USING ADAPTATION STRATEGIES TO INCREASE WATER USE EFFICIENCY FOR MAIZE UNDER CLIMATE CHANGE CONDITIONS

Samiha A. Ouda*, Fouad A. Khalil, and Hassan Yousef

Water Requirements and Field Irrigation Research Department, Soil, Water, and Environment Research Institute, Agricultural Research Center, Egypt
* Corresponding author, E-mail: samihaouda@yahoo.com

ABSTRACT

The impact of climate change on water use efficiency under climate change conditions and under using three adaptation strategies was tested for two maize hybrids (TWC310 and TWC324) planted in two growing seasons (2007 and 2008) at Giza, Egypt 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 maize yield and consumptive use. The scenarios were used to run the CropSyst model and to predict the expected yield in the year of 2038s. Sowing maize two weeks earlier, two irrigation schedules (I1; irrigation every 14 days with a total of 7 irrigations and I2; applying the 2nd irrigation 20 days after planting, then irrigation every 13 days with a total of 8 irrigations) and the interaction between early sowing and irrigation schedules were use as adaptation strategies. The Effective adaptation strategy is the one that increase percent of yield improvement, decrease percent increase in irrigation water and increase water use efficiency. The results indicated that CropSyst predictions for yield and consumptive use were highly accurate. Furthermore, A2 scenario predicted greater reduction in maize yield, compared with B2 scenario in the year of 2038. The results also demonstrated that under climate change condition, maize hybrid TWC324 was more tolerant to heat stress than TWC310 in both growing season. This result implied that TWC324 possess traits of yield stability under the variability of climate. This stability also reflected by lower deterioration in water use efficiency under heat stress. The two irrigation schedules were effective in reducing yield losses and increasing water use efficiency under climate change without large increase in irrigation amount, compared with early sowing and the interaction between early sowing and irrigation schedules.

Keywords: Heat stress, A2 and B2 climate change scenarios, early sowing, irrigation schedules.

INTRODUCTION

Climate change as projected by climate models for the twenty-first century has the potential to significantly alter the conditions for crop production, with important implications for worldwide food security (Rosenzweig and Hillel 1998). Changes in yield behavior in relation to shifts in climate can become critical for the economy of farmers. An increasing probability of low returns as a consequence of the more frequent occurrence of adverse conditions could prove dramatic for farmers operating at the limit of economic stress (Torriani et al., 2007b).

In Egypt, many studies predicted the implications of climate change on agricultural sector and raise a sensible anxiety about the threat of climate change to sustainable development. Furthermore, these studies have revealed that yields and water use efficiency will be decreased in comparison with current climate conditions, even when the beneficial effects of CO_2 are taken into account (Eid and El-Marsafawy 2002). These studies also indicated that climate change could increase water needs by 16% for summer crops and decrease it by 2% for winter crops (Eid and El-Mowelhi, 1998).

Maize occupies a unique position in science and agriculture, in addition of being a crop with enormous uses. Previous research on climate change effect showed that national maize production in Egypt will be decreased by 25% by the year 2050 as it was projected using GCMs or MAGICSENGEN scenarios (Eid and El-Mowelhi, 1998; Eid et al., 1992 and Eid et al., 1997). However, Climate change is urgently needs to be assessed at the level of the farm, so that poor and vulnerable farmers dependent on agriculture can be appropriately targeted in research and development activities on poverty alleviation (Jones and Thronton 2003). Assessing the possible impact of climate change on production risks is therefore necessary to help decision makers and stakeholders identify and implement suitable measures of adaptation (Torriani et al., 2007b).

Using process-based models of crop growth such as CropSyst along with a set of daily weather data spanning a reasonable number of years could be the ultimate solution to assess the impact of climate change on agriculture (Tubiello et al., 2000; Torriani et al., 2007a). The application of such models allows the simulation of many possible climate change scenarios from only a few experiments for calibration.

