Impact of Climate Change on the Behaviour of Some Rice varieties in Egypt

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Abstract: Climate change may affect food systems in several ways ranging from direct effects on crop production (e.g. changes in rainfall leading to drought or flooding, or warmer or cooler temperatures leading to changes in the length of growing season), to changes in markets, food prices and supply chain infrastructure. Inclusion of climatic risks in the design and implementation of development initiatives is necessary to reduce vulnerability and enhance sustainability**.** Enhancement of adaptive capacity is a necessary condition for reducing vulnerability, particularly for the most vulnerable regions, nations, and socioeconomic groups. Activities required for the enhancement of adaptive capacity are essentially equivalent to those promoting sustainable development. This study employed the DSSAT simulation model to measure the adverse impacts of climate change on some rice varieties in Egypt. CERES-Rice model, embedded in the Decision Support system for Agrotechnology Transfer (DSSAT3.5) were used for the 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 carried out at different agroclimatological zones in 2009 and 2010 seasons to calibrate and validate the models. Simulation of rice productivity was done on data covering 25 years under the normal weather conditions and climate change conditions. Results indicated that future climatic changes would decrease the national production of rice crop in Egypt. The change percent in productivity of different rice varieties ranging from -34 to -47 % at Gemmiza area and -26 to -36 % at Sakha area compared with their productivity under current conditions. The highest tolerant variety to high temperature under future climate was found for V_2 at the two areas. In addition, increase rice water consumption at Gemmiza area around 3.5 % and 8.0 % with increasing temperature 1.5°C and 3.5°C, respectively. However, at Sakha area it was increased around 3.0 % and 7.5 % for the same respective increasing temperatures. Concerning rice adaptation strategies, results indicated that select optimum sowing date could reduce the potential risks of climate change up to about 14 % at Gemmiza area and up to about 6 % at Sakha area. The optimum sowing date at Gemmiza and Sakha was found for 1st April and 25th April, respectively. On the other hand, more reduction of rice yield will be happened under sacristy of water supply. The reduction will be ranged from 41 to 57 %. However, increasing irrigation water up to 20 % could increase rice yield up to 22%. The highest variety under excess water supply is V_2 at the two sites under study.

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1. Introduction

Climate change affects agriculture and food production in complex ways. It affects food production directly through changes in agro-ecological conditions and indirectly by affecting growth and distribution of incomes, and thus demand for agricultural produce. Impacts have been quantified in numerous studies and under various sets of assumptions **(IPCC, 2007a).**

Assessment of the effects of global climate changes on agriculture might help to properly anticipate and adapt farming to maximize agricultural production **(Fraser, 2008).**

Climate change may affect food systems in several ways ranging from direct effects on crop production (e.g. changes in rainfall leading to drought or flooding, or warmer or cooler temperatures leading to changes in the length of growing season), to changes in markets, food prices and supply chain infrastructure **(Gregory *et al.*, 2005).**

The impacts of climate change on agriculture activities have been shown to be significant for low input farming systems in developing countries in Africa **(Rosenzweig and Parry, 1994; McGuigan *et al.,* 2002).** Furthermore, tropical regions in developing countries are usually characterized by poor marginal soils that cover extensive areas, making them unusable for agriculture, leaving the developing countries particularly vulnerable to potential damage from environmental changes (**Mendelsohn and Dinar 1999**).

By the end of the 21st century, the Arab region will face an increase of 2 to 5.5ºC in the surface temperature. This increase will be coupled with a projected decrease in precipitation up to 20%. These projected changes will lead to shorter winters and dryer summers, hotter summers, more frequent heat wave occurrence, and more variability and extreme weather events occurrence (**IPCC, 2007b**).

Climate change could exacerbate the food security issues that Egypt already faces. Egypt's report to the UNFCCC states that "climate change may bring about substantial reductions in the national grain production." Grain is only one of Egypt's food sources endangered by unmitigated climate change. Even without climate change, by 2020 Egypt is projected to import 300-360 thousand metric tons of fish, which is a third of its projected domestic production. However, climate change could drastically increase Egypt's trade imbalance in fish products while simultaneously tightening the global fish market. As the sea level rises, salt water will infiltrate the North Egyptian lakes where 60% of Egypt's fisheries are located.

Enhancement of adaptive capacity is a necessary condition for reducing vulnerability, particularly for the most vulnerable regions, nations, and socioeconomic groups. Activities required for the enhancement of adaptive capacity are essentially equivalent to those promoting sustainable development. Climate adaptation and equity goals can be jointly pursued by initiatives that promote the welfare of the poorest members of society- for example, by improving food security, facilitating access to safe water and health care, and providing shelter and access to other resources. Development decisions, activities, and programs play important roles in modifying the adaptive capacity of communities and regions, yet they tend not to take into account risks associated with climate variability and change. Inclusion of climatic risks in the design and implementation of development initiatives is necessary to reduce vulnerability and enhance sustainability. (**IPCC, 2001**).

