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# Impact of Weather Extremes on Wheat Production in Egypt

**Elsayed M.[1], A.A. Khalil[1], M.K. Hassanein[2], M.A Fahim[3] and M.M. Abdel-Wahab[4]**

[1]*Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center (ARC), Egypt.*
[2]*Field Crop Research Institute (FCRI), Agricultural Research Center (ARC), Egypt.*
[3]*Climate Change Information Center & Renewable Energy & Export system, Egypt.*
[4]*Faculty of science - Cairo University, Egypt.*

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## ABSTRACT

A sudden rise in air temperature can lead to a great loss in productivity of the wheat crop.to study the interaction between such factors, many crop models were designed, tested, and evaluated in order to simulate possible losses caused by extreme weather variability. The aim of this study was to evaluate the impacts of extreme temperature variabilities on four bread-wheat cultivars in three different locations of Egyptian regions. Results showed a yield reduction in the growing season 2009/2010, due to sudden rise in temperature which affected both growth and productivity of wheat plants in the three locations. CERES-Wheat model is responsive to different weather date at each growing season to high temperature and its ability to mimic growth and yield of wheat under the weather conditions of the selected sites. When the climate is at normal levels, the wheat yield is high. During heat waves, the damage of wheat yield in the north of Egypt could be less than the damage in the south because the rainfall and relative humidity in the north were high which reduced the effect of heat wave on wheat production. Annual and seasonal analysis has been done in order to compare impact of the heat wave on production season of 2009/2010 and the last 10 years.

***Keywords:*** Weather extremes, bread wheat, *Triticum aestivum*, crop simulation, calibration, validation, impacts and adaptations

## 1. Introduction

Extreme weather events can affect agricultural production significantly, for instance heat waves and droughts (Ciais *et al.,* 2005 and van der Velde *et al.,* 2010), also hail storms (Sanchez *et al.,* 1996), excessive cold, and heavy and prolonged precipitation (Rosenzweig *et al.,* 2002). The frequency and magnitude of extreme weather events are expected to increase under climate change (Solomon *et al.,* 2007). Weisheimer & Palmer (2005) examined changes in extreme seasonal temperatures using multi-model and multi-scenario ensembles; they showed that by the end of the century, the probability of extreme warm seasons is projected to rise over many areas. This increase in extreme warm seasons arises from the combined effect of a shift in the temperature mean and an increase in the temperature variability. Extreme weather events can in fact impact crops both via negative impacts on plant physiological processes and direct physical damage, as well as by affecting the timing and conditions of field operations (van der Velde *et al.,* 2011). Several crop simulation models have been released and developed in the last two decades. Few of these models are truly predicting growth, development, and yield of a given crop (Hassanein *et al.,* 2012). Simulation models are often used to verify the potentiality of crop management, allowing multi-year and multi-location runs with minimum time spending (Rinaldi and Ubaldo, 2007). Decision Support System for Agrotechnology Transfer (DSSAT) is a software application program that comprises crop simulation models for over 28 crops, as of Version 4.5 used in this study (Jones *et al.,* 2003; DSSAT.net, 2011; and Hoogenboom *et al.,* 2012). Choice of such model was because of its ability to simulate plant growth, development, and yield of several crops. CERES-Wheat model (Godwin *et al.,* 1981; Ritchie and Otter, 1985) is a simulation model for wheat

**Corresponding Author:** Elsayed M., Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center (ARC), Egypt. E-mail: elsayed.maha@gmail.com

in the DSSAT package that describes daily phonological development and growth in response to environmental factors (soils, weather and management). Primary variable influencing phasic development rate is temperature (Iglesias, 2006). Temperature also 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). 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 (McMaster, 1997).

Salem (2013) found that wheat grain germinates in a range of temperature between 3-4.5ºC to 30-32ºC with optimum temperature of 25ºC. Fit the wheat blossom temperatures ranging between 13º to 25ºC. Exposure of wheat plants to high temperatures in the period of tillering to the expulsion of spikes lead to less axis of spike and few spikes. High temperatures during the flowering period lead to few grains as a result of the death of pollen. Heat waves (high temperatures) during the three or four weeks after the flowers lead to the early maturity of grain and atrophy it. Heat waves (high temperatures) increase transpiration and evaporation and thus reduce photosynthesis and dry matter partitioning to plant parts.

The aim of this research is to use DSSAT model to simulate wheat yield under extreme weather events and to use the model to test the effect of different irrigation levels as an adaptation option on relieving the harm effect of weather extremes on wheat yield.

## 2. Materials and Methods

### 2.1. Field experiments

Data for the study were obtained from field experiments conducted for four bread wheat, *Triticum aestivum,* cultivars (Gemmeiza 9, Giza 168, Sakha 93 and Misr 1) at three different agro climatic locations: Sakha (31° 7' N; 30° 56' E) at Kafr-El-Sheikh Governorate, Sids (29° 4' N; 31° 6' E) at Bani Suef Governorate, and Shandaweel (31° 39' N; 26° 37' E) at Sohag Governorate . Details of the experiments and data collected were published by Hassanein *et al.,* (2012).

