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Simulating the Impact of Climate Change on Growth and Yield of Maize Using CERES-Maize Model under Temperate Kashmir

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Authors' contributions

This work was carried out in collaboration between all authors. Authors BAL and ST designed the study, performed the DSSAT analysis and wrote the protocol and wrote the first draft of the manuscript. Authors AF and PS managed the analyses of the study. Authors AQ,SK and ZAD managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Climate variability has been and continues to be, the principal source of fluctuations in global food production in countries of the developing world and is of serious concern. Process-based models use simplified functions to express the interactions between crop growth and the major environmental factors that affect crops (i.e., climate, soils and management), and many have been used in climate impact assessments. Average of 10 years weather data from 1985 to 2010, maximum temperature shows an increasing trend ranges from 18.5 to 20.5°C.This means there is an increase of 2°C within a span of 25 years. Decreasing trend was observed with respect to precipitation was observed with the same data. The magnitude of decrease was from 925 mm to 650 mm of rainfall which is almost decrease of 275 mm of rainfall in 25 years. Future climate for 2011-2090 from A1B scenario extracted from PRECIS run shows that overall maximum and minimum temperature increase by 5.39°C (±1.76) and 5.08°C (±1.37) also precipitation will

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decrease by 3094.72 mm to 2578.53 (±422.12) The objective of this study was to investigate the effects of climate variability and change on maize growth and yield of Srinagar Kashmir. Two enhanced levels of temperature (maximum and minimum by 2 and 4°C) and CO_2 enhanced by 100 ppm & 200 ppm were used in this study with total combinations of 9 with one normal condition. Elevation of maximum and minimum temperature by 4°C anthesis and maturity of maize was earlier 14 days with a deviation of 18% and 26 days with a deviation of 20% respectively. Increase in temperature by 2 to 4°C alone or in combination with enhanced levels of CO_2 by 100 and 200 ppm the growth and yield of maize was drastically declined with an reduction of about 40% in grain yield. Alone enhancement of CO_2 at both the levels fails show any significant impact on maize yield.

Keywords: DSSAT; maize; climate change; yield; growth.

1. INTRODUCTION

The effect of climate change on the crop productivity is usually investigated with the experimental methods using a growth chamber or with the numerical methods using a crop model. According to the IPCC Third Assessment Report [1], climate change is already happening, and will continue to happen even if global greenhouse gas emissions are curtailed.

Many studies document the implications of climate change for agriculture and pose a reasonable concern that climate change is at threat to poverty and sustainable development, especially in developing countries. Future crop production will be adapted to climate change by implementing alternative management practices and developing new genotypes that are adapted to future climatic conditions. Long term weather data of Kashmir valley revealed (Fig. 1) that there is increasing trend in temperature. Average maximum temperature has increased by $1^{\circ C}$ during last 30 years. Consequently average minimum temperature has increased by $0.5^{\circ C}$. Precipitation trend is decreasing and erratic. Crop simulation models can be used in decision making in advance along with GIS in future effectively by saving time.

Maize known as the “Queen of Cereals” is the third most important cereal crop in India after rice and wheat and is cultivated on 8.85 million (m) ha with production of 22.84 million tonnes with productivity of 25.80 kgha^{-1} [2].Among the major crops of Jammu and Kashmir in terms of acreage maize is grown in area of 0.31mha with the production of 0.48 m ton [3]. The average yield of 1566 kg/ha [4] of this crop has also nearly doubled since 2000. This increase in yield has been mainly achieved by increase in the area under high yielding varieties. However, the genetic potential of the improved varieties is at least three times of the present average yield of the state.

Being an important cereal, over 85% of its production in the country is consumed directly as food in various forms, the chapatis is the common ‘preparation, whereas, roasted ears, pop corns and porridge are other important forms in which maize is consumed. Besides, it is also used for animal feeding, particularly for poultry and in starch industry. Green maize plants furnish a very succulent fodder during spring and monsoon particularly in North India. Maize is grown under wide range of climatic conditions, mostly in warmer parts of the temperate region and areas of humid sub-tropical climate. It is grown practically at all altitudes except where it is too cold or the growing season is too short. The crop requires considerable moisture and warmth from the time of planting to the termination of flowering period.

1.1 Process-Based Crop Models

Researchers first evaluated model performance using data from cropping systems currently used in their respective countries, then used the models to assess the potential impacts of climate change on their cropping systems using different climate scenarios. Use of crop simulation models would help in studying impacts of climate change on crops as well as identifying and prioritizing the management options for adapting/mitigating the climate change effects.