In the same direction, **Eid and EL-Marsafawy (2002)** studied vulnerability and adaptation of climate change on some main crops in Egypt. They found that climate change could decrease national production of many crops (ranging from-11% for rice to -28% for soybeans) by the year 2050 compared to current production. At the same time, water needs for summer crops will be increased up to 8% for corn and up to 16 % for rice by the year 2050 compared to their current water needs.

The simulation studies considered on-farm adaptation techniques such as use of alternatives 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 that may imply few additional costs to the agricultural system, can partially up to completely compensate for the yield losses or increase more the benefit in case of cotton crop improvement with the 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 recent policy of crop liberalization is giving the farmers the possibility of adapting to more suitable crops in each area.

Specific goals

The study objectives follow the general objectives as set by FAO and IFAD project "Climate change risk management" UNJP/EGY/022. These redefined objectives are impact of climate change on some main food crops in Egypt and mitigate the potential effects of climate change on crop yields through adaptation strategies.

2. Materials and Methods

Vulnerability studies (Simulation studies):

Vulnerability studies were made to assessment the potential impacts of climate change on crop yield and water consumptive use (crop evapotranspiration, ET crop). The potential impact of climate change on the yield and ET crop were carried out through DSSAT3.5 models and CropWat model, respectively.

Input data

Climatic data and climate change scenarios

Daily maximum and minimum temperatures, precipitation, and solar radiation for Gemmiza and Sakha areas (1975 to 1999) were used to simulate the impact of climate change on some rice varieties in Egypt. All data were collected from Soil, Water & Environment Res. Institute, SWERI, and Central Laboratory for Agricultural Climate, CLAC, ARC, Ministry of Agriculture, unpublished data).

Using 2GCMs, the observed climate data were modified to create climate change scenarios. The general circulation models (GCMs) were developed by the Canadian Climate Center Model (CCCM) (**Boer *et al.*,1992**) and the GFD3 model from the Geophysical Fluid Dynamic Laboratory (**Manabe and Wetherald, 1987**) were used. The Intergovernmental Panel on Climate Change (IPCC) Technical Guidelines for Assessing Climate Change Impacts and Adaptations endorse this approach (**IPCC, 1994**). The two equilibrium general circulation models used in this study to create the climate change scenarios at the high level end of the IPCC range (1.5^{o}C to 3.5^{o}C).

Crop models

Crop yield was estimated with the CERES-Rice model (Singh *et.al.*, 1998) imbedded in the Decision Support system for Agrotechnology Transfer DSSAT3.5 (**Tsuji *et al.*, 1998**).

The CERES models simulate crop growth and development, soil water dynamics, and soil nitrogen dynamics in response to weather, soil characteristics, cultivar characteristics and crop management. This version simulates barley, maize, millet, sorghum, rice and wheat crops. In addition, CERES-Rice, could simulates both low land (flooded) and upland rice crops.

Calibration and validation sites

The CERES-Rice model were validated by comparing measured data (field data) of physiological maturity date, grain yield (kg/ ha), grain weight (g) to simulated values (predicted values by the model) to calibrate and validate the model to the conditions of the study.

Crop water Use

Water consumptive use or Evapotranspiration (ET crop) for rice crop was calculated according to **Doorenbos and Pruitt (1977)** as follows:

ETcrop = ET0 * Kc

Where:

ETcrop: Crop evapotranspiration

ET0: Reference crop evapotranspiration

Kc: Crop coefficient

Reference crop evapotranspiration (ET0) was calculated using CROPWAT4.3 model, and crop coefficient (Kc) was obtained from the FAO paper No. 33 (**Doorenbos and Kassam, 1986**), and modified for the crop under study.

Adaptation Studies:

Studies of adaptation strategy evaluation to climate change were carried out using DSSAT3.5 simulation model. To identify appropriate crop management strategies, maximize benefits and minimize risks associated with maize and rice crops production, the following treatments were suggested:

Sowing dates: To select the optimum sowing date under climate change conditions, four sowing dates in addition to the base sowing date have been tested, these are:

- Base sowing date (25thApril).
- Sowing on 1stApril
- Sowing on 10thApril
- Sowing on 20thApril
- Sowing on 10thMay

Irrigation water amounts: To determine the impact of excess or deficit irrigation under future climate the following treatments were examined:

