Maize Yield Response toClimate Changewith DSSAT Model

ABSTRACT

Crop production is inherently sensitive to variability in climate. Temperature and CO_2 are two important parameters related to climate change, which affect crop yield of a particular region. In this study, an attempt has been made to assess the impact of these two parameters on the productivity of maize crop taking sub tropical region of Jammu as study area. A CERES-Maize model 4.0 was used for this purpose. Three year weather data (2004-06) is used to simulate the actual yield under rainfed and irrigated conditions. Yield was simulated with elevated temperature (1, 3 and 5^oC) and CO_2 (440, 550 and 660 ppm) during the growing season. As changes in CO_2 concentration and temperature likely to occur concomitantly, so growth and development of maize plant at three temperature regimes (1, 3 and 5^oC) under double (660 ppm) CO_2 concentration to the baseline (330 ppm) was also assessed. The difference in yield, biomass, grain number and LAI was estimated and analyzed to assess the effect of elevated temperature and CO_2. Results revealed that the rise in temperature accelerated plant phenology, reducing dry matter accumulation and crop yield by 5 to 60 per cent. Elevation of CO_2 in the level of 440, 550 and 660 ppm showed gradual yield increment of 2.01, 3.92 and 5.37 per cent under rainfed conditions and 2.33, 4.52 and 7.41 per cent under irrigated conditions, respectively. Doubled CO_2 increased yield at all the temperature rise situation and completely mitigated the yield and biomass reduction due to temperature rise up to 1^oC.

Key words: DSSAT, simulation model temperature rise, elevated CO_2, maize

Introduction

Climate change is one of the primary concerns for humanity in the 21st century. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report concludes that there is strongly evidence that human activities have influenced the world's climate over the last century and a half (IPCC, 2007). Global atmospheric carbon dioxide concentration has been estimated that it will increase between 540 and 970 μmol mol^{-1} by the end of 21st century (Prentice *et al.*, 2001). Recent projections have also suggested that global surface air temperature may increase 1.4-5.8^oC in association with the doubling of carbon dioxide concentration (Cubasch*et al.*, 2001).According to the report of Intergovernmental Panel on Climate Change (IPCC), global mean temperature will rise 0.3^{o}C per decade reaching to approximately1 and 3^{o}C above the present value by years 2025 and 2100, respectively and leads to global warming.

Agriculture is one of the few sectors of the modern economy directly exposed to and thus likely to be effected by climate change. Climate change is expected to impact crop yield both in positive and negative ways, though the magnitude may differ at various locations. An assessment of the possible net impact of climate change can help in formulating new strategies to mitigate negative impacts while sustaining positive impacts of climate change on crop production through proper adaptation methodology.Recent studies confirm that the impact of global warming beyond a certain limit may be serious for agricultural productivity (IPCC, 2007).

Different aspects of climate change such as higher atmospheric CO_2 concentration and increased solar radiation and temperature have different effects on plant production and crop yields. In general, higher CO_2concentration increases plant production because the increased content of CO_2 in the air stimulates photosynthesis. Simultaneously, the transpiration intensity is reduced by partially closing the stomata, which leads to the improved water use efficiency (WUE) (Dhakhwa*et al.*, 1997; Leakey *et al.*, 2009). Increasing solar radiation simulates the leaf assimilation (Wolf and van Diepen, 1995) thereby increasing the yields (Maytin *et al.*, 1995; Brown and Rosenberg, 1997). However, as the increased solar radiation stimulates evapotranspiration, the yields may decrease due to a deepened water stress if the water supply is at its critical level. Rising temperature will leads to altered growing season of agriculture crops by allowing the threshold temperature for the start of the season and crop maturity to reach earlier (Porter 2005). High temperature affects morphological, biochemical and physiological processes in plants and the major effect entail scorching of aerial plant parts, leaf abscission and senescence and causes inhibition of root and shoot growth and ultimately reduced yield in maize (Ashraf and Hafeez, 2004; Wahid *et al*., 2007).

The interaction of these factors will determine the impact on crop productivity, management and economics of agriculture and climate change. Since both carbon dioxide concentration and temperature are among the most important environmental variables that regulate physiological and phenological processes in plants, it is critical to evaluate the effects of CO_2 concentration and air temperature on the growth and yield of key crop plants. Because changes in carbon dioxide concentration and temperature are likely to occur concomitantly, it is of particular interest to quantify the interactions of these two variables.

Crop growth models have considerable potential in agriculture research, development of cropping technologies and the exploration of management and policy decisions for implementations and adapting to current and future climate change (Boote *et al*., 1996). Crop modeling helps to understand functioning of crops and agricultural systems and particularly about the interactions between crops and their environment (Jones *et al*., 2000; Hammer *et al*., 2002).The decision support system for Agrotechnology transfer (DSSAT) was developed to operationalize this approach and make it available for global applications. The DSSAT helps decision-makers by reducing the time and human resources required for analyzing complex alternative decisions (Tsuji *et al*., 1998).