Pervious research on the effect of climate change on agricultural sector suggested that increasing nitrogen fertilizers, changing sowing date and increasing the applied irrigation amount could be used as adaptation options to reduce the vulnerability of the growing crops to climate change. However, increasing nitrogen fertilizer could increase soil and ground water pollution. Change sowing date is a very feasible and easy to implement adaptation option to reduce the harm effect of climate change. Whereas, warming could also affect water resources and that could cause water scarcity. Therefore, it is important to develop adaptation strategies, which could reduce the vulnerability of maize to climate change, without large increase in the applied irrigation water.

The objectives of this work are: (i) to calibrate and validate CropSyst model for two-year maize experiment; (ii) to use the model to predict the expected maize yield under two climate change scenarios; and (iii) to use the model to predict the improvement in maize yield as a result of using several adaptation strategies.

MATERIALS AND METHODS

1. Field experiments

Two field experiments were carried out at Giza Agricultural Research Station, Agricultural Research Center, Egypt during 2007 and 2008 growing seasons to collect field data on two maize hybrids (TWC 310 and TWC 324) to be used to calibrate and validate CropSyst model. The experimental treatments were arranged in a randomize complete plot design in three replicates. Plot area was 4 X 6.2 m^2 in both growing seasons. Sowing was done on the 19^{th} and 21^{st} of June in the 1^{st} and 2^{nd} growing season, respectively. Nitrogen fertilizer was applied in the form of urea (288 kg/ha, 46% N) and was applied before the 2^{nd} irrigation. Phosphorus fertilizer was applied in the form of single super phosphate (480 kg/ha, 15.5% P_2O_5) and was incorporated into the soil during land preparation. Potassium sulfate was applied before planting (120 kg/ha, 48% KO_2). Surface irrigation was used. The second irrigation was applied 22 days after planting then irrigation was applied every 14 days in both growing seasons with a total of 7 irrigations. Actual evapotranspiration was estimated by the soil sampling method and calculated according to the Israelsen and Hansen (1962) using the following formula:

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

Where: CU=the amount of consumptive use in mm, Θ_2=soil moisture percentage after irrigation, Θ_1=soil moisture percentage before the following irrigation, Bd=bulk density in g/cm^3 and ERZ= effective root zone (0.6 m). The soil moisture constants (% per weight) and bulk density (g/cm^3) in the depth of 0-60 cm are shown in Table (1).

Table (1): Soil moisture constants of the experimental field at Giza Agricultural 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

Harvest was done in the 2^{nd} week of October during the two growing seasons and maize yield was measured. Water use efficiency (kg/m^3) values for the two varieties were calculated by the following equation (Vites, 1965).

$$WUE= Grain\ yield\ (kg/ha)/Consumptive\ use\ (m^3/ha) \quad (2)$$

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 et al., 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 maize 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 yield and consumptive use of two maize hybrids. 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 a., 1998) and Willmott index of agreement (Willmott, 1981).

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 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 maize yield and consumptive use in the year of 2038s. The reason for choosing that year to predict potential maize yield is to perceive how maize productivity on farm level 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 sowing maize two weeks earlier (ES), two irrigation schedules and the interaction between early sowing and irrigation schedules on maize yield and consumptive use was predicted under the two climate change scenarios using CropSyst model. The proposed irrigation scenarios were: irrigation every 14 days with a total of 7 irrigations (I1) and applying the 2^{nd} irrigation 20 days after planting, then irrigation every 13 days with a total of 8 irrigations (I2). The effect of these adaptation strategies on maize yield and required irrigation amount will be compared with respect to percent of yield improvement, percent increase in irrigation water and water use efficiency. Efficient adaptation strategy is the one that increase percent of yield improvement, decrease percent increase in irrigation water and increase water use efficiency.