- Base amount
- Base amount -20%
- Base amount +20%

3. Results and Discussion

Crop model validation

CERES- Rice model was used to carry out the calibration and validation test for rice crop (Oryzasativa) at Gemmiza and Sakha areas. Results as recorded in Tables 1 and 2 indicated that the measured data (field data) of physiological maturity date, grain yield and grain weight were more harmonizing with the corresponding predicted values (simulated by the model). According to these results, CERES- rice model was considered validated for the conditions of the study

Table 1: Calibration and validation test for rice crop at Gemmiza area

Varieties	V_1		V_2		V_3	
Variable	Predicted	Measured	Predicted	Measured	Predicted	Measured
Panicle initiation date (dap)	23	...	37	...	38	...
Flowering date (dap)	58	...	71	...	72	...
Physiol. Maturity (dap)	95	95	100	100	105	105
Grain yield (kg/ha) at 14% H_2O	8169	8180	9623	9620	9917	9920
Wt. Per grain (g)	0.030	0.027	0.030	0.023	0.030	0.029

Notes: V1: Giza177 variety V2: Giza178 variety V3: Sakha101 variety

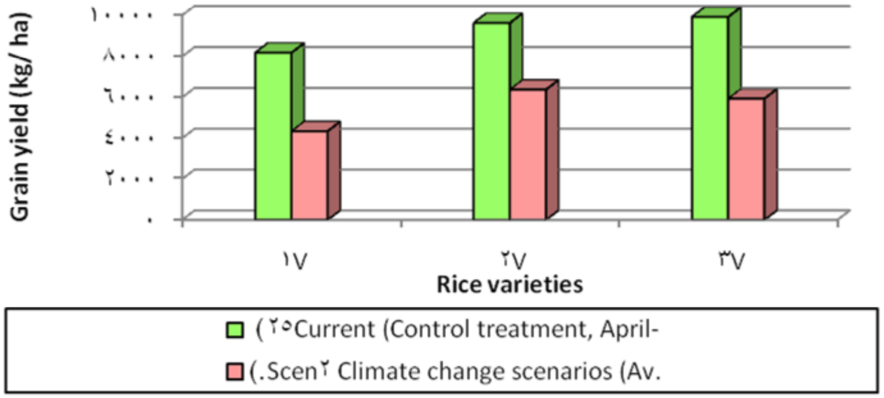
Table 2: Calibration and validation test for rice crop at Sakha area.

Varieties	V_1		V_2		V_3	
Variable	Predicted	Measured	Predicted	Measured	Predicted	Measured
Panicle initiation date (dap)	37	...	37	...	38	...
Flowering date (dap)	71	...	71	...	72	...
Physiol. Maturity (dap)	125	125	135	135	145	145
Grain yield (kg/ha) at 14% H_2O	9939	9980	10275	10270	11048	11000
Wt. Per grain (g)	0.030	…	0.030	…	0.030	…

Vulnerability studies (Simulation studies):
Simulation of rice grain yield under GCMs.

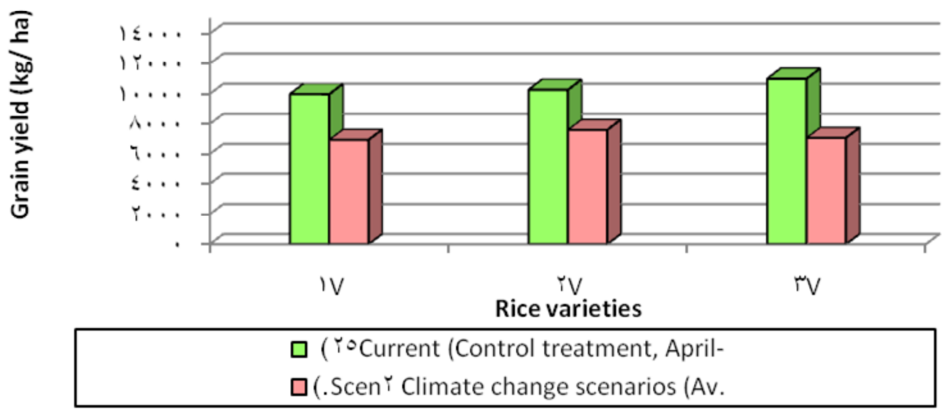
Future climatic changes would be decreased rice grain yield at the selected sites. The change percent of grain yield at Gemmiza area would reach about -47, -34 and -40 % for V_1, V_2 and V_3, respectively compared to their production under current conditions (Fig. 1). It could be concluded that the variety of V_2 is the most tolerant and V_1 is the most vulnerable under future Gemmiza conditions.

Fig . 1: Simulation of rice grain yield under climate change conditions compared to current conditions at Gemmiza area.



