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Studies on Vulnerability of Egyptian Maize Varieties to Future Climatic Changes

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Abstract: Climate variability and change have a direct, often adverse, effect on the quantity and quality of agricultural production. The climate of an area is highly correlated with its vegetation and, by extension, the type of crop that can be cultivated. The current study employed the DSSAT and CropWat simulation models to measure the adverse impacts of climate change on ten maize varieties grown in Egypt. CERES-Maize was embedded in the Decision Support System for Agro-technology Transfer (DSSAT3.5) and used for crop simulations with current and possible future management practices. Equilibrium doubled CO_2 climate change scenarios were derived from the Canadian Climate Center (CCCM) and the Geophysical Fluid Dynamic Laboratory (GFD3) general circulation models (GCMs).Field experiments were done in different agroclimatological zones during 2009 and 2010 seasons to calibrate and validate the models. Changing sowing dates before and after the recommended times were tested as an adaptation strategy to reduce the adverse impact of future climatic change on crop production. The calibration and validation test was carried out in the present study. Simulations of maize varieties were carried out on data covering 25 to 30 years under normal weather conditions as well as under climate change conditions. The 20 maize varieties covered in the study were the followings: twelve SC varieties Nos:10, 114Y,120,122,123,124,125,128,129,155,162 and 166, six TWC varieties Nos: 49,311,314,321,324 and 352; two SK varieties N0s 93Y and 122Y.Simulation studies indicate that climate change will cause negative impacts on crop production. Meanwhile, high temperature resulting from future climatic changes would be another challenge facing agricultural development since it will cause increased crop water requirement. In view of the limited water resources in Egypt, this will affect future agricultural development plans. Adaptation strategies reveal that the most appropriate sowing date is through 10th to 20th May in the Gemmiza and Sids areas and through July in the Mallawy area.Most suitable varieties in future climate are SC10 (Gemmiza), SC129(Sids) and SC166 (Mallawy).

Key words: Climate variability and change · Crop model validation · Maize varieties

INTRODUCTION

Climate variability and change have a direct, often adverse, influence on the quantity and quality of agricultural production. The climate of an area is highly correlated with the vegetation and, by extension, the type of crop that can be cultivated. Temperature, rainfall, humidity, sunshine (day length) are important climatic elements that affect crop production. The overall predictability of these climatic elements is imperative for the day-to-day and medium term planning of farm operations [1]. Agriculture in Egypt is expected to be especially vulnerable to warming of climate. Further warming would reduce crop productivity. These effects are exacerbated by the fact that agriculture and agro-ecological systems are especially prominent in the economy of Egypt as the case with the African countries. Besides, high temperature expected in future climatic changes would be facing agricultural development and cause increased crop water requirements. Since Egyptian

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water resources are limited, this will affect the future agricultural development plans.

Adaptation to climate change in Egypt is a major issue to identify appropriate crop management strategies, maximize benefits and minimize risks associated with agriculture in Egypt. In this connection, Eid and EL-Marsafawy [2] concluded that climate change could decrease national production of many crops (ranging from -11% for rice to -28% for soybeans). At the same time, by the year 2050, water needs for summer crops will be increased up to 8% for maize and 16 % for rice. Simulation studies consider on-farm adaptation techniques such as use of alternatives for existing varieties and optimization of the timing of planting, increasing water and/or nitrogen fertilizer amounts as well as modifying plant population in the field. Fortunately these on-farm techniques may imply few additional costs to the agricultural system. They can partially up to completely compensate for the yield loss or increase the benefit in case of cotton crop by improving it with warmer climate. They may also improve the crop water-use efficiency. In general, there are crop changes that can be considered as adaptation alternatives to climate change. The current Egyptian policy of crop liberalization is giving the farmers the possibility of adapting to more suitable crops in their areas.

The aim of the present study is to assess the impact of climate change on productivity of twenty maize varieties grown in Egypt and their water consumption under different agro- climatological areas in Egypt. In addition, examine of mitigate the potential effects of climate change on crop yields through adaptation strategies.