Process-based models use simplified functions to express the interactions between crop growth and the major environmental factors that affect crops (i.e., climate, soils, and management), and many have been used in climate impact assessments. Most were developed as tools in agricultural management, particularly for providing information on the optimal amounts of input (such as fertilizers, pesticides, and irrigation) and their optimal timing. Dynamic crop models are now available for most of the major crops. In each case, the aim is to predict the response of a given crop to specific climate, soil, and management factors governing production. Crop models have been used extensively to represent stakeholder's management options [5].

The ICASA/IBSNAT dynamic crop growth models (International Consortium for Application of Systems Approaches to Agriculture – International Benchmark Sites Network for Agro technology Transfer) are structured as a decision support system to facilitate.

2. METHODOLOGY

DSSAT is a software package integrating the effects of soil, crop phenotype, weather and management options that allows users to ask "what if" type questions and simulate results by conducting, in minutes on a desktop computer, experiments which would consume a significant part of an agronomist's career. It has been in use for more than 15 years by researchers in over 100 countries. The DSSAT simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil, water, carbon, and nitrogen that take place under the cropping system over time. The ICASA/IBSNAT models have been used widely for evaluating climate impacts in agriculture at different levels ranging from individual sites to wide geographic areas [6]. This type of model structure is particularly useful in evaluating the adaptation of agricultural management to climate change. The DSSAT software includes all ICASA/IBSNAT models with an interface that allows output analysis. On the basis of above observations the following environmental modifications will be studied with respect to growth and yield of maize under temperate Kashmir using DSSAT 4.5.

2.1 Simulation Models

Crop growth simulation models and biogeochemical and biophysical models have been very helpful in projecting the future crop and soil productivity. These models in connection with different General Circulation Models predict the future agricultural practices that can adapt to different climate change scenarios. Here are a few of the models that can be used for different scenarios analysis to combat impact of climate change on agricultural production of the globe. Simulation models that are able to assess climate change impact on crop growth, yield and farm economy, still lack complete feedback structures. Only single aspects can be investigated. However, modelling these single aspect increases knowledge on to the aspects of expectations from climate change, if interpreted carefully and in the context of the model's abilities. Simulation models are widely used to address "what if" type questions, such as, what if the climate changes, different irrigation or fertilization regimes are used, different sowing dates are used, different cultivars are used, etc. In addressing actual yield predictions required by governments, private corporations, or Non Government Organizations, different types of simulation models are used for solving these "what if" type questions. Here, capabilities of different simulation models will be discussed in assessing the impact of climate change on agro ecosystem and what would be the possible mitigation and adaptation.

Assuming an appropriate model is at hand and a reference crop production scenario exists, simulating the effects of climate change mainly involves running the model for the weather and CO_2 scenarios of interest. For a single site or region, the scenarios may be specified as fixed (e.g. an increase in daily mean temperature of 2°C) or relative (20% decrease in daily precipitation). These adjustments may be held constant over the crop cycle or varied. The choice depends on the objectives and the source of the climate change scenario. Because a season might be unrepresentative of long-term trends, simulations are usually run for 20 or more years. The requisite weather data may come from historical records or from weather generator software that reproduces the statistical properties of historic conditions [7,8].

Using DSSAT, [9] simulated the impact of climate change on maize production in Africa and Latin America and showed that there is 10% decrease in aggregate maize production by 2055. Keeping in view the importance of climate change, maize Simulation studies will be carried out using DSSAT V.4.5 (CERES-Maize) model with an objective "To access the impact of climate change on growth and yield of maize using CERES-Maize model DSSAT 4.5" with below mentioned environmental modifications.

Table 1. Environmental modifications in the study will be as under

Environmental modification	Treatments (Climate change)		
	Max. temp. (°C)	Min. temp. (°C)	CO_2 (ppm)
E_1 (control)	Normal	Normal	Normal
E_2	+2	+2	Normal
E3	+4	+4	Normal
E_4	Normal	Normal	480
E_5	+2	+2	480
E_6	+4	+4	480
E_7	Normal	Normal	580
E_8	+2	+2	580
E9	+4	+4	580

3. RESULTS AND DISCUSSION

Location of study is Shalimar Srinagar which is situated 16 Km away from city center that lies between 34.08°N latitude and 74.83°E longitude at an altitude of 1587 meters above the mean sea level.