Concerning Sakha area, results as recorded in Fig. 2 indicated that future climatic changes will reduce the productivity of selected rice varieties under study at rates ranging from 26 to 36 % compared to the productivity of these varieties under current conditions. The highest tolerant variety and lowest one were found for V_2 and V_3, respectively.

Fig . 2: Simulation of rice grain yield under climate change conditions compared to current conditions at Sakha area.



It could be concluded that, climate change would decrease the national production of rice crop in Egypt. The change percent in productivity of different rice varieties under study under future climate change conditions compared to current climate ranging from -34 to -47 % at Gemmiza area &. -26 to -36 % at Sakha area. The highest tolerant variety to high temperature under future climate was found for V_2 at the two areas.

In this connection, the response of rice to temperature differs with variety. In general, below 12°C germination does not occur. Rice seedling from the nursery bed can be transplanted to the field when the mean daily temperature is about 13 to 15°C. Temperatures between 22 and 30°C are required for good growth at all stages but during flowering and yield formation small differences between day and night temperatures are required for good yield. Optimum day time air and water temperatures for the growth of rice are in the range of 28 to 35°C. The decrease of temperature of water during the night under hot conditions helps to maintain favourable water temperatures during daytime but should not decrease below 18°C (FAO No. 33, Doorenbos and Kassam, 1986).

Simulation of rice water consumption (crop evapotranspiration, ETcrop) under current and future climate change conditions.

Simulation of ET for rice crop at different sowing dates under current and different scenarios of climate change are presented in Tables 3 - 8. Scenarios of current temperature +1.5°C and current temperature +3.5°C were examined to represent future climatic changes.

Results as recorded in Table 3 indicated that monthly ETcrop at Gemmiza area started low at the beginning of the growing season, then increased gradually and reached maximum ET at mid-season (in June) and declined again at the end of growing season. Results indicated also that ETcrop was increased with the early sowing date as compared with the late sowing date.

An increase in temperature of 1.5°C would increase seasonal ETcrop by 3.4, 3.4, 3.4 and 3.5 % for sowing on April 25, May 6, May 16 and May 28, respectively as compared with ET under current conditions (see Tables 3 and 4). However, with a 3.5°C increase, ET would increase by 8.1, 8.1, 8.2 and 8.3 %, for the same respective sowing dates compared with current ET (Tables3 and 5).

Table 3: Monthly and seasonal water consumption (ETcrop) for rice at different sowing dates under current conditions, Gemmiza area.

Month	Sowing dates			
	Apr-25	May-06	May-16	May-28
April	25.3	0.0	0.0	0.0
May	178.7	144.1	86.5	17.3
June	207.4	207.4	207.4	207.4
July	179.5	179.5	179.5	179.5
August	123.7	166.8	166.8	166.8
September	0.0	13.5	58.6	112.8
Seasonal ET	714.5	711.3	698.7	683.7

Table 4: Monthly and seasonal water consumption (ETcrop) for rice at different sowing dates under climate change conditions (current +1.5°C), Gemmiza area.

Month	Sowing dates			
	Apr-25	May-06	May-16	May-28
April	26.2	0.0	0.0	0.0
May	184.5	148.8	89.3	17.9
June	214.2	214.2	214.2	214.2
July	185.7	185.7	185.7	185.7
August	128.1	172.7	172.7	172.7
September	0.0	14.0	60.8	117.0
Seasonal ET	738.6	735.4	722.7	707.4

Table 5: Monthly and seasonal water consumption (ETcrop) for rice at different sowing dates under climate change conditions (current +3.5°C), Gemmiza area.

Month	Sowing dates			
	Apr-25	May-06	May-16	May-28
April	27.5	0.0	0.0	0.0
May	192.7	155.4	93.2	18.6
June	223.9	223.9	223.9	223.9
July	194.4	194.4	194.4	194.4
August	134.1	180.7	180.7	180.7
September	0.0	14.8	64.0	123.0
Seasonal ET	772.5	769.2	756.2	740.7

Concerning Sakha area, results as tabulated in Tables 6 and 7 show that an increase in temperature of 1.5°C would increase rice ET by 2.9, 3.1, 3.1 and 3.2 % for sowing on April 25, May 6, May 16 and May 28, respectively. At the same time, temperature increases of 3.5°C will increase rice ET by 7.3, 7.4, 7.6 and 7.7 %, for the same respective sowing dates (Tables 6 and 8).

Table 6: Monthly and seasonal water consumption (ETcrop) for rice at different sowing dates under current conditions, Sakha area.