The season was winter of 2009/2010 to study the effects of two sowing dates (the recommended and 15 days later) and three irrigation levels (60, 80 and 100% of the full water requirements) on grain yield and its attributes of four bread wheat, *Triticum aestivum,* cultivars (Gemmeiza 9, Giza 168, Sakha 93 and Misr 1).

### 2.2. Climate data

Climatic data for the three locations were obtained from Egyptian Meteorological Authority (EMA), Egypt. (Table1) and the historical average climate data (maximum and minimum temperatures) for thirty years from 1960 to 1990 was obtained from Central Laboratory for Agricultural Climate (CLAC) to compare between it and season 2009/2010.

### 2.3. Crop Model Validation

Experimental conditions and results obtained from those locations (Sakha, Sids and Shandaweel) were used as a database for calibration and validation of CSM-CERES-Wheat model through DSSAT 4.5 software to simulate and predict wheat yield. The comparison between actual data and predicted data were done through CERES-Wheat model under DSSAT interface in three steps, retrieval data (converting data to CERES-Wheat model), and validation data (comparing between predicted and observed data) and run the DSSAT model provides validation of the crop models that allows users to compare simulated outcomes with observed results. Necessary files were prepared as required. Calibration and validation of applying CSM-CERES-Wheat model was done through using d-Stat index of agreement between simulated and observed data.

### 2.4. Agricultural statistics data

Bread wheat productions (Grain yield (Ton/Fed)) at Kafr.El-Sheikh, Bani Suef and Sohag for the years from 2009 to 2011 were obtained from (Agricultural Statistics Bulletin) to compare between the productions of season 2009/2010 with the production of seasons 2008/2009, 2009/2010.

### 2.5. Comparing production and temperature of the year 2009/2010 with the last ten years

Comparison had been done between annual and seasonal temperature (maximum, minimum and mean) and the winter wheat production for the year 2009/2010 and the previous ten years. This part of study was applied for the three governorates in order to see the influence of different agro-meteorological zones.

## 3. Results and Discussion

Evaluating prediction ability of CSM-CERES-Wheat model showed impacted results related to extreme weather events, which was happened in the growing season 2009-2010. Plants productivity was really subjected to a decrease caused by the waves of high temperature.

### 3.1. At Sakha Kafr El-Sheikh governorate

Frequency and magnitude of extreme weather events are expected to increase under climate change (Solomon *et al.,* 2007). CSM-CERES-Wheat model was used to simulate the wheat yield of four cultivars in three sites under three growing seasons. Table (1) shows that the reduction in grain yield of wheat for all cultivars under weather conditions was observed in 2009/2010 season, where heat wave actually occurred in Febrauary. Figure (1) shows the reduction in grain yield of wheat for all cultivars under current weather.

**Table 1:** Simulated grain yield of wheat at Sakha location for the three growing seasons (under current conditions 2009/2010 and two normal seasons 2008/2009 and 2010/2011.

| Season | Gem 9 (Ard./Fed.) | Giza 168 (Ard./Fed.) | Misr 1 (Ard./Fed.) | Sakha 93 (Ard./Fed.) |
|---|---|---|---|---|
| **2008/2009** | 14.79 | 16.54 | 16.81 | 16.54 |
| **2009/2010** | 13.94 | 15.65 | 16.09 | 15.65 |
| **2010/2011** | 14.91 | 16.64 | 16.87 | 16.64 |

**Ard. :** Ardab = 150 Kg **, Fed. :** Fedan = 4200 $m^2$

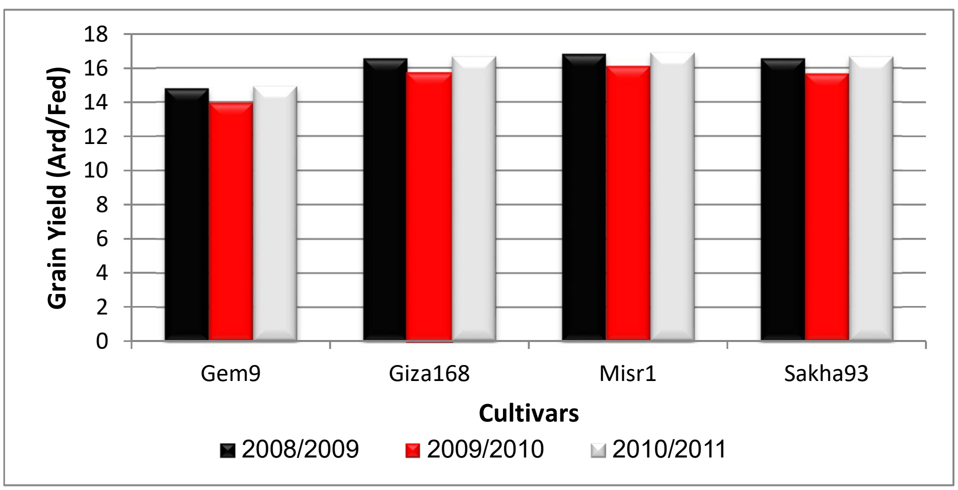


**Fig. 1:** Changes in grain yield for wheat cultivars under current conditions (season 2009/2010) and two normal seasons (2008/2009 and 2010/2011) at Sakha location.