3.1 Input Requirements to Run CERES – Maize Model

For simulation of CERES maize model, minimum data sets (MDS) on crop management, macro and micro-environmental parameters associated with weather, soil and crop are required as input. Input data files of CERES-maize model are as per IBSNAT standard input/output formats and file structure described in DSSAT v 3 [10].

3.2 Weather Information

Daily weather data of Kashmir , Shalimar Srinagar (2015) was used with parameters solar radiation (MJ m^{-2} day^{-1}) minimum and maximum air temperature (°C) and rainfall (mm). These daily weather data including site specific information, other optional weather variables were collected and used for creating weather file (WTH) and running CERES maize model.

Genetic coefficients were calibrated and below mentioned values were used in Table 3.

3.3 Climate Trends of Study Area

Weather data of Kashmir, Shalimar Srinagar was undertaken to observe the ends of maximum, minimum temperature and precipitation. It was observed that average of 10 years weather data from 1985 to 2010, maximum temperature shows an increasing trend ranges from 18.5°C to 20.5°C. This means there is an increase of 2°C within a span of 25 years. Decreasing trend was observed with respect to precipitation was observed with the same data. The magnitude of decrease was from 925 to 650 mm of rainfall which is almost decreased of 275 mm of rainfall

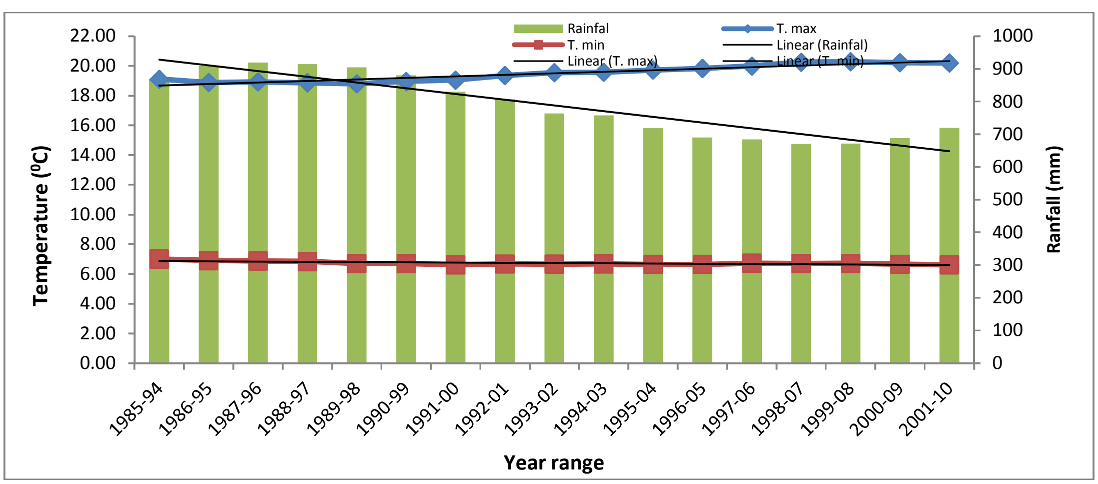

Fig. 1. Trend of 10 year average yearly mean of maximum temperature, minimum temperature and rainfall at Shalimar, Srinagar (J&K), India

Table 2. Soil information

Soil depth Cm	Lower limit cm^3/c	Upper limit m^3	Sat SW cm3/cm3	Extr SW cm	Init SW 3/cm3	Root dist	Bulk dens g/cm3	pH	NO3 ugN/g	NH4 ugN/g	ORG C %
0- 5	0.204	0.34	0.392	0.136	0.322	1	1.45	6.9	11.2	1.2	2.19
5-10	0.204	0.34	0.392	0.136	0.322	1	1.45	6.9	11.2	1.2	2.19
15- 25	0.209	0.345	0.39	0.136	0.322	0.75	1.45	7.2	11.2	1.2	1.21
25- 35	0.209	0.345	0.39	0.136	0.322	0.5	1.45	7.2	11.2	1.2	1.21
35- 50	0.198	0.335	0.39	0.137	0.281	0.35	1.49	8	11.2	1.2	0.53
50- 65	0.185	0.323	0.395	0.138	0.257	0.2	1.58	8.2	11.2	1.2	0.2
65- 80	0.185	0.323	0.395	0.138	0.244	0.15	1.58	8.2	11.2	1.2	0.2
80- 99	0.201	0.328	0.408	0.127	0.239	0.1	1.54	8.1	11.2	1.2	0.1
99-122	0.198	0.325	0.41	0.127	0.325	0.05	1.58	8.2	0.01	0.01	0.09