Month	Sowing dates			
	Apr-25	May-06	May-16	May-28
April	28.1	0.0	0.0	0.0
May	193.0	155.7	93.4	18.7
June	221.8	221.8	221.8	221.8
July	183.2	183.2	183.2	183.2
August	126.3	170.2	170.2	170.2
September	0.0	13.6	58.8	113.0
Seasonal ET	752.3	744.4	727.3	706.8

Table 7: Monthly and seasonal water consumption (ETcrop) for rice at different sowing dates under climate change conditions (current +1.5°C), Sakha area.

Month	Sowing dates			
	Apr-25	May-06	May-16	May-28
April	29.0	0.0	0.0	0.0
May	198.5	160.1	96.0	19.2
June	227.9	227.9	227.9	227.9
July	188.8	188.8	188.8	188.8
August	130.9	176.4	176.4	176.4
September	0.0	14.1	61.0	117.3
Seasonal ET	775.0	767.2	750.1	729.5

Table 8: Monthly and seasonal water consumption (ETcrop) for rice at different sowing dates under climate change conditions (current +3.5°C), Sakha area.

Month	Sowing dates			
	Apr-25	May-06	May-16	May-28
April	30.1	0.0	0.0	0.0
May	206.3	166.4	99.8	20.0
June	236.9	236.9	236.9	236.9
July	196.9	196.9	196.9	196.9
August	137.1	184.8	184.8	184.8
September	0.0	14.8	64.0	123.0
Seasonal ET	807.2	799.6	782.3	761.5

From the previous results it can be concluded that, increase rice ET under future climatic changes at Gemmiza area around 3.5 % and 8.0 % with increasing temperature 1.5°C and 3.5°C, respectively. However, at Sakha area rice ET was increased around 3.0 % and 7.5 % for the same respective increasing temperatures.

Adaptation Studies for rice crop under future climatic changes conditions.

Studies of sowing dates and irrigation water amounts (as adaptation measures) on rice yield were carried out through DSSAT3.5 model. Four sowing dates (1st April, 10th April, 20th April and 1st May) with base sowing date (25th April) were examine to determine the optimum sowing date could be applied to obtain maximum yield. In addition, deficit and excess irrigation water amount were carried out to determine the most appropriate amount of irrigation water could compensation the reduction in crop productivity under conditions of high temperature. Also, what would happen under the shortage of water resources under future or if this crop subjected to shortage in quantity of water added to him.

Adaptation under different sowing dates

Effect of simulated sowing dates on rice crop at Gemmiza area

Results as indicated in Fig.3 showed that the optimum sowing date for all varieties under study was found for early sowing date (1st April). However, the lowest one was registered for late sowing date (1st May). The reduction of rice grain yield under late sowing dates (10th April, 20th April, 25th April (Base) and 1st May) compared with early sowing date (1st April) reached about 4.7, 10.0, 11.7, 13.8 % for V_1; 2.3, 4.0, 5.6, 11.4 % for V_2 and 0.3, 3.0, 3.7, 4.7 % for V_3.

In the same direction, the highest change percent of rice grain yield under future climate compared with current climate (Fig.4) was found for V_1 when sown on 1st May (-48 %), however the lowest one was obtained for V_2 when sown on 1st April (-30 %).

Fig. 3: Simulation of rice grain yield at different sowing dates (as adaptation strategy) under climate change conditions at Gemmiza area.

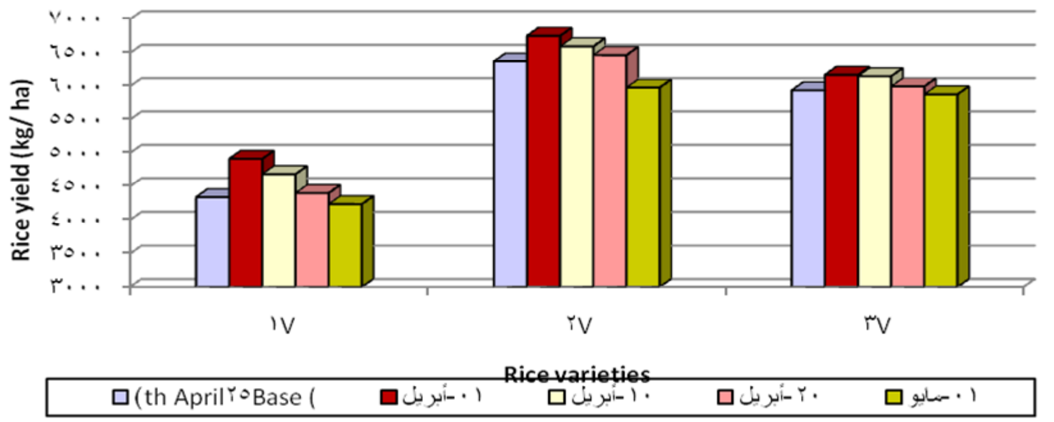
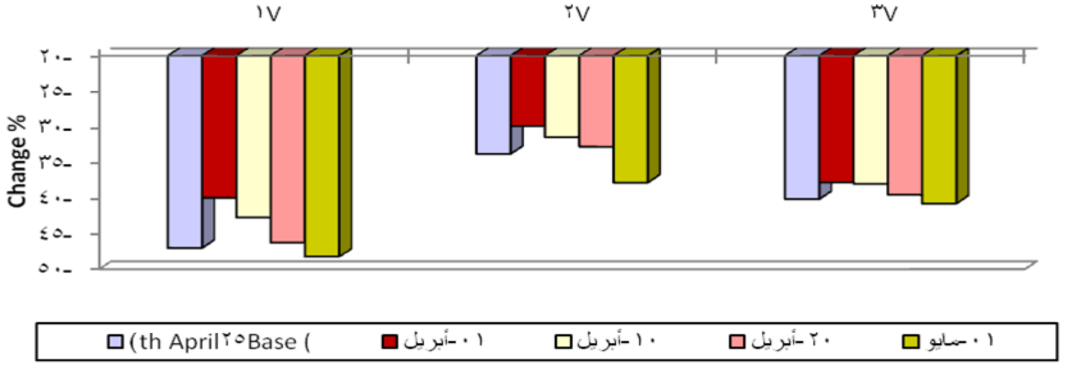