MATERIALS AND METHODS

Crop Growth Simulation Model: The CERES (Crop-Environment Resource Synthesis) family of crop models is used in the Decision Support System for Agrotechnology Transfer (DSSAT) to predict the performance of crop yield [3]. All crops of these models are designed to use a minimum set of soil, weather, genetic and management information. The models are daily incremented and require daily weather data consisting of maximum and minimum temperatures, solar radiation and rainfall. They calculate crop phasic and morphological development using temperature, day length, genetic characteristics and vernalization where appropriate. Leaf expansion, growth and plant population provide information for determining the amount of light intercepted, which is assumed to be proportional to biomass production. The biomass is partitioned into various growing organs in the plant using a priority system. A water and nitrogen balance submodel provides feedback that influences the development of growth processes. Climate change scenarios for each site were created combining the output of two equilibrium General Circulation Models (the Canadian Climate Change Model "CCCM" and the Geophysical Fluid Dynamics Laboratory "GFDL R-30" model "GFD3") with the daily climate data for each site. The IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations endorse this approach [4].

Baseline Climate and Climate Change Scenarios: Daily maximum and minimum temperatures, precipitation and solar radiation for Lower Egypt (Delta), represented by Gemmiza area (1975 to 1999) and Middle Egypt, represented by Mallawy and Sids areas (1960 to 1989) were used to simulate the impact of climate change on maize varieties in Egypt. All data were collected from the Soil, Water and Environment Research Institute (SWERI) and the Central Laboratory for Agricultural Climate (CLAC), of the Egyptian ARC (Agricultural Research Center).

Crop Models: Crop yield was estimated using the CERES-Maize model [5] imbedded in the Decision Support system for Agro-technology Transfer DSSAT3.5 [6].

Water Consumptive Use: Water consumptive use or Evapotranspiration (ET_{crop}) for maize crop was determined using the CROPWAT4.3 computer program model [7].

RESULTS AND DISCUSSION

Crop Model Validation: The Results in Tables 1 to 3 show a strong matching between the measured values (field data) and the corresponding predicted (simulated) values. The CERES- Maize model is validated for conditions of the study and can be used correctly to find out the impact of climate change on crop yield at the selected sites.

Vulnerability Studies (Simulation Studies): Vulnerability studies were made to assess the potential impacts of climate change on crop yield and water consumptive use (crop evapotranspiration, ET_{crop}).

Table 1: Results of calibration/validation test of maize varieties at Gemmiza area

	Variety									
	V_1		V_2		V_3		V_4		V_5	
Variable	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured
Flowering date(dap*)	61	62	59	62	64	60	64	63	64	62
Grain yield (kg/ ha)	11720	11790	10442	10400	11483	11530	10806	10720	10421	10420
No. of grains/m^2	3321	3569	3630	3880	3682	3688	3549	3867	3884	3951
No. of grains /ear	583	580	637	636	646	641	622	622	681	680

	Variety									
	V_1		V_2		V_3		V_4		V_5	
Variable	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured
Flowering date (dap*)	64	60	64	60	64	62	64	63	59	59
Grain yield (kg/ ha)	10177	10220	10774	10720	11090	11070	12346	12320	9530	9580
No. of grains/m^2	3467	3741	3467	3707	3159	3281	3449	3515	3836	4132
No. of grains /ear	608	608	608	608	554	554	605	605	673	684

V1: SC125 variety V2: SC123 variety V3: SC128 variety V4: SC162 variety V5: SC166 variety V6: SK93Y variety
V7: SK122Y variety V8: SC114Y variety V9: SC10 variety V10: TWC49 variety (*dap=days after planting)

Table 2: Results of Calibration/validation test of maize varieties at Sids area

	Variety											
	V_1		V_2		V_3		V_4		V_5		V_6	
Variable	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured
Floweringdate(dap*)	57	58	57	58	57	57	57	58	57	57	57	56
Grain yield (kg/ ha)	7598	7594	7831	7870	8619	8669	9441	9374	8468	8534	10111	10114
No. of grains/m^2	3617	3617	3572	3589	3617	3743	3311	3416	3357	3292	3546	3586
No. of grains/ear	635	647	627	642	634	643	581	581	589	589	622	629