RESULTS

1. CropSyst model calibration/validation for maize yield and consumptive use

CropSyst was calibrated for maize grown at Giza location for the two growing seasons. After calibration, CropSyst model was used to predict maize yield and consumptive use for the two hybrids under both growing seasons. CropSyst model predicted maize yield and consumptive use with high degree of precision. Percent difference between measured and predicted values was less than 1% for both yield and consumptive use. Willmott index of agreement was the highest and root mean square error was very low (Table 2). Díaz-Ambrona et al., (2004) stated that the simulations of maize yield by CropSyst were close to measured values, where RMSE was 1.2 ton/ha. These results are in agreement with what was found by Rivington et al., (2007), Moriondo et al., (2007) and Tingem et al., (2007), where they stated that CropSyst is recognized by its robustness and relatively easy applicability with commonly available information.

Table (2): Measured versus predicted maize yield and consumptive use in the two growing seasons

Growing Season	Hybrid	Maize yield (ton/ha)		PD%	Consumptive use (mm)		PD%
		Measured	Predicted		Measured	Predicted	
2007	TWC310	5.71	5.70	0.17	545.70	542.82	0.53
	TWC324	5.41	5.42	0.18	531.00	530.59	0.08
2008	TWC310	5.92	5.89	0.51	540.60	539.14	0.27
	TWC324	5.79	5.78	0.17	525.00	524.02	0.19
Willmott index		0.9999			0.9999		
RMSE/observation		0.0087			0.0092		

PD%= percent difference between measured and predicted values, RMSE= root mean square error.

The accurate results obtained from running the model for the two maize hybrids under both growing seasons implied that the model can be used in simulating maize 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 maize yield and water requirements.

2. Effect of climate change scenarios on maize yield and consumptive use

As it was stated earlier, two climate change scenarios were examined in this study i.e. A2 and B2. These two scenarios were used to predict maize yield and consumptive use in the year of 2038s.

Excessive losses in maize yield could occur under A2 climate change scenario and high increase in consumptive use would be expected too in the year of 2038s (Table 3). Under that scenario, yield losses could be as high as 59% and consumptive use could be elevated by 13%. Furthermore, TWC324 was found more tolerant to heat stress, compared with TWC310 under both growing seasons. That tolerance was translated by lower yield reduction, compared with TWC310 in both growing seasons and lower consumptive use values (Table 3).

Table (3): Predicted maize yield and consumptive use under A2 scenario for both two growing season

Growing Season	Hybrid	Maize yield (ton/ha)		PR%	Consumptive use (mm)		PI%
		Measured	Predicted		Measured	Predicted	
2007	TWC310	5.70	2.31	59.47	542.82	616.03	19.95
	TWC324	5.42	2.35	56.64	530.42	597.90	18.01
2008	TWC310	5.89	2.57	56.37	539.14	605.75	15.00
	TWC324	5.78	2.93	49.31	524.02	579.80	10.77

PR%= percent reduction between measured and predicted values**,** PI%= percent increase between measured and predicted values**.**

Regarding to B2 climate change scenario in the year of 2038s, the reduction in maize yield was lower, compared with its corresponding values under A2 scenario. Yield losses under this scenario could reach 49% and consumptive use could increase to 13%. The tolerance of TWC324 to heat stress was also shown under this scenario in both growing seasons (Table 4).

Table (4): Predicted maize yield and consumptive use under B2 scenario for both two growing season

Growing Season	Hybrid	Maize yield (ton/ha)		PR %	Consumptive use (mm)		PI%
		Measured	Predicted		Measured	Predicted	
2007	TWC310	5.70	3.35	41.23	542.82	651.13	13.49
	TWC324	5.42	3.17	41.51	530.42	625.94	12.72
2008	TWC310	5.89	2.98	49.41	539.14	620.01	12.35
	TWC324	5.78	3.04	47.40	524.02	580.48	10.64

PR%= percent reduction between measured and predicted values**,** PI%= percent increase between measured and predicted values.