Fig. 4: Change percent of rice yield at different sowing dates under climate chagne conditions compared to current conditions at Gemmiza area.



Effect of simulated sowing dates on rice crop at Sakha area

Results as presented in Fig.5 indicated that the optimum sowing date for all varieties under study was found for 25th April compared with the other sowing dates. The reduction of rice grain yield for the respective sowing dates of 1st April, 10th April, 20th April and 1st May compared with 25th April (Base sowing date under future climate) reached about 4.8, 2.8, 2.0, 1.5 % for V_1; 4.7, 3.8, 3.0, 5.6 % for V_2 and 6.2, 4.3, 3.0, 3.5 % for V_3.

At the same time, results as recorded in Fig.6 revealed that the highest change percent of rice grain yield under future climate compared with current climate was found for V_3 when sown on 1st April (-40 %), however the lowest one was obtained for V_2 when sown on 25th April (-26 %).

Fig. 5: Simulation of rice grain yield at different sowing dates (as adaptation strategy) under climate change conditions at Sakha area.

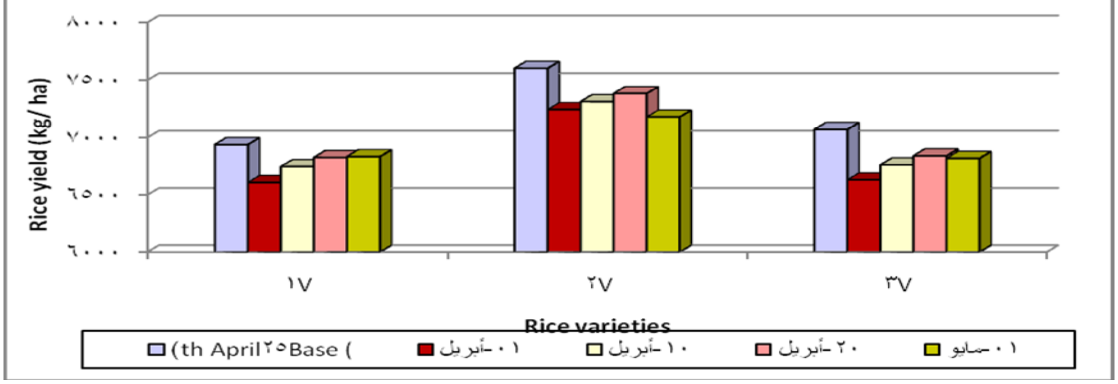
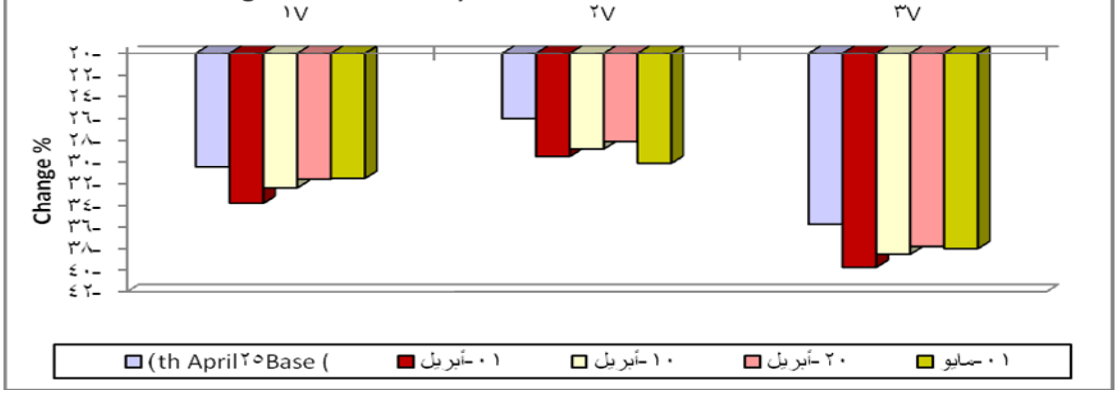