	Variety											
	V_1		V_2		V_3		V_4		V_5		V_6	
Variable	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured
Flowering date (dap*)	57	56	57	57	62	58	57	58	57	58	57	57
Grain yield (kg/ha)	8225	8198	7499	7426	7445	7392	7021	7065	6301	6283	7232	7258
No. of grains/m^2	3142	3115	3572	3509	3906	3853	3344	3194	3471	3302	3369	3333
No. of grains/ear	551	552	627	628	685	689	587	589	609	609	591	590

V1: SC10 variety V2: SC120 variety V3: SC122 variety V4: SC123 variety V5: SC124 varietyV6: SC129 variety V7: SC155 variety V8: TWC311 variety
V9: TWC314 variety V10: TWC321 variety V11: TWC324 variety V12: TWC352 variety

Table 3: Results of Calibration/validation test of maize varieties at Mallawy area

	Variety									
	V_1		V_2		V_3		V_4		V_5	
Variable	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured
Flowering date (dap*)	65	63	63	63	60	59	64	63	62	63
Grain yield (kg/ ha)	13890	13870	12440	12414	15370	15370	11620	11623	15730	15748
No. of grains/m^2	3627	3918	3269	3335	3731	3694	4211	4011	4873	4512
No. of grains/ear	636	636	585	585	648	648	704	704	792	792

Table 3: Continued

	Variety									
	V_1		V_2		V_3		V_4		V_5	
Variable	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured
Flowering date (dap*)	59	59	59	61	63	64	63	63	59	58
Grain yield (kg/ ha)	12992	12970	13525	13570	12759	12780	13136	13180	12505	12560
No. of grains/m^2	3693	3878	3563	3669	3390	3459	3390	3326	3863	3824
No. of grains/ear	648	648	525	525	595	595	595	595	678	678

V1: SC125 variety V2: SC123 variety V3: SC128 variety
V4: SC162 variety V5: SC166 variety V6: SK93Y variety
V7: SK122Y variety V8: SC114Y variety V9: SC10 variety
V10: TWC49 variety (* dap=days after planting)

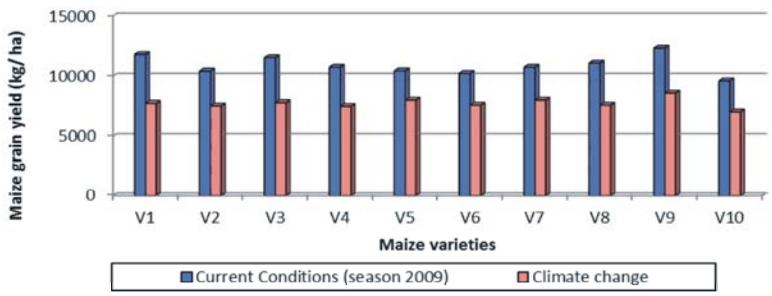

Fig. 1: Simulation of maize grain yeild under climate change conditions compared to current conditions at gemmize area.

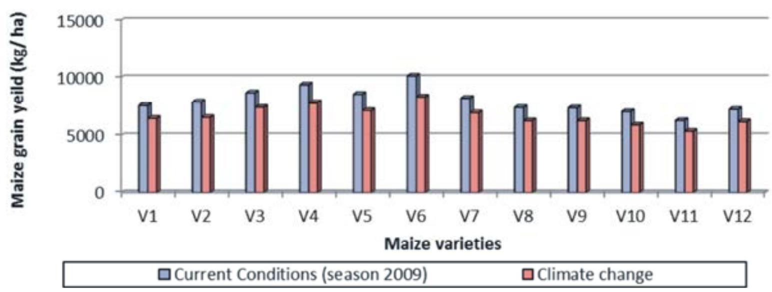

Fig. 2: Simulation of maize grain yeild under climate change conditions compared to current conditions at side area.