At Cameron, A2 and B2 climate change scenarios predicted a decrease in maize yield by 5.9 to 24.7% in the 2020s and by 20.6 to 69.6% in the 2080s (Tingim et al., 2008). Similarly, in Honduras, A2 and B2 climate change scenarios increased yield variability and reduced yield by 0 to 22 % (Díaz-Ambrona et al., 2004). Torriani et al. (2007b) reported that maize yield could decrease by 10% even when positive effects of a doubling of the atmospheric CO_2 concentration are taken into account in Switzerland. They also found that the coefficient of yield variation could increase by as much as a factor or two, implying depressed yield stability and thus higher production risks.

3. Effect of climate change on water use efficiency

Water use efficiency was greatly reduced under climate change conditions, compared with its value under current conditions (Table 5). The highest reduction in water use efficiency in 2007 growing season was found for TWC310 in both growing seasons and under both climate change scenarios.

Table (5): Water use efficiency (kg/m^3) under current climate and the two climate change scenarios

Growing Season	Hybrid	Current Climate	A2 scenario	PR (%)	B2 scenario	PR (%)
2007	TWC310	0.85	0.33	61.34	0.46	46.12
	TWC324	0.82	0.32	60.75	0.45	45.13
2008	TWC310	0.88	0.36	59.45	0.40	54.67
	TWC324	0.86	0.43	49.97	0.43	49.82

PR%= percent reduction between water use efficiency under current climate and under climate change scenarios.

4. Effect of adaptation strategies on water use efficiency

Several adaptation strategies were investigated. Sowing maize two weeks earlier, changing irrigation schedule and the interaction between early sowing and irrigations were tested under climate change scenarios.

4.1. The effect in 2007 growing season

Regarding to 2007 growing season and under A2 climate scenario, results in Table (6) indicated that sowing maize two weeks earlier did not produce a remarkable improvement for TWC310 (+0.53%), with 7.77% increase in the applied irrigation water, which considered a waste of irrigation water. On the contrary, the two irrigation schedules gave the highest water use efficiency (0.37 kg/m^3). Thus, percent of yield improvement was high for I2 (applying the 2nd irrigation 20 days after planting then irrigation every 13 days) (+2.98%), with unnoticeable increase in the applied irrigation amounts (+0.21%). The interaction between irrigation and early sowing increased the applied amount of irrigation water (Table 6) with low percent of yield improvement.

The same trend of the effects of early sowing and the interaction between early sowing and irrigation on maize hybrid TWC310 was observed for TWC324. The best adaptation for maize hybrid TWC310 was I1 (irrigation every 14 days), which increase the percent of yield improvement (+4.24%), increase in the amount of applied irrigation water by 2.69% and have the highest water use efficiency (0.38 kg/m^3) (Table 6).

Table (6): Percent change in maize yield and applied irrigation amounts and water use efficiency in 2007 growing season using A2 climate change scenario

Adaptation strategy	TWC310			TWC324		
	% increase in yield	% change in irrigation	WUE (kg/m^3)	% change in yield	% increase in irrigation	WUE (kg/m^3)
ES	+0.53	+7.77	0.32	-9.23	+12.03	0.25
I1	+1.93	-2.40	0.37	+4.24	+2.69	0.38
I2	+2.98	+0.21	0.37	+3.87	+5.74	0.37
ES x I1	+1.23	+8.37	0.33	+0.18	+8.38	0.33
ES x I2	+4.39	+14.14	0.33	+3.87	+15.76	0.34

ES= early sowing, I1= irrigation every 14 days with total of 7 irrigations, I2= 2nd irrigation applied 20 days after planting then irrigation every 13 days with total of 8 irrigations ES x I1 = interaction between early sowing and irrigation every 14 days, ES x I2= interaction between early sowing and irrigation applied 20 days after planting then every 13 days, WUE= water use efficiency (kg/m^3).

Similarly, the highest water use efficiency could be obtained for TWC310 under I2 (applying the 2nd irrigation 20 days after planting then irrigation every 13 days), where yield improvement was 1.40% with 4.53% increase in the applied irrigation water under B2 climate change scenario. Regarding to TWC324, the highest water use efficiency could be obtained under I1 (irrigation every 14 days) (Table 7).