Fig. 6: Change percent of rice yield at different sowing dates under climate chagne conditions compared to current conditions at Sakha area.

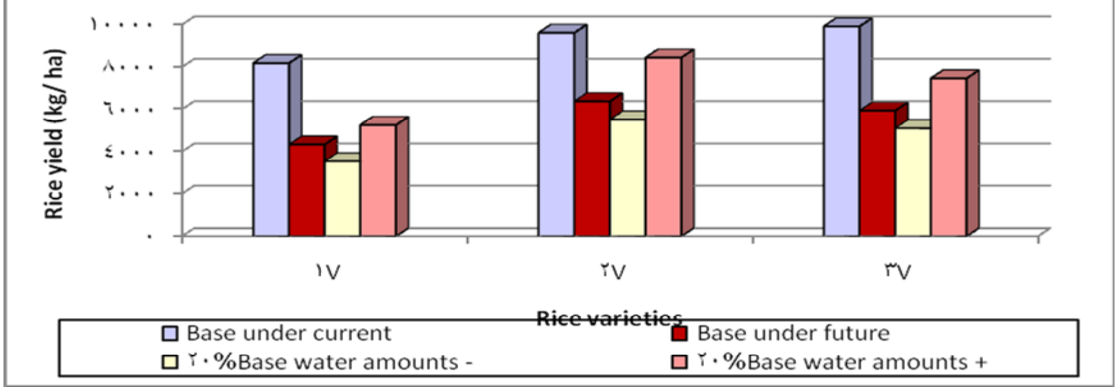


Adaptation under different irrigation water amounts

Effect of simulated irrigation water amounts on rice crop at Gemmiza area

Results at Gemmiza area as presented in Figs. 7 and 8 indicated that different irrigation water amount (excess or deficit) affect rice productivity. Under deficit irrigation (base amount -20%), the reduction in grain yield ranging from 43% up to 57%. The most sensitive variety to water deficit was found for V_1 which registered more reduction in grain yield. However, under excess of irrigation water (base amount +20%), rice yield increased 11 – 22 % as compared with base treatment under future climate. The highest rice yield under excess of water was found for V_2.

Fig. 7: Simulation of rice grain yield at different water amounts (as adaptation strategy) under climate change conditions at Gemmiza area.



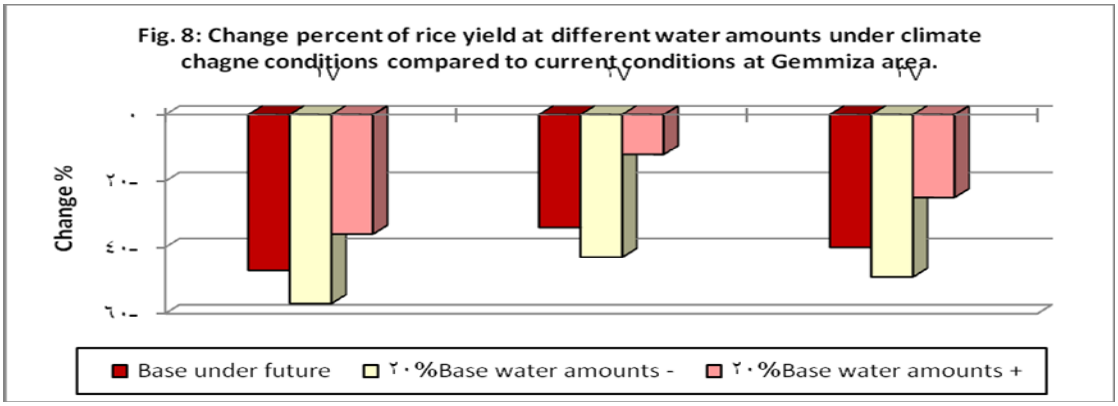


Fig. 8: Change percent of rice yield at different water amounts under climate chagne conditions compared to current conditions at Gemmiza area.