### 3.2. At Sids Bani Suef governorate

Similar trend was observed at Sids in Table (2). The table showed that the reduction in grain yield of wheat for all cultivars occurred under weather conditions of 2009/2010 season. Figure (2) shows the reduction in grain yield of wheat for all cultivars under current weather.

**Table 2:** Simulated grain yield of wheat at Sids location for the three growing seasons (under current conditions 2009/2010 and two normal seasons 2008/2009 and 2010/2011.

| Season | Gem 9 (Ard./Fed.) | Giza 168 (Ard./Fed.) | Misr 1 (Ard./Fed.) | Sakha 93 (Ard./Fed.) |
|---|---|---|---|---|
| **2008/2009** | 12.97 | 14.83 | 15.05 | 14.83 |
| **2009/2010** | 11.34 | 12.97 | 13.31 | 12.97 |
| **2010/2011** | 13.66 | 15.23 | 15.32 | 15.23 |

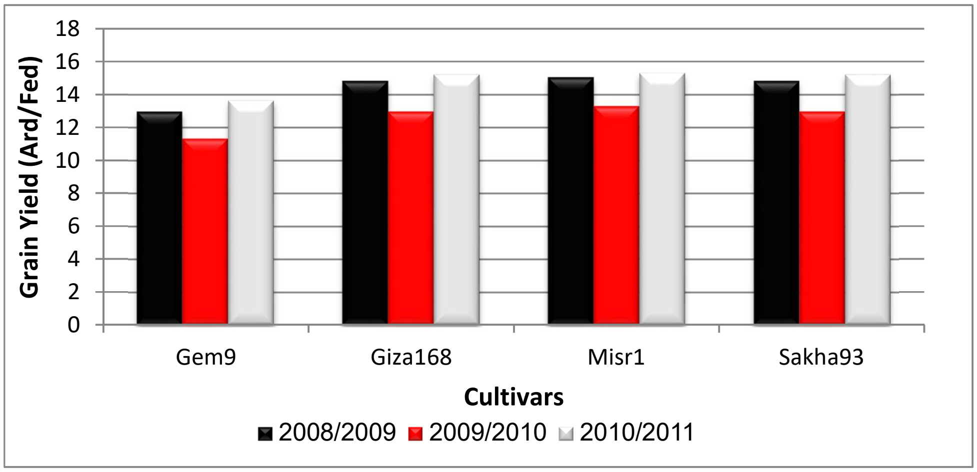


**Fig. 2:** Changes in grain yield for wheat cultivars under current conditions (season 2009/2010) and two normal seasons (2008/2009 and 2010/2011) at Sids location.

### 3.3. At Shandaweel Sohag governorate

At Shandaweel, Table (3) showed that the reduction in grain yield of wheat for all cultivars under weather conditions was in 2009/2010 season.

Figure (3) shows the reduction in grain yield of wheat for all cultivars under current weather.

**Table 3:** Simulated grain yield of wheat at Shandaweel location for the three growing seasons (under current conditions 2009/2010 and two normal seasons 2008/2009 and 2010/2011.

| Season | Gem 9 (Ard./Fed.) | Giza 168 (Ard./Fed.) | Misr 1 (Ard./Fed.) | Sakha 93 (Ard./Fed.) |
|---|---|---|---|---|
| **2008/2009** | 12.35 | 14.07 | 14.29 | 14.07 |
| **2009/2010** | 10.66 | 12.77 | 13.01 | 12.77 |
| **2010/2011** | 13.69 | 15.61 | 15.95 | 15.61 |

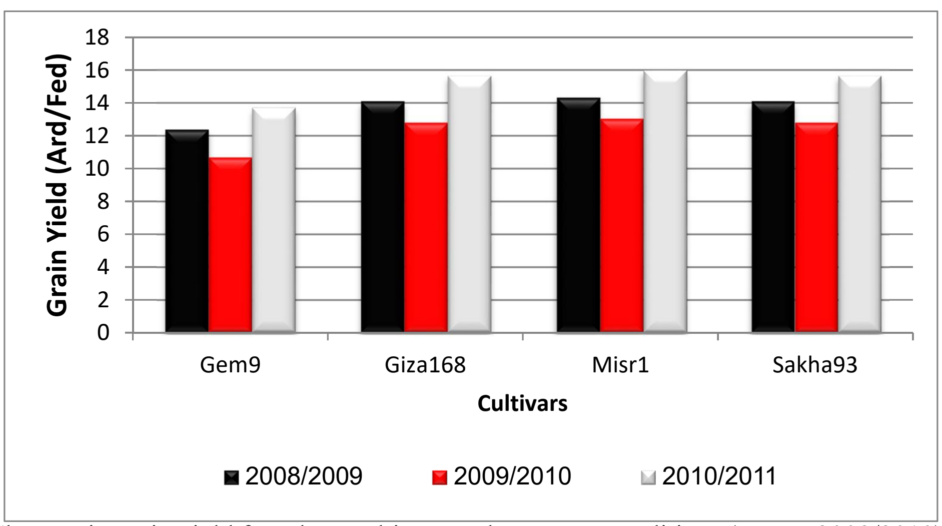


**Fig. 3:** Changes in grain yield for wheat cultivars under current conditions (season 2009/2010) and two normal seasons (2008/2009 and 2010/2011) at Shandaweel location.