Table (7): Percent change in maize yield and applied irrigation amounts and water use efficiency in 2007 growing season using B2 climate change scenario

Adaptation strategy	TWC310			TWC324		
	% change in yield	% increase in irrigation	WUE (kg/m^3)	% change in yield	% increase in irrigation	WUE (kg/m^3)
ES	0	+16.18	0.43	+0.92	+14.96	0.43
I1	-3.68	+0.85	0.46	+0.55	+2.17	0.48
I2	+1.40	+4.53	0.49	+0.74	+3.31	0.47
ES x I1	-4.74	+6.56	0.43	-3.51	+5.97	0.43
ES x I2	+4.04	+12.51	0.47	+5.72	+11.59	0.47

ES= early sowing, I1= irrigation every 14 days with total of 7 irrigations, I2= 2nd irrigation applied 20 days after planting then irrigation every 13 days with total of 8 irrigations ES x I1 = interaction between early sowing and irrigation every 14 days, ES x I2= interaction between early sowing and irrigation applied 20 days after planting then every 13 days, WUE= water use efficiency (kg/m^3).

Thus, in 2007 growing season and under the two climate change scenarios, to reduce the harm effect of climate change on maize hybrid TWC310, the 2nd irrigation should be applied 20 days after planting then irrigation every 13 days with total of 8 irrigations, which increase water use. Regarding to maize hybrid TWC324, irrigation every 14 days could result in the highest water use efficiency.

4.2. The effect in 2008 growing season

Relatively high improvement in TW310 in yield could be attained (+14.26%), with relatively high increase in the applied irrigation water (+11.54%), in addition to the highest water use efficiency under I1 (irrigation every 14 days). However, the increase percentage in the applied irrigation water was less than the improvement percentage in the yield (+11.54% versus +14.26% in yield and applied water, respectively). For TW324, the highest water use efficiency could be obtained also under the previously mentioned adaptation option. Thus, less than 1% increase in irrigation water produced 10.21% increase in the yield obtained under A2 climate change scenario (Table 8).

Table (8): Percent change in maize yield and applied irrigation amounts and water use efficiency in 2008 growing season using A2 climate change scenario

Adaptation strategy	TWC310			TWC324		
	% increase in yield	% increase in irrigation	WUE (kg/m^3)	% change in yield	% increase in irrigation	WUE (kg/m^3)
ES	+8.66	+13.87	0.41	+2.42	+6.63	0.43
I1	+1.70	+10.23	0.36	+1.56	+1.14	0.44
I2	+14.26	+11.54	0.46	+10.21	+0.93	0.52
ES x I1	+3.06	+8.10	0.38	+3.63	+1.72	0.46
ES x I2	+11.21	+13.45	0.43	+8.65	+5.4	0.48

ES= early sowing, I1= irrigation every 14 days with total of 7 irrigations, I2= 2nd irrigation applied 20 days after planting then irrigation every 13 days with total of 8 irrigations ES x I1 = interaction between early sowing and irrigation every 14 days, ES x I2= interaction between early sowing and irrigation applied 20 days after planting then every 13 days, WUE= water use efficiency (kg/m^3).

The situation was different under B2 climate change scenarios, where highest water use efficiency (0.47 kg/m^3) was attained under the interaction between early sowing and I2 (applying the 2nd irrigation 20 days after planting then irrigation every 13 days) for TWC310. The increase in the amount of applied water was high (+15.31%) producing 10.19% increase in maize yield. However, I2 attained a little bet lower water use efficiency (0.46 kg/m^3), but with 7.76% increase in the applied irrigation water, compared with what was used under the interaction between early sowing and I2 (15.31% under the interaction between early sowing and I2 minus 7.55% under I2 = 7.76%), with about 6% increase in the yield (Table 9). Therefore, to save irrigation water I2 should be recommended.

Similar situation was obtained for TWC324, where the highest water use efficiency was obtained under I1 (irrigation every 14 days). However, we could save on the applied irrigation water, while attaining the same percentage of yield improvement with a little bit reduction in water use efficiency from 0.53 kg/m^3 to 0.52 kg/m^3 if we use I2 (apply the 2nd irrigation 20 days after planting then irrigation every 13 days) (Table 9).