Effect of simulated irrigation water amounts on rice crop at Sakha area

Results as recorded in Fig.9 and 10show that deficit irrigation water could be reduced rice yield at Sakha area ranging from 41% up to 49 %. The most sensitive variety to water deficit was found for V_3 which registered more reduction in rice yield. However, under increasing irrigation water amount 20 %, rice yield increased 12 – 16 % as compared with base treatment. The highest rice yield under excess of water was found for V_2.

It can be concluded that changing sowing date could reduce the potential risks of climate change for rice crop up to about 14 % at Gemmiza area and up to about 6 % at Sakha area. The optimum sowing date at Gemmiza and Sakha was found for 1st April and 25th April, respectively. On the other hand, more reduction of rice yield will be happened under sacristy of water supply. The reduction will be ranged from 41 to 57 %. However, increasing irrigation water up to 20 % could increase rice yield up to 22%. The highest variety under excess water supply is V_2 at the two sites under study.

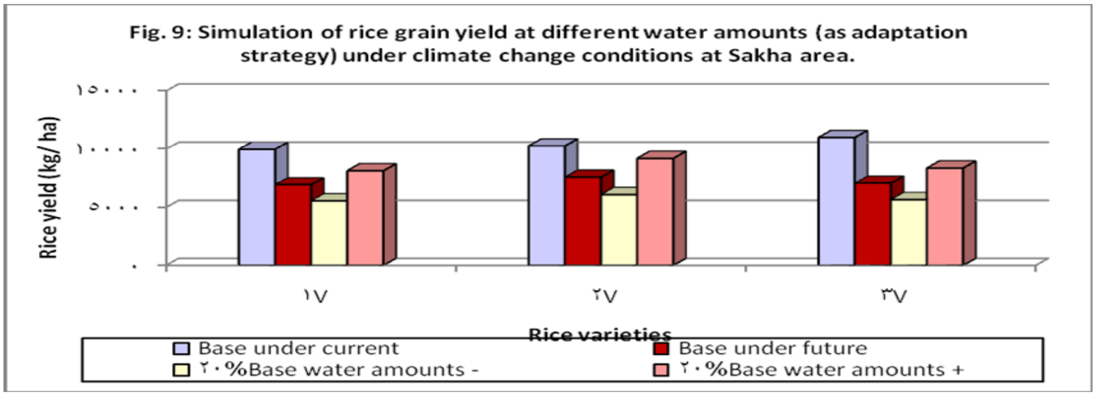


Fig. 9: Simulation of rice grain yield at different water amounts (as adaptation strategy) under climate change conditions at Sakha area.

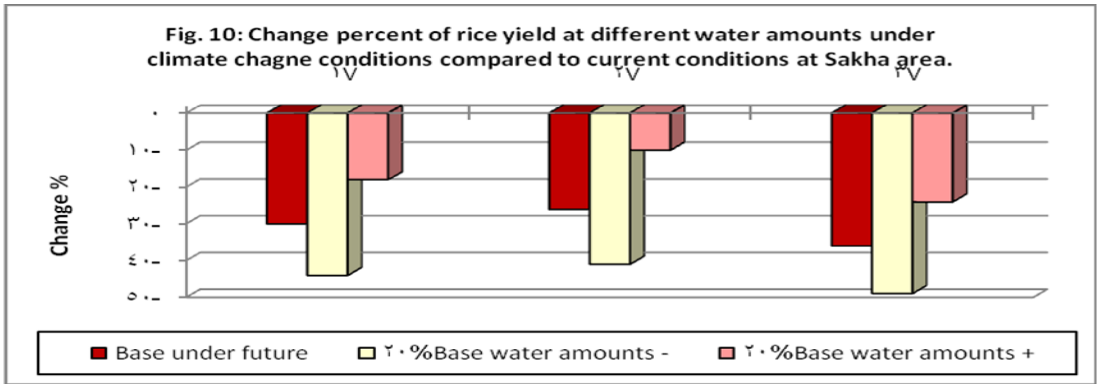


Fig. 10: Change percent of rice yield at different water amounts under climate chagne conditions compared to current conditions at Sakha area.

Conclusions and policy suggestions

The potential impact of climate change on rice varieties and their water consumption was evaluated by simulating under different climatic scenarios in the Nile Delta (Lower Egypt). Under GCM climate change scenarios, yield of rice varieties decreased in comparison to current climate conditions at all areas under study. At the same time, water consumptive use will be increased for all varieties. According to the present simulation study, the impact of climate change on rice yields would be severe in comparison with current climate conditions.

Future adaptation strategies to climate change could defeat the adverse impact of climate change on crop production. Results of adaptation studies illustrated that the suitable varieties, suitable sowing date, increasing 10 to 20% of amounts of irrigation water could be reduced the harmful impacts of climate change on crop production.

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