The soil file already developed at Shalimar for DSSAT was used for running model

Table 3. Genetic coefficients of maize cultivar of shalimar maize composite 4

Coefficient	Unit	Definition	Value
P1	°C day	Thermal time from seedling emergence to the end of the juvenile phase	280
P2	Days	Extent to which development is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 h).	0.30
P5	°C days	Thermal time from silking to physiological maturity	789
G2	Number	Maximum possible number of kernels per plant.	650
G3	mg/day	Kernel filling rate during the linear grain filling stage and under optimum conditions	6.03
PHINT	°C day	Phyllochron interval; the interval in thermal time between successive leaf tip appearances	48

in 25 years (Fig. 1). Future climate for 2011-2090 from A1B scenario extracted from PRECIS run shows that overall maximum and minimum temperature increasing by 5.39°C (±1.76) and 5.08°C (±1.37) also precipitation will decrease by 3094.72 mm to 2578.53 (±422.12)mm [11].

Simulated effect elevated ambient maximum and minimum temperature by 2°C (E_2) resulted early anthesis of maize by 7 days. Further elevation of maximum and minimum temperature by 4°C (E_4) anthesis of maize was earlier by 14 days with a deviation % age of -18. However elevation of CO_2 both at +100 ppm and + 200 ppm alone or in combination with maximum and minimum temperature failed to show any impact on anthesis date. Simulated effect elevated ambient maximum and minimum temperature by 2°C (E_2) resulted early maturity of maize by 15 days. Further elevation of maximum and minimum temperature by 4°C (E_4) maturity of maize matured earlier by 26 days with a deviation % age of -20. However elevation of CO_2 both at +100 ppm and + 200 ppm alone or in combination with maximum and minimum temperature failed to show any impact on anthesis date.

Maximum simulated tops and grain weight Kg/ha of 27172 was recorded with (E7) at enhanced level of CO_2 with 200 ppm followed by E4 (CO_2 +100ppm) with 26935 Kg /ha i.e. when CO_2 was enhanced by 100 ppm than normal. Magnitude of increase was 3% at 200 ppm enhanced CO_2 level and 2% at 100 ppm enhanced. However increase in temperature there was a decrease in tops weight when tried alone or with combination of CO_2. Least tops weight of 22231 Kg /ha was recorded when temperature was increased by +4°C with deviation of -16% as compared to normal, which was closely followed by E6 (Max, Min temp +4 and CO_2 +100ppm) with 15%. Enhanced level of temperature with + 2°C alone or in combination with enhanced levels of CO_2 showed only -5 to -6% deviation in tops weight than normal environment (Fig. 2).

Table 4. Simulated Days to anthesis of maize as function of enhanced levels of temperature and CO_2

Environmental modification	Simulated days to anthesis	Deviation of anthesis from normal	% age of deviation
$E_{1\ (control)}$	80	-	-
E_2 (Max, Min temp +2)	73	7	-9
E3(Max, Min temp +4)	66	14	-18
E_4 (CO_2 +100ppm	80	0	0
E_5 (Max, Min temp +2 and CO_2 +100ppm)	73	7	-9
E_6(Max, Min temp +4 and CO_2 +100ppm)	66	14	-18
E_7(CO_2 +200ppm)	80	0	0
E_8(Max, Min temp +2 and CO_2 +200ppm)	73	7	-9
E9(Max, Min temp +4 and CO_2 +200ppm)	66	14	-18

Table 5. Simulated days to maturity of maize as function of enhanced levels of temperature and CO_2

Environmental modification	Simulated days to maturity	Deviation in maturity from normal	%age of deviation
$E_{1\ (control)}$	131	_	-
E_2 (Max, Min temp +2)	116	15	-11
E3(Max, Min temp +4)	105	26	-20
E_4 (CO_2 +100ppm	131	0	0
E_5 (Max, Min temp +2 and CO_2+100ppm)	116	15	-11
E_6(Max, Min temp +4 and CO_2 +100ppm)	105	26	-20
E_7(CO_2 +200ppm)	131	0	0
E_8(Max, Min temp +2 and CO_2+200ppm)	116	15	-11
E9(Max, Min temp +4 and CO_2 +200ppm)	105	26	-20