Simulation of Maize Grain Yield Under GCMs: The two climate change scenarios resulted in a simulated decrease in yield at the three sites. The decrease percent in grain yield at Gemmiza area reached -35, -28, -33, -30, -23, -26, -26, -32, -30 and -27 % for V_1 up to V_{10}, respectively under climate change conditions (Fig. 1). The SC-166 variety (V_5) is the most tolerant to increased temperature under future climate. The most sensitive variety under future climate is the SC 125 variety (V_1). The main cause for yield decrease is the shortening of the growing period, due to rapid accumulation of thermal units associated with higher temperatures. With respect to Sids, the twelve varieties exhibited decreased yields under future climate (Fig. 2). The decrease percent in grain yield was -15, -17, -14, -17, -16, -18, -15, -16, -15, -16, -14 and -15 % for V_1 up to V_{12}, respectively (Fig. 2). The biggest decrease is given by SC-129 (V_6) and the smallest is by SC-122 (V_3) as well as TWC-352 (V_{11}). Although the decrease in grain yield for V_6 was biggest, this variety showed the highest grain yield under climate change conditions (8312 kg/ha) in Sids.

Concerning Mallawy, the two GCMs scenarios resulted in a decrease in grain yield for the ten varieties. The decrease percent in grain yield was -33, -33, -31, -27, -29, -24, -24, -28, -28 and -25 % for V_1 up to V_{10}, respectively (Fig. 3). The most sensitive varieties to high temperature under future climate are SC 125 (V_1) and SC-123 (V_2) (-33 % each). The most tolerant varieties are SK-93Y (V_6) and SK-122Y (V_7) (-24 % each).

Table 4: Seasonal water consumption (ETcrop) for maize crop under current and future climate change conditions at different locations under study

		Seasonal water consumptive use (ETcrop, mm)		
Scenario	Sowing date	Gemmiza area	Sids area	Mallawy area
Current	1st sowing date	511.97	639.26	617.9
Current +1.5		530.26	660.57	640.26
Current +3.5		555.73	689.16	668.16
Current	2nd sowing date	447.09	569.96	545.57
Current +1.5		463.88	590.03	565.68
Current +3.5		487.14	617.4	591.54

1st sowing date: 6th June, 2nd sowing date: 1st July

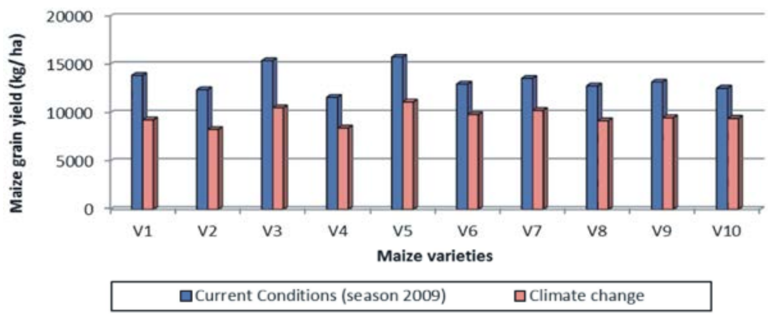

Fig. 3: Simulation of maize grain yeild under climate change conditions compared to current conditions at Mallawy area.

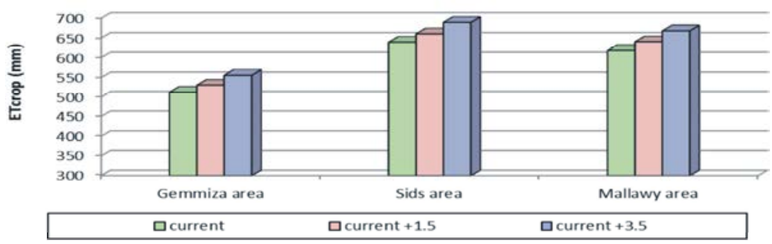

Fig. 4: Water consumptive use (Etcrop, mm) under future climate change scenarios compared to current conditions. (Ist showing date).