The above results indicated that CSM-CERES-Wheat model is responsive to different weather data at each growing season.

### 3.4. Egyptian heatwave of 2010

A severe heatwave over large parts of Egypt (Delta, middle and uper Egypt) in 2010 was observed during the winter season from October to May. (Figure 4) showed the comparison between average monthly temperatures during winter season (2009/2010) and climatological normal from 1960 -1990 in the studied governorates (Kafr El-Sheikh, Bani Suef and Sohag). The results indcated that the minimum and maximum temperatures in winter season (2009/2010) was above the noraml in the studied governorates for all months from October to May.

Rising in winter temperatures by 0.9 to 2.9 °C for maximum temperature and from 0.9 to 3.7 for minimum temperature in Kafr El-Sheikh governorate. At Bani Suef governorate the raising in maximum temperatue was from 0.9 to 3.6 and for minimum temperature was from 1.1 to 4.2 while the raising in maximum temperature in Sohag governorate was from 0.7 to 4.2 and for minimum temperature was from 0.9 to 4.7.

### 3.5. Wheat productions from statistics data

Figure (5) showed the bread wheat production (Grain yield (ton/Fed)) at Kafr El-Sheikh, Bani Suef and Sohag governorates were obtained from (Agricultural Statistics Bulletin) to compare between wheat productions during the three winter seasons from 2009 to 2011. The results indicated that wheat production decreased in 2010 in comparison with 2009 and 2011. The highest reduction in wheat yield was found in Sohag governorate, while the lowest reduction was found in Kafr El-Sheikh governorate.

Figures (6) and (7) showed also the strong negative correclation between wheat yield at different locations and in the three different seasons (2009, 2010, and 2011) with increasing difference of temperature from normals data (1960-1990). This confirm the findings of rising temperature and its impact on amount of yield in the three seasons under study.

### 3.6. Annual and seasonal comparison between season 2009/2010 and previous ten years

According to winter wheat yield data for the last ten years we compared between productoin of different years and the targeted season of 2009/2010. Comparisons showed in figures from 8 to 13 indicated that by each increase in temperature there was an influence on yield. This influence was clear in the season 2009/2010 by sharp increasing in temperature at that season specially in months December, January, February and March, specially in minimum temperature. That influence was observed clearly when you compared the targeted season with climatological normal from 1960 - 1990 (Figure 4). Such heatwave had an impact on final yield at the three agroclimatc zones.

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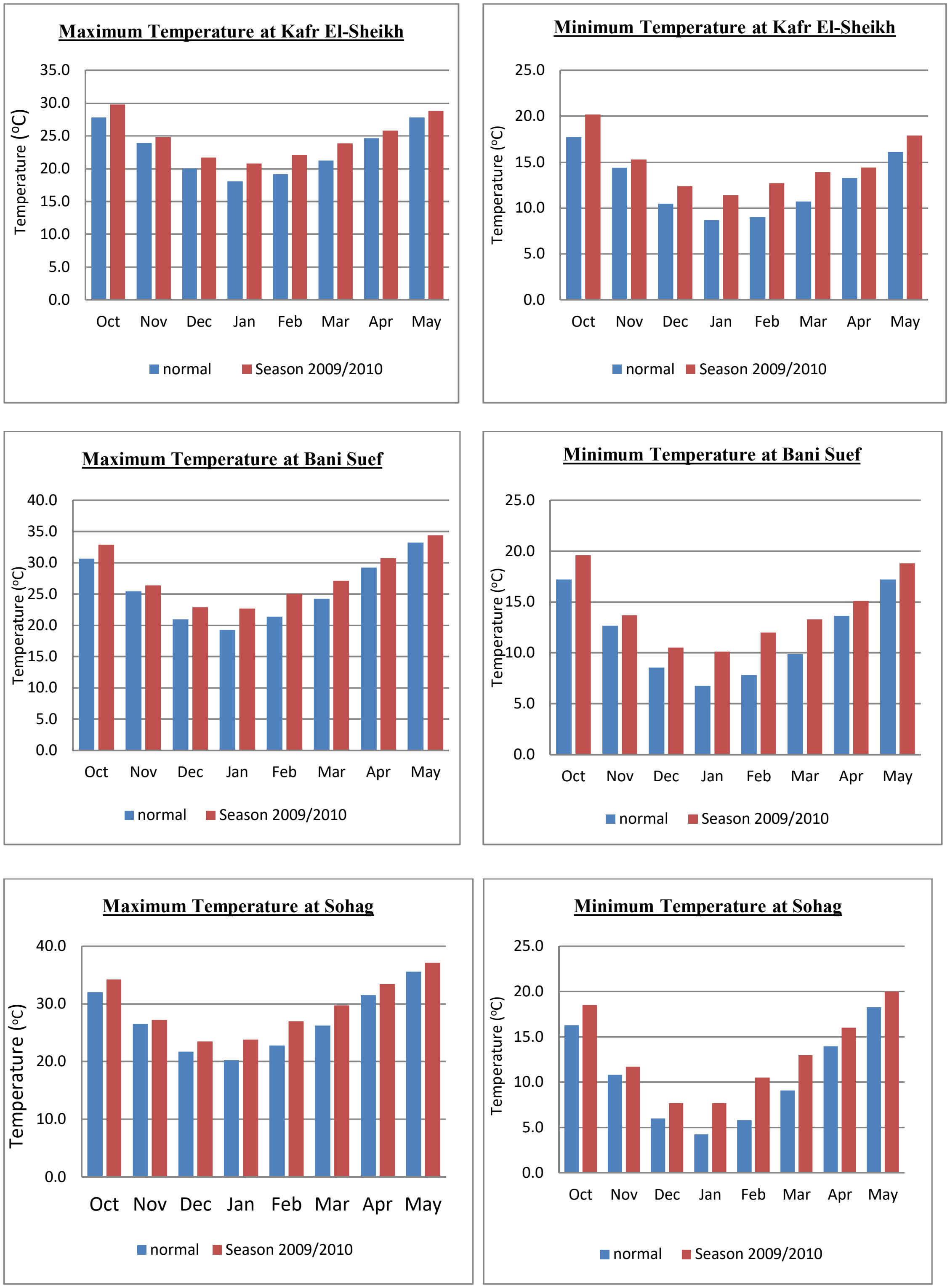