Table 6. Simulated tops weight grain weight and their deviation of maize as function of enhanced levels of temperature and CO_2

Environmental modification	Simulated tops weight kg/ha	Deviation in tops weight kg/ha (%)	Simulated grain weight kg/ha	Deviation in grain weight kg/ha (%)
$E_{1\ (control)}$	26479	-	4441	-
E_2 (Max, Min temp +2)	24343	-8	3189	-28
E3(Max, Min temp +4)	22231	-16	2561	-42
E_4 (CO_2 +100ppm)	26935	2	4573	3
E_5 (Max, Min temp +2 and CO_2 +100ppm)	24710	-7	3278	-26
E_6(Max, Min temp +4 and CO_2 +100ppm)	22615	-15	2643	-40
E_7(CO_2 +200ppm)	27172	3	4644	5
E_8(Max, Min temp +2 and CO_2 +200ppm)	24916	-6	3327	-25
E9(Max, Min temp +4 and CO_2 +200ppm)	22813	-14	2687	-39

Maximum simulated Grain weight Kg/ha of 4644 was recorded with (E7) at enhanced level of CO_2 alone with 200 ppm followed by (E4) i.e. when CO_2 was enhanced by 100 ppm than normal with grain weight of 4573 Kg/ha. Magnitude of increase was 5% at 200 ppm enhanced CO_2 level and 3% at 100 ppm enhanced CO_2 level. However enhanced levels of temperature shows drastic decrease in grain yield.. When crop was tested at enhanced level of max and min temperature E_2 (Max, Min temp ±2°C) the grain yield recorded was 3189 Kg/ha with a decrease in yield of 28% (Fig. 6). Further more increase in the temperature from 2°C to 4°C(both min and max) the magnitude of decrease was 42% with the grain yield of 2561 kg/ha our findings are in agreement with [12,13,14 and 15]. Enhanced levels of Maximum and minimum temperature by 2 and 4°C in combination with 100 ppm and 200 ppm enhanced levels of CO_2 the magnitude of decrease was 26, 40, 25 and 39%, respectively (Fig. 3).

Ceres Maize model DSSAT 4.5, shows that increase in the temperature by 2 or 4°C alone or in combination with the enhanced levels of CO_2 with 100 ppm and 200 ppm the grain yield of maize shows drastic decrease in yield under temperate conditions of Kashmir, Shalimar. This may be due to the fact that at higher temperature the plants shift earlier from vegetative to reproductive phase as in (Figs. 4 and 5) less number of days were taken to anthesis and maturity at higher levels of temperature, which causes more biomass but which lower portioning of dry matter towards reproductive , ultimately lower grain yield.