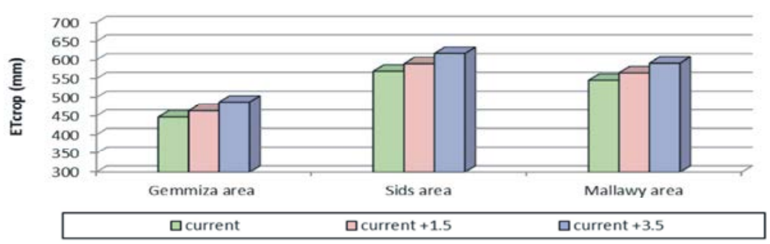

Fig. 5: Water consumptive use (Etcrop, mm) under future climate change scenarios compared to current conditions. (2st showing date).

It can be concluded that climate change would decrease the national production of maize grains in Egypt. The lowest yields under future climate would be given by SC-114Y in Gemmiza, TWC-324 in Sids and SC-125 in Mallawy (with yields of 6995, 5372 and 8279 kg/ha for each variety and site, respectively). On the other hand,the highest yields, would be given by SC-10 in Gemmiza, SC-129 in Sids and SC-166 in Mallawy (with yields of 8573, 8312 and 11129 kg/ ha, respectively).

Simulation of Water Consumption: Simulation studies under current and future conditions were carried out using CropWat 4.3 model. Scenarios of current temperature +1.5°C and current temperature +3.5°C were examined to represent future climatic changes. Results indicate that climate change will increase ET_{crop} in varying degrees according to the agro-climatological zones in Egypt; the seasonal water consumptive use (seasonal ET_{crop}), would slightly increase (Table 4 and Figs. 4 and 5)

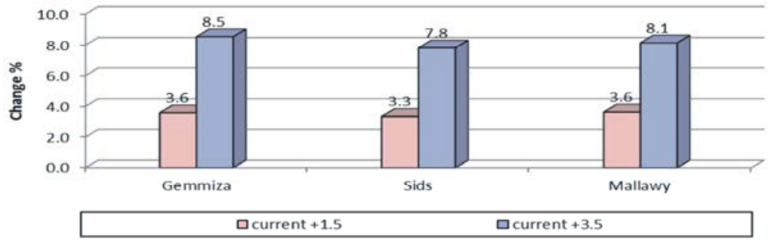

Fig. 6: Change percent of Etcrop under future climate compared to current climate. (I[st] showing date).

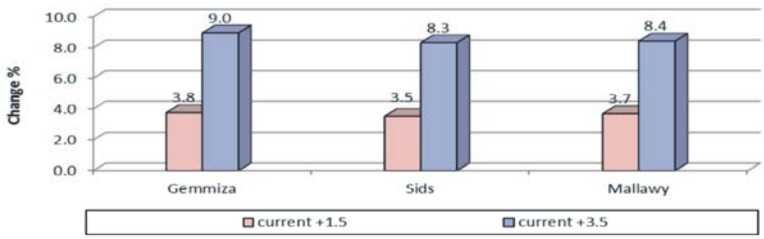

Fig. 7: Change percent of Etcrop under future climate compared to current climate. (2[nd] showing date).

upon increasing the temperature by +1.5°C, with more increase by +3.5°C. The increase percent of ET_{crop} under future climate change are presented in Figs. 6 and 7; and could be summarized as follows for each of the two sowing dates:

- Under 1[st] sowing date: The +1.5°C in temperature would increase ET_{crop} by 3.6, 3.3 and 3.6 % at Gemmiza, Sids and Mallawy areas, respectively; whereas the + 3.5°C, would cause increases of 8.5, 7.8 and 8.1 %, respectively.
- Under 2[nd] sowing date: The +1.5°C in temperature would increase ET_{crop} by 3.8, 3.5 and 3.7 % for Gemmiza, Sids and Mallawy, respectively, whereas the + 3.5°C, would cause increases of 9.0, 8.3 and 8.4 % respectively.