**Fig. 4:** The comparison between average monthly temperatures during winter season (2009/2010) and Climatological normal from 1960 -1990 in Kafr EL-Sheikh, Bani Suef, and Sohag governorates.

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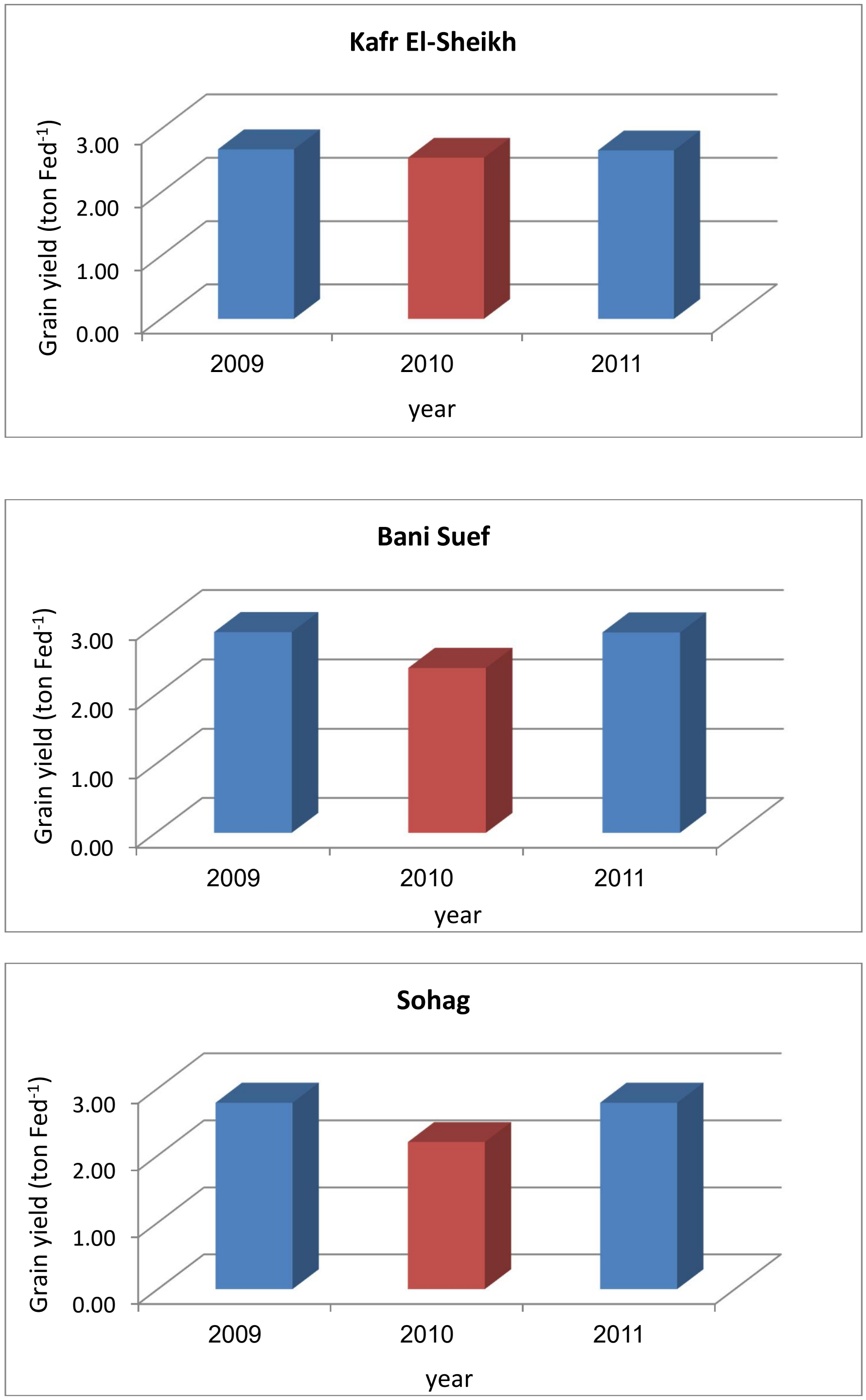


**Fig. 5:** Changes in grain yield for wheat productionfrom 2009 to 2011 at Kafr El-Sheikh, Bani Suef and Sohag governorates.