Table (9): Percent change in maize yield and applied irrigation amounts and water use efficiency in 2008 growing season using B2 climate change scenario

Adaptation strategy	TWC310			TWC324		
	% increase in yield	% increase in irrigation	WUE (kg/m^3)	% increase in yield	% change in irrigation	WUE (kg/m^3)
ES	+6.62	+18.55	0.43	+8.65	+10.28	0.48
I1	+2.89	+4.33	0.45	+8.48	+1.08	0.53
I2	+5.77	+7.55	0.46	+8.30	+0.86	0.52
ES x I1	+4.41	+11.03	0.44	+7.79	+5.60	0.49
ES x I2	+10.19	+15.31	0.47	+9.17	+9.16	0.48

ES= early sowing, I1= irrigation every 14 days with total of 7 irrigations, I2= 2nd irrigation applied 20 days after planting then irrigation every 13 days with total of 8 irrigations ES x I1 = interaction between early sowing and irrigation every 14 days, ES x I2= interaction between early sowing and irrigation applied 20 days after planting then every 13 days, WUE= water use efficiency (kg/m^3).

Hence, in 2008 growing season and under both climate change scenarios, the 2nd irrigation should be applied 20 days after planting then irrigation every 13 days with total of 8 irrigations to both maize hybrids to reduce maize yield losses and increase water use efficiency.

DISCUSSION AND CONCLUSION

Regional assessments of the effects of climate change on crop production are needed at various decision levels, and they are necessary to quantify the economic impacts at the farm and regional scale (Torriani et al., 2007b). Small holder farmers are perhaps the segment of the population whose livelihoods are most susceptible to the impacts of climate variability. The possible increase in climate variability has been recognized in recent years as one of the most critical issues (Mearns et al. 1997; Porter and Semenov 2005). Shifts in yield and yield stability largely depend on assumptions about future emissions, the climate projections, and the downscaling procedure used to generate the climatic data at the regional scale typically required as input to crop models. Olesen et al. (2007) noted that for a site-based analysis the method used for downscaling is more crucial than the choice of a specific climate scenario. They also pointed out that use of climate model outputs directly as input to crop simulation model is appropriate. Thus, our results showed that the downscaling process of HadCM3 model was appropriate to Egypt as it was shown by statistical analysis.

Assessing the possible impact of climate change on production risks is necessary to help decision makers and stakeholders identify and implement suitable measures of adaptation. Our results implied that under current climate change conditions maize hybrid TWC324 produce less yield than TWC310 in both growing seasons (Table 2). However, under climate change condition, maize hybrid TWC324 was more tolerant to heat stress than TWC310 in both growing season, where yield losses for the former were less than the latter (Table 3 and 4). This trend is also hold true for its water use efficiency. This result implies that TWC324 possess traits of yield stability under the variability of climate. This stability also reflected by lower deterioration in water use efficiency under heat stress (Table 5). Thus, to reduce losses in household subsistence production and farm incomes, it is important to identify hybrids acquires such stability to be used in breeding programs. Our results showed that TWC324 is a candidate to be use in breeding programs to produce more tolerant maize hybrids posse high yield stability under heat stress.

In our research, we proposed three different adaptation strategies. The first one was early sowing. In former studies by Tubiello et al., (2000) and Torriani et al., (2007a), early sowing for summer crops had positive effect on yield levels. However, our results indicated that this might not generally be true. Planting maize two weeks earlier increased season length and increased the amount of applied irrigation water, which reduced water use efficiency under both climate change scenarios, compared with other adaptation strategies (Table 6, 7, 8 and 9). This finding is supported with what was found by Torriani et al., (2007b), who stated that delay sowing resulted in a considerable loss in maize productivity.