These results are in agreement with those obtained by Eid *et al.* [8] who found that the rise in temperature increased maize ET by 7.9 %, 7.8 % and 8 % for Sakha, Giza and Shandaweel respectively. The rise in temperature would decrease the yields further, particularly at the third growth stage of the crop. Generally, the effect of climate change on maize is to further increase ET and further decrease yields. According to FAO [9], extremes of heat and cold, droughts and floods and various forms of violent weather phenomena and climate change wreak havoc on the agricultural systems and contribute immensely to vulnerability to economic loss, hunger and famine in the world.

Adaptation Studies under Future Climate: Studies of sowing dates (as adaptation measures) on yield were carried out through the DSSAT3.5 model. Four sowing dates (1[st] May, 10[th] May, 20[th] May and 10[th] June) with a base sowing date of 1[st] July were examined under future climate. The choice of these dates is on the basis that the majority of maize in the area is a summer season, while the minority is a Nili season. Summer maize is sown during May and June while Nili maize is sown during July and August.

Gemmiza Area: The optimum sowing date for SC-10,SC-123, SC-125 and TWC49 varieties was 10[th] May (Figs. 8 and 9). The other varieties were superior under Nili season of 1[st] July. The highest decrease in grain yield was shown by SC-125 when sown on 10[th] June (-36 %), while, the lowest decrease was shown by SC-166 when sown on 1[st] July (-23 %). Thus weather plays vital role in maize productivity. Optimum growth temperature frequently corresponds to optimum temperature for photosynthesis. High temperature affects plant development and speeds annual crop growth through the developmental processes.

Sids Area: The optimum sowing date is10[th] May for all varieties except TWC-314 (Figs. 10 and 11). Increases in grain yield for that date were 9, 9, 9, 9, 10, 9, 10, 9, 9, 8, 7, 9 % for SC-10, SC-120, SC-122, SC-123, SC-124, SC-129, SC-155, TWC-311, TWC-314, TWC-324 and TWC-352 varieties, respectively as compared with the 1[st] July date.

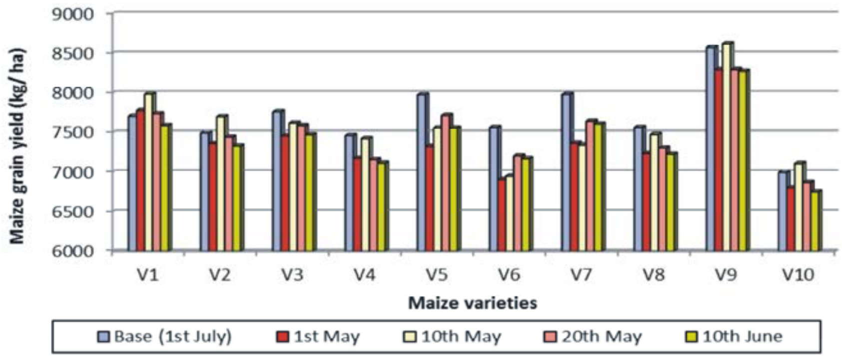

Fig. 8: Simulation of maize grain yield at different showing dates (as adaptation strategy) under climate change conditions at gemmize area.

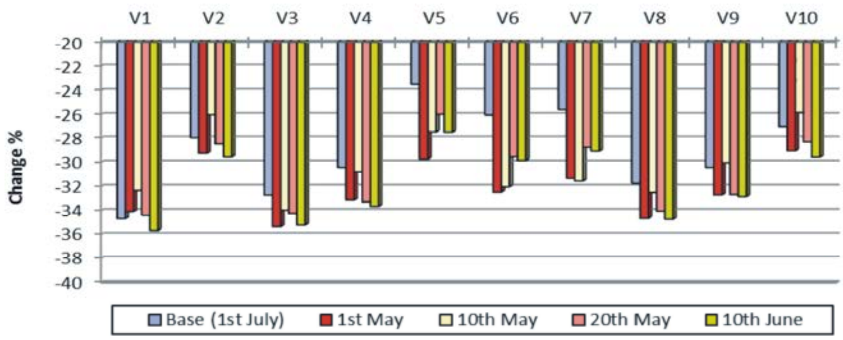

Fig. 9: Change percent of maize yield at different showing dates under climate change conditions compared to current conditions at gemmize area.

