheat management in a wheat-fallow region of the US Pacific Northwest. Agric. Syst. 57(2):121-133.

Piper, C. S. (1950): Soil and plant analysis. University of Adelaide, Australia.

Pope, V. D., M. L. Gallani, P.R., Rowntree, R.A. Stratton. 2000. The impact of new physical parameterization in the Hadley Centre Climate Model-HadCM3. Climate Dynamics (16): 123-146.

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.

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.

Wang, Z., B. Zhang, L. Xiao-yan, K. Song, D. Liu and S. Zhang. 2006. Using CropSyst to simulate spring wheat growth in Black Soil Zone of Northeast China. Pedoshere. 16(2):121-134.

Wilhelm, W. W. and G. S. McMaster. 1995. The importance of phyllochron in studying the development of grasses. Crop Sci. 53:1-3.

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

Wrigley, C. 2006. Global warming and wheat grain quality. C. F. W. 51(1): 34-36.

Vites, F. G. Jr. 1965. Increasing water efficiency by soil management. Amer. Soci. Agron., Wisc. 26; 259-274.