Changing irrigation schedule could provide a cheap and easy to implement adaptation options, as long as the increased amount is low. Our results showed that either irrigation schedule could reduce yield losses and increase water use efficiency, without low additional amount of irrigation water (Table 6, 7, 8 and 9). This finding emphasis how crucial is to use improved irrigation management practices. These practices could reduce irrigation water losses, enhanced plant's growth characteristics and increase final yield, especially under climate variability conditions.

Finally, technological advances in production, including crop improvements through breeding (Duvick 2005 and Sinclair and Muchow 2001) or planting varieties with higher water use efficiency could reduce yield losses to minimal.

REFERENCES

Díaz-Ambrona, C. G. H., R. G. Pazos and C. O. M. Tovar. 2004. Global climate change and food security for small farmers in Honduras. 4th international Crop Science Congress, Australia, 26 Sep – 1 Oct.

Duvick D. N. 2005. The contribution of breeding to yield advances in maize (Zea Mays L.). Adv. Agron. 86:83–145.

Eid, H. M, S. M. El-Marsafawy, N. G. Ainer, N. M. El-Mowelhi and O. El- Kholi 1997. Vulnerability and adaptation to climate change in maize crop. Meteorology & Environmental Cases Conference 2-6 March.

Eid, H. M., N. G. Ainer, K. M. R. Yousef, M. A. Sherif, W. I. Miseha, and D. Z. El-Sergany. 1992. Climate Change Crop Modeling Study on Maize. 5th Egypt. Botan. Conf. Saint Catherine, Sianai, pp. 93-111.

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.

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.

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.

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

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.

Jones, P. G. and P. K. Thorntonb. 2003. The potential impacts of climate change on maize production in Africa and Latin America in 2055. Global Environ. Change. 13:51-59.

Mearns L. O., C. Rosenzweig, R. Goldberg. 1997. Mean and variance change in Climate scenarios: method, agricultural applications, and measures of uncertainty. Clim. Change. 35:367-396.

Moriondo M, Maselli F, Bindi M. 2007. A simple model of regional wheat yield based on NDVI data. Eur J Agron 26:266-274.

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.

Olesen, J. E., T. R. Carter, C. H. Dı´az-Ambrona, S. Fronzek, T. Heidmann, T. Hickler, T. Holt, M. I. Minguez, P. Morales, J. P. Palutikof, M. Quemada, G. H. Ruiz-Ramos, Rubæk, F. Sau, B. Smith and M. T. Sykes. 2007. Uncertainties in projected impacts of climate change on European agriculture and terrestrial ecosystems based on scenarios from regional climate models. Clim. Change 81:123-143.

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.

Porter J. R. and M. A. Semenov. 2005. Crop responses to climatic variation. Phil Trans. R. Soc. B. 360:2021-2035.

Rivington M., Matthews K.B., Bellocchi G., Buchan K., Stöckle C.O., Donatelli M. 2007. An integrated assessment approach to conduct analyses of climate change impacts on whole-farm systems. Environ. Model Softw. 22:202-210.

Rosenzweig C., Hillel D. 1998. Climate change and the global harvest. Oxford University Press, New York.

Sinclair, T. R., R. C. Muchow. 2001. System analysis of plant traits to increase grain yield on limited water supplies. Agron. J. 93:263-269.

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.

Tingem, M., Rivington M., Azam Ali SN, Colls J. J. 2007. Assessment of the ClimGen stochastic weather generator at Cameroon sites. Africa J Environ Sci Technol 1:86-92.

Tingem, M., Rivington M., G. Bellocchi, Azam Ali SN, Colls JJ. 2008. Effects of climate change on crop production in Cameroon. Clim Res. 36:65-77.

Torriani, D.S., P. Calanca, S. Schmid, M. Beniston, J. Fuhrer. 2007a. 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

Torriani, D., P. Calanca, M. Lips, H. Ammann, M. Beniston, and J. Fuhrer. 2007b. Regional assessment of climate change impacts on maize productivity and associated production risk in Switzerland. Reg. Environ. Change. 16:23-29.

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

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

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