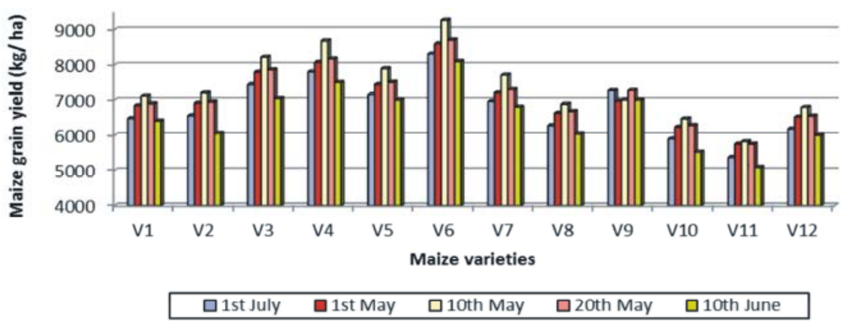

Fig. 10: Simulation of maize grain yield at different showing dates (as adaptation strategy) under climate change conditions at side area.

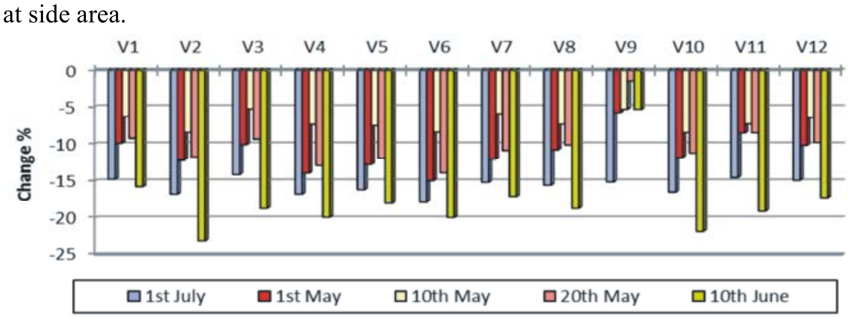

Fig. 11: Change percent of maize yield at different showing dates under climate change conditions compared to current conditions at side area.

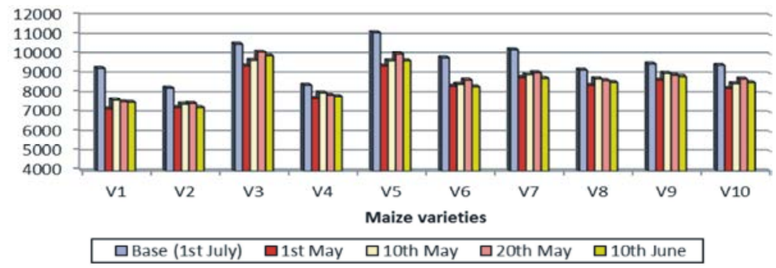

Fig. 12: Simulation of maize grain yield at different showing dates (as adaptation strategy) under climate change conditions at Mallawy area.

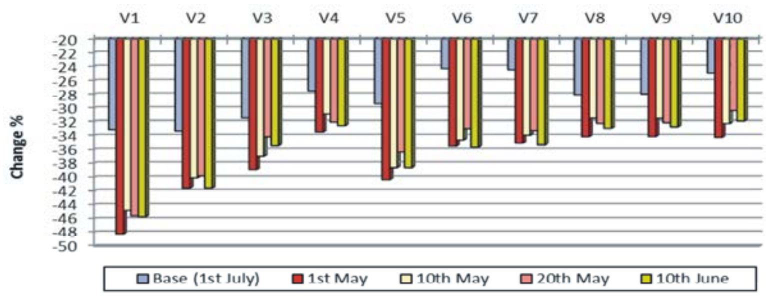

Fig. 13: Change percent of maize yield at different showing dates under climate change conditions compared to current conditions at Mallawy area.