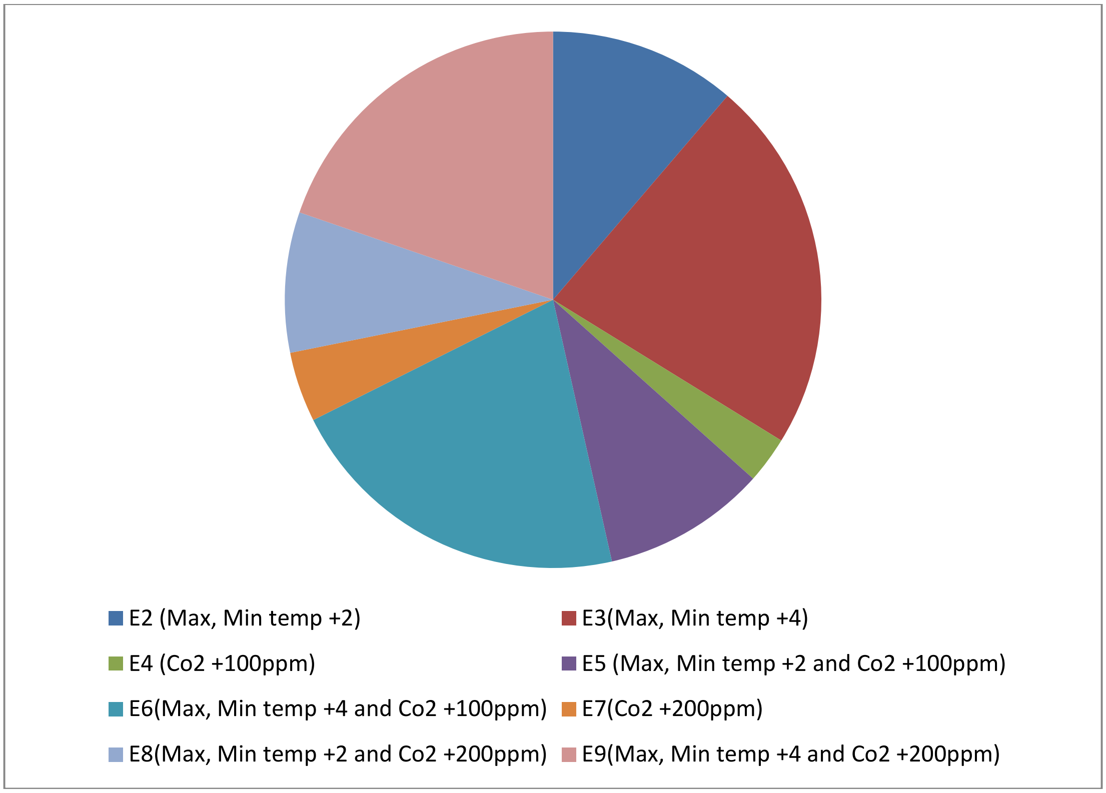

Fig. 2. Deviation in tops weight % as function of change in temperature and CO_2 levels

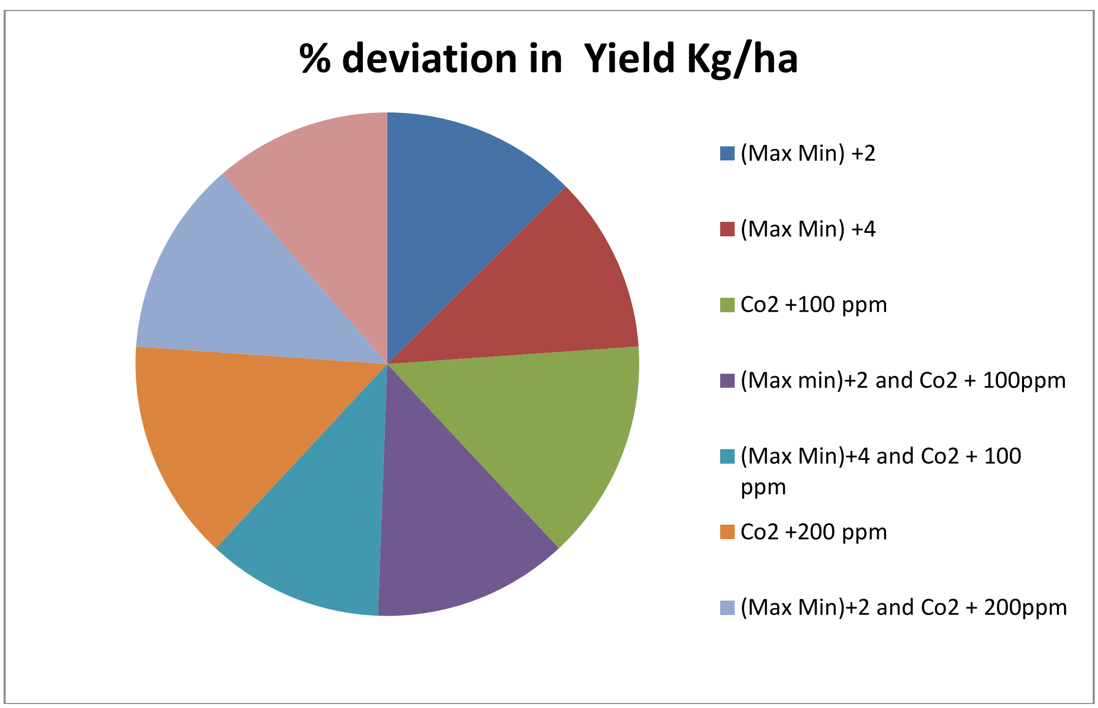

Fig. 3. Deviation in grain weight % as function of change in temperature and CO_2 levels