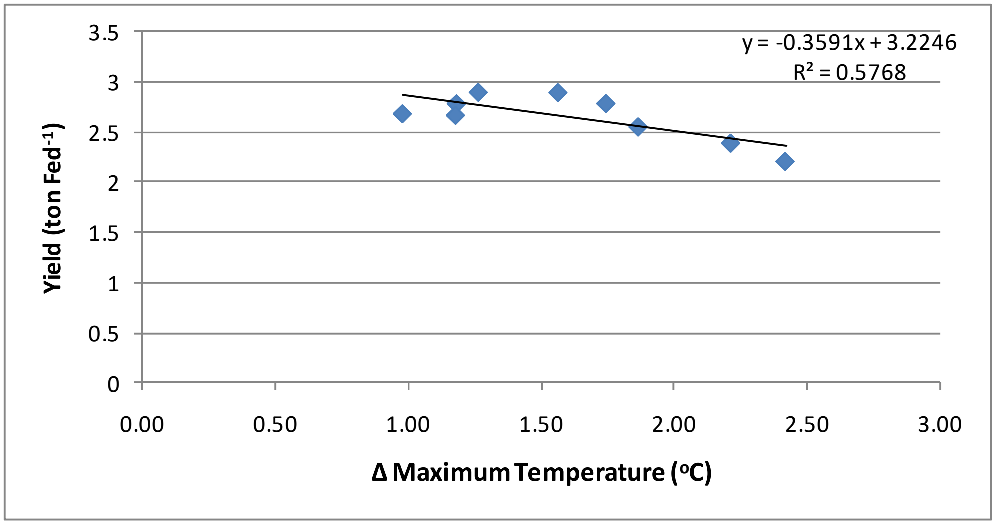


**Fig. 6:** Correlation between wheat yield and difference between normals and current maximum temperature for seasons 2009 and 2010 under different locations.

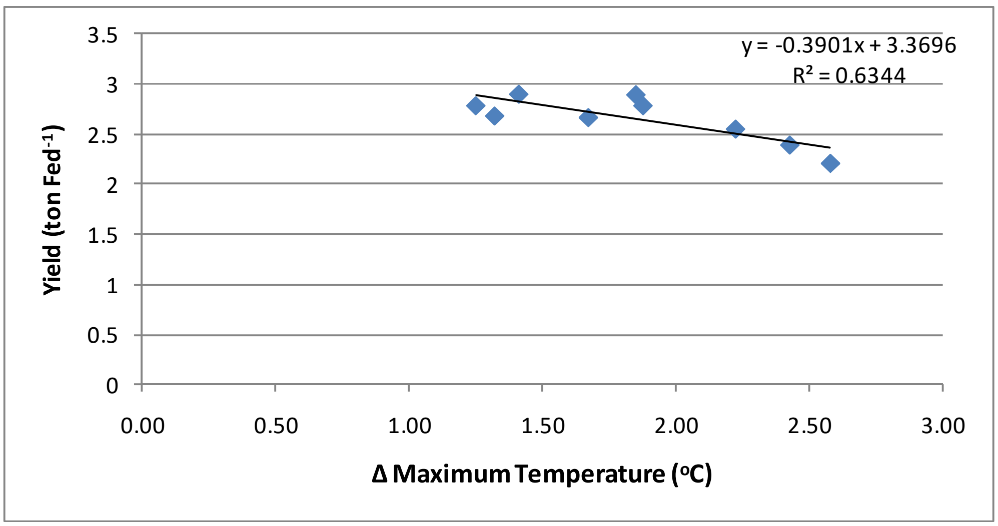


**Fig. 7:** Correlation between wheat yield and difference between normals and current maximum temperature for seasons 2009 and 2010 under different locations.

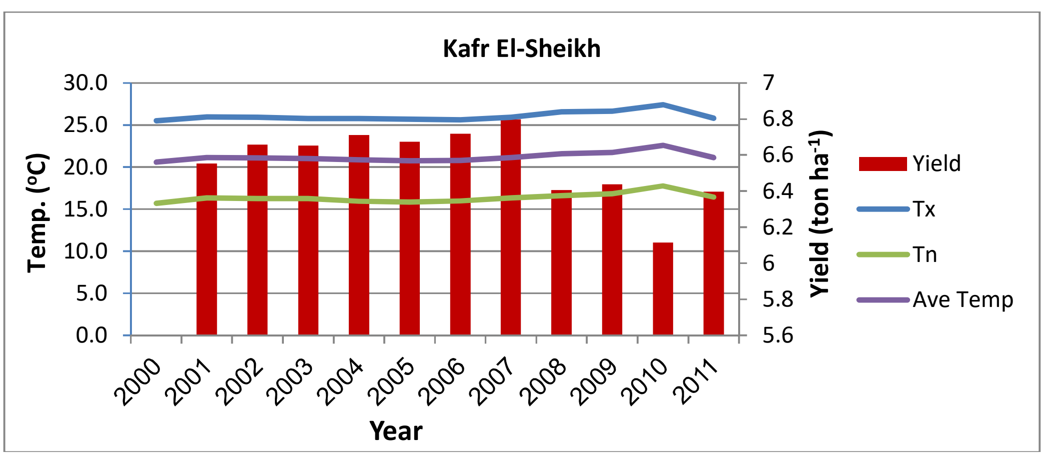


**Fig. 8:** Annual comparison between temperatures and yield for year 2009/2010 and last 10 years at Kafr El-Sheikh governorate.