With respect to TWC-314, it was superior with the 20th May date giving 13 % increase. The highest grain yield under climate change was given by SC-120, sown on 10th May (9267 kg/ha); and the lowest was given by TWC-324, sown on 10th June (5085 kg/ha).

Mallawy Area: The optimum sowing date is 1st July Nili date (Figs. 12 and 13). Although summer maize is relatively less prevalent in this area, the most appropriate date under future climatic conditions for such season is 10th May to 20th May. The highest decrease (-48 %) in maize grain yield under climate change was shown by SC-125, sown on 1st May, while, the lowest decrease(-24 %) was by SK-93Y as well as SK-122Y, sown on 1st July. The highest grain yield was given by SC-166 sown on 1st July (11129 kg/ha) and the lowest was by SC-125, sown on 1st July (7186 kg/ha).

Overall Assessment for the Three Areas: Mallawy area seems the most superior in maize production under current and future climatic conditions, with most appropriate sowing date being through the July month. Accordingly, farmers of this area must know that the crop rotation will change and they must rearrange their crop rotation to get maximum benefit from the crop rotation of their decision. The highest grain yield in the Mallawy area under climate change conditions was shown by SC-166 variety (11129 kg/ha).As for the Gemmiza and Sids areas, the most appropriate sowing date is 10th to 20th May and the most suitable varieties in future climate are SC-10 for Gemmiza (8622 kg/ha) and SC-129 for Sids (9267 kg/ha). Doorenbos and Kassam [10] (FAO No. 33) stated that, adaptability of varieties in different climates varies widely and that successful cultivation depends on the right choice of varieties so that the length of crop growing period matches the length of its growing season and the purpose for which it is grown. Trials aiming at selection of the most suitable variety (varieties) for given areas are therefore of a vital importance. When the mean daily temperatures during the growing season are greater than 20°C, early grain varieties take 80 to 110 days and medium varieties 110 to 140 days to maturity. When grown as a vegetable, these varieties are 15 to 20 days shorter. On the other hand, when the mean daily temperatures are below 20°C, there is an extension in days to maturity ranging from10 to 20 days for each 0.5°C decrease depending on the variety and at 15°C maize grain crop takes 200 to 300 days to maturity. With a mean daily temperature of 10°C to 15°C, maize is mostly grown as a forage crop because of the problem of seed set and grain maturity under cool conditions. For germination the lowest mean daily temperature is about 10°C, with 18°C to 20°C being optimum. The crop is very sensitive to frost, particularly in the seedling stage but it tolerates hot and dry atmospheric conditions so long as sufficient water is available and temperatures are below 45°C. Temperature requirements, expressed as the sum of mean daily temperatures, for medium varieties are 2500 to 3000 degree days, while, early varieties require about 1800 and late varieties 3700 or more.

CONCLUSIONS AND POLICY SUGGESTIONS

Global Circulation Models (GCMs) and the dynamic crop growth model CERES- Maize and CropWat model were used to assess the potential impact of climate change on maize crop productivity and its water consumption in Egypt. Based on two climate change scenarios considered in the study there were simulated decrease in maize yield and increase in water consumption. The lowest maize yield under future climate was found for TWC-49 in Gemmiza,TWC-324 in Sids and SC-123 in Mallawy (with respective yields of 6995, 5372 and 8279 kg/ha). The highest yields were given by SC-10 in Gemmiza registered for V_9, SC-129 in Sids V_6 and SC-166 in Mallawy (with respective yields of 8573, 8312 and 11129 kg/ha). Increasing water consumptive use under future climate change ranged from 3 to 9 % depending on the area and the crop variety. Adaptation studies, indicate that maize sowing date must be between 10th to 20th May in Gemmiza and Sids and through July in Mallawy in order to minimize unfavourable effects of climate change.

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