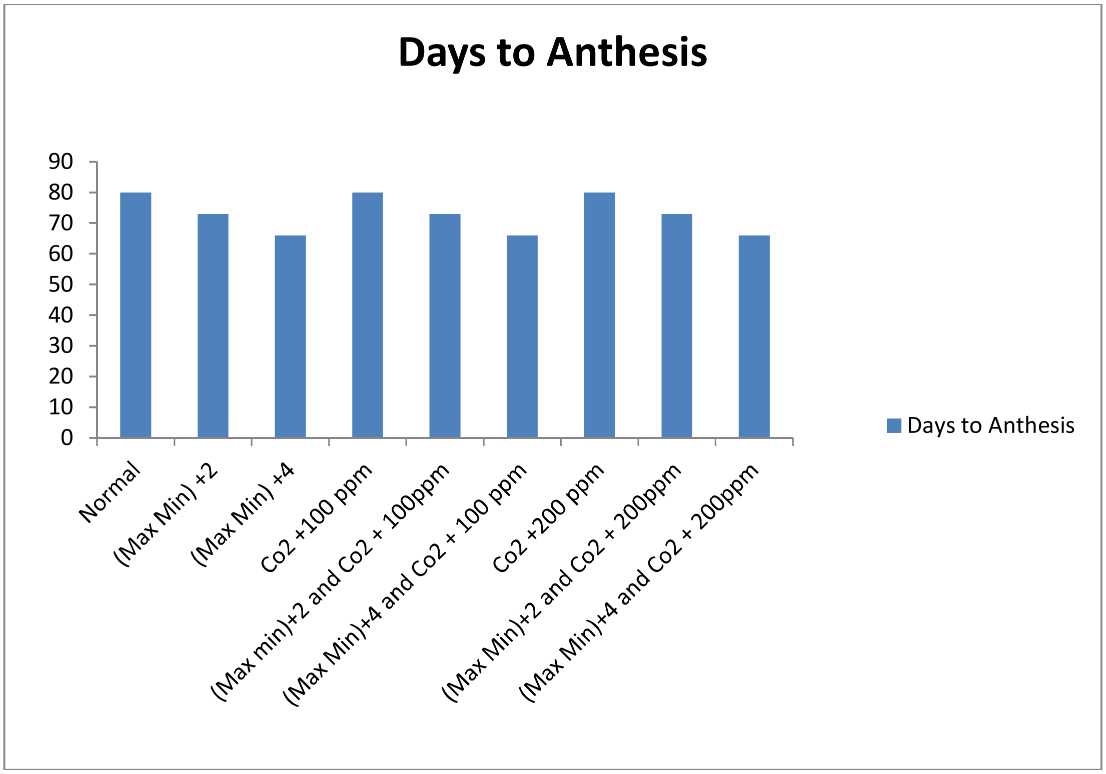

Fig. 4. Days to anthesis as function of change in temperature and CO_2 levels

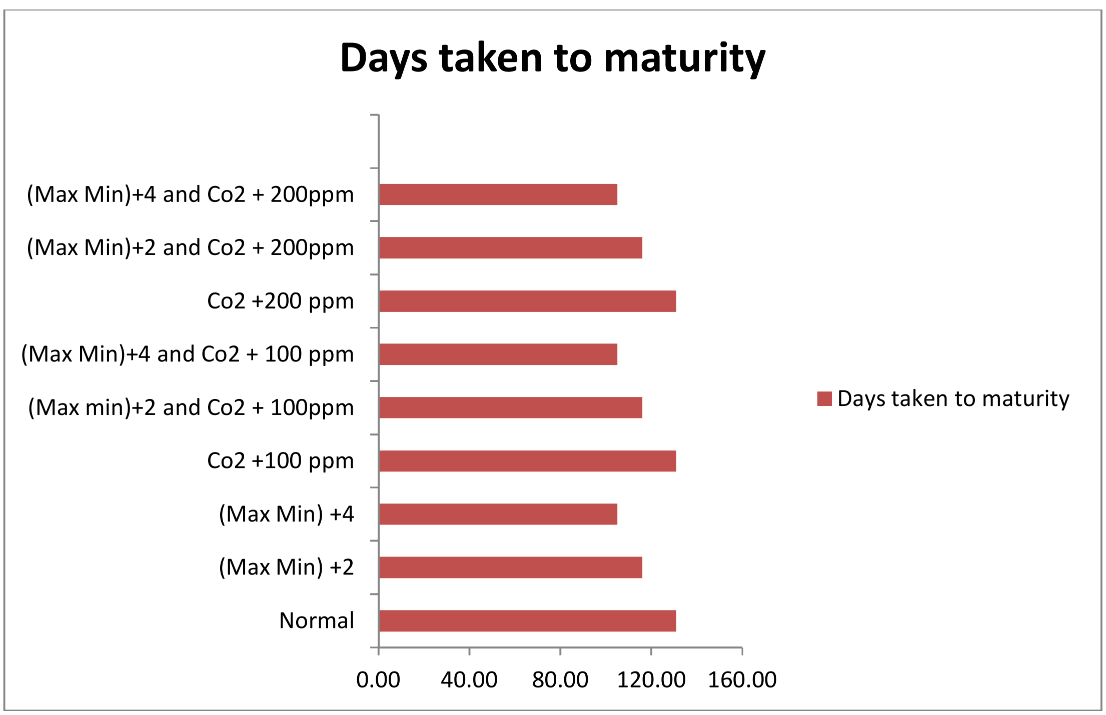

Fig. 5. Days to maturity as function of change in temperature and CO_2 levels

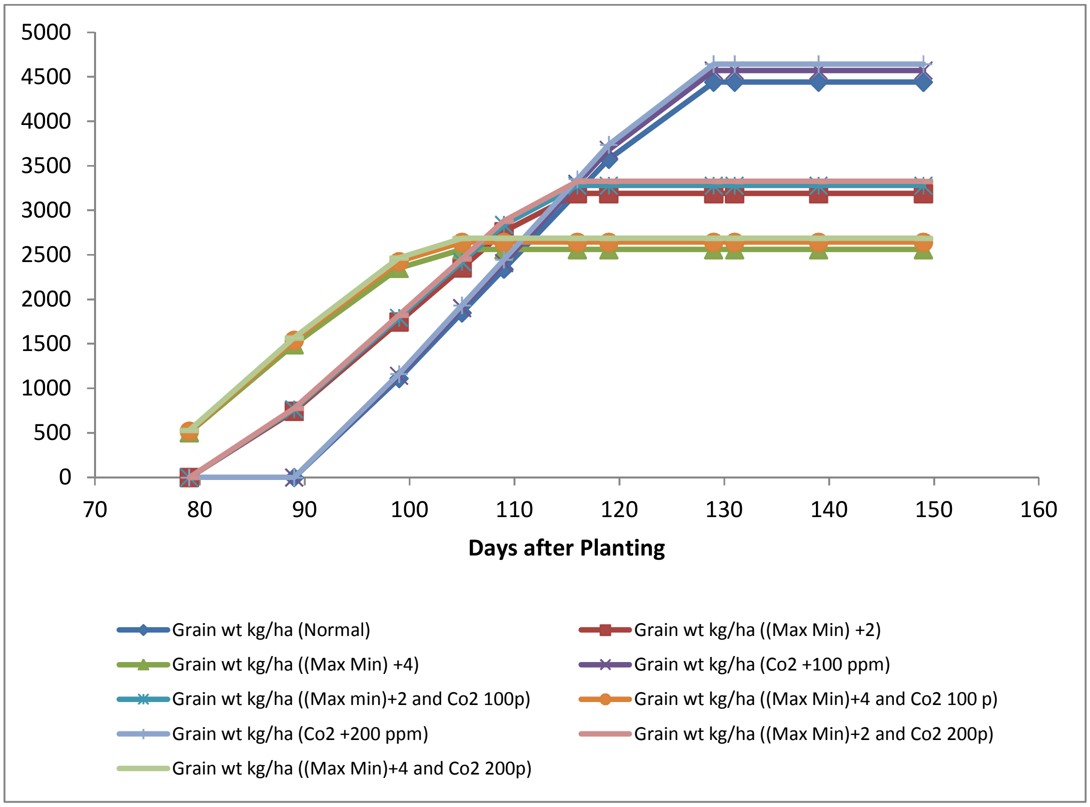

Fig. 6. Grain weight Kg/ha as function of change in temperature and CO_2 levels

4. CONCLUSION

Climate change impacts on crop yield are often integrated with its effects on water productivity and soil water balance. Global warming will influence temperature and rainfall, which will directly have effects on the soil moisture status and groundwater level. Crop yield is constrained to crop varieties and planting areas, soil degradation, growing climate and water availability during the crop growth period. With temperature increasing and precipitation fluctuating, water availability and crop production will decrease in the future. Using DSSAT 4.5 Assuming management practices continue as present, Ceres maize model predicted that enhanced level of CO_2 up to 200 ppm failed to show any impact on crop growth and yield. However increase in temperature by 2 to 4°C alone or in combination with enhanced levels of CO_2 by 100 and 200 ppm the growth and yield of maize was drastically declined with an reduction of about 40% in grain yield. Further studies needs to be carried out for authentications of results.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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