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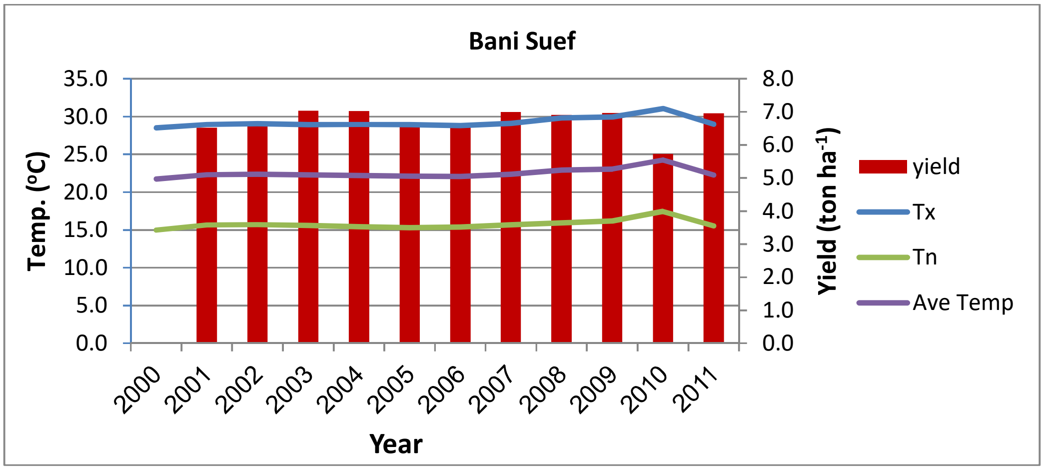


**Fig. 9:** Annual comparison between temperatures and yield for year 2009/2010 and last 10 years at Bani Suef governorate.

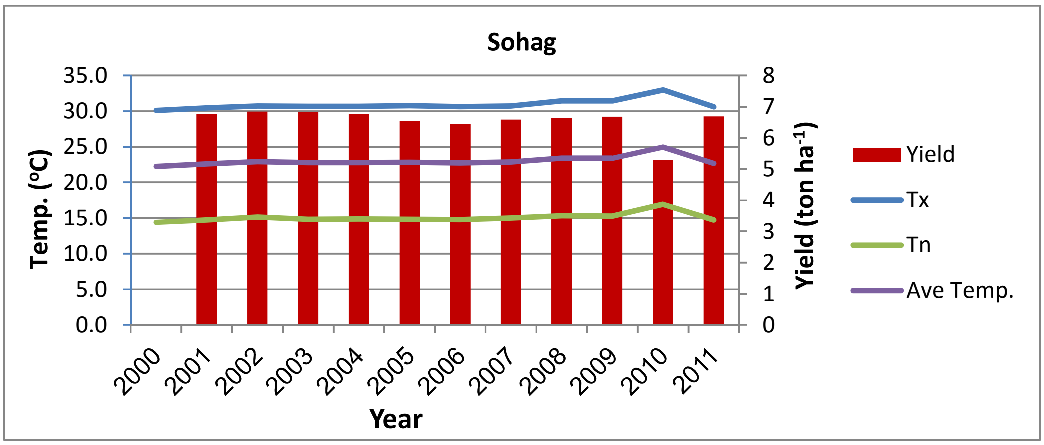


**Fig. 10:** Annual comparison between temperatures and yield for year 2009/2010 and last 10 years at Sohag governorate.

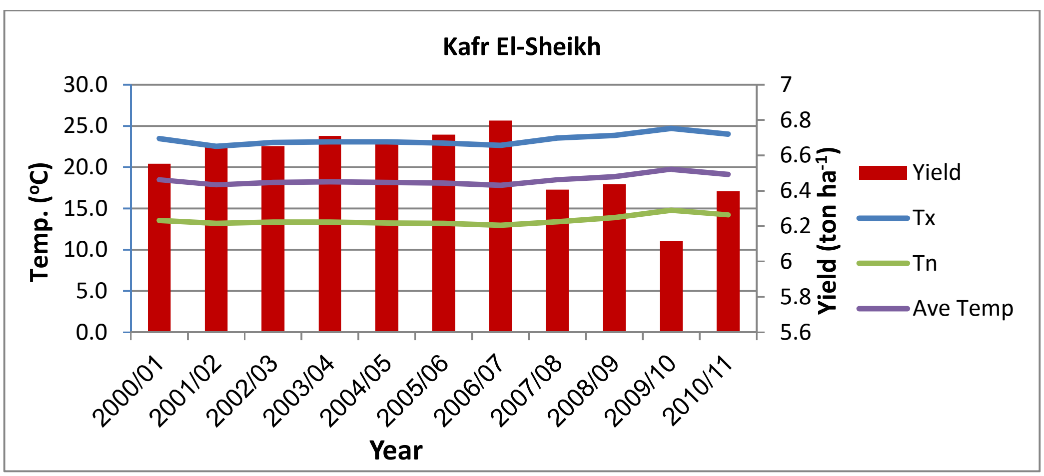


**Fig. 11:** Seasonal comparison between temperatures and winter wheat yield for season 2009/2010 and last 10 seasons at Kafr El-Sheikh governorate.

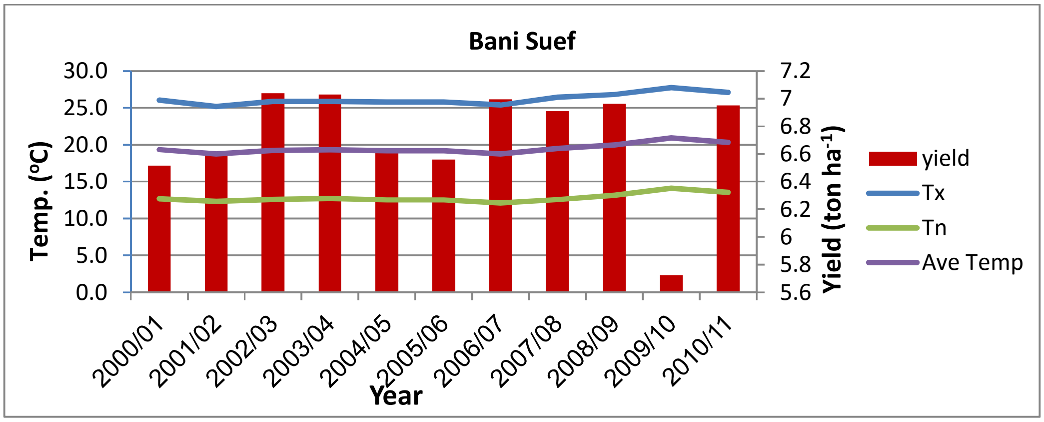


**Fig. 12:** Seasonal comparison between temperatures and winter wheat yield for season 2009/2010 and last 10 seasons at Bani Suef governorate.

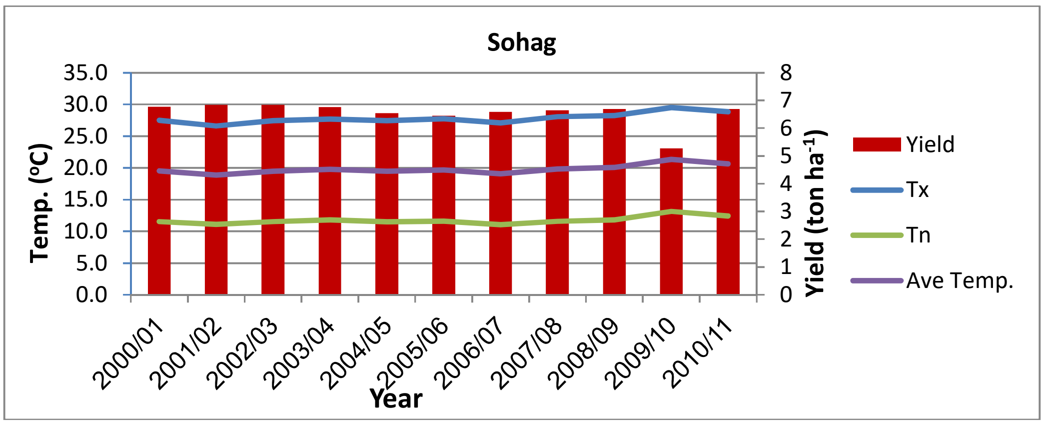


**Fig. 13:** Seasonal comparison between temperatures and winter wheat yield for season 2009/2010 and last 10 seasons at Sohag governorate.

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## Conclusion

Temperature is the primary factor driving wheat growth and consequently influence yield. Therefore, it could accelerate plant growth if it rises above its normal. In turn, the final yield will be reduced.

Results of this study revealed that, whenever heat wave occurred, wheat yield was reduced. Furthermore, simulation of wheat yield showed the responsiveness of CSM-CERES-Wheat model to high temperature and its ability to mimic growth and yield of wheat under the weather conditions of the selected sites.

When the climate is moderate at the optimum temperature for wheat growing conditions, wheat yield is high. During heat waves the damage of wheat yield in the north of Egypt could be less than the damage in south of Egypt because of the higher rainfall and relative humidity in the north of Egypt. Warm rainy seasons could give higher wheat yield. Furthermore, lower temperature and cold seasons could give higher wheat yield.

Comparing temperatures and production of the last ten years with the targeted season of 2009/2010 showed clear influence of the heat wave on the production of season 2009/2010, which confirmed the role of increase in minimum temperature in the yield reduction at that season compared to the other seasons.

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