The objectives of this study is to assess the impact of important components of climate change i.e. temperature, $CO_2$and solar radiation on the productivity of maize by comparing model crop yields simulated with use of weather series representing the present climate and changed climate (Fig 1).

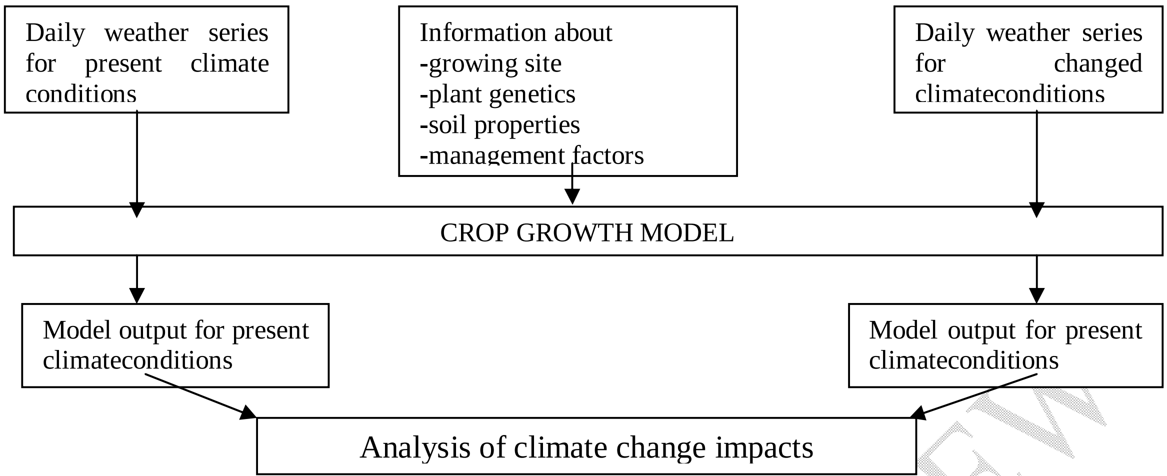

Fig. 1: The scheme of thecrop model experiments used in climate change impact studies

MATERIAL AND METHOD

Study Site

The field experiments were conducted during Kharif seasons of 2018 to 2020 at KVK,Reasi Farm SKUAST- Jammu. The geographical location of which is 32^0 59' North latitude and 74^0 58' East longitude at an elevation of 867 meters above MSL. The annual rainfall is 917.5 mm, which mostly occur during June to September. July receives highest monthly rainfall of 345.6 mm followed by August 210.5 mm. A solar radiation receipt is lowest (13.1 Wm^{-2}) during January followed by December (13.3 Wm^{-2}). The maximum solar radiation is observed during May (22.8 Wm^{-2}). The mean monthly maximum temperature varies between 17.5^0C in January to 38.5^0C in June while minimum temperature increases from 5.7^0C in January to 25.3^0C in July and thereafter decreases continuously to 7.1^0C in December.The soil was sandy loam in texture with 67% sand, 21% silt and 12.5% clay having soil moisture retention capacity.

Crop model

To investigate physiological responses of the maize crop to changes in climate, crop growth model CERES-Maize version 4 is used in this study. The model was developed within the frame of IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project and was run with in the DSSAT [Decision Support System for Agrotechnology Transfer]environment. The model was chosen because of its ability to simulate both the stressed yield, which is limited by the genetic potential of the crop, temperature, solar radiation and available water and nutrients and the potential yield which is limited by the genetic potential of the crop, temperature and solar radiation.

The CERES-Maize model is a mechanistic process- based model, which increments crop growth in the daily steps. The input data required for the simulations include: (i) cultivar characteristics (given in terms of genetic coefficients), (ii) field attributes (slope, drains, longitude, latitude), (iii) soil characterstics (texture, bulk density), (iv)planting details (date of seeding, seedling population, row spacing, planting depth), (v)management factors (tillage irrigation and fertilization), (vi) series of daily weather characteristics (sum of solar radiation, maximum and minimum air temperature and precipitation amount)

The CERES-maize was calibrated and validated with the data obtained from experimental field. The model was run for three year (2004-06) with baseline climate and climate change scenarios under rainfed and irrigated conditions.

Input Data to CERES-Maize model

Weather data of the study area were collected from the observatory of Agrometereological Research Field, Main Campus Chatha, SKUAST-J, Jammu for a period of three years (2004-2006). This includes maximum and minimum temperature, precipitation and solar radiation. Calibrated crop coefficients of the maize crop and soil data were collected. The variety of maize for which calibrated coefficients were taken is Ganga Safed-2. The calibrated coefficients were validated for another year.

Climate change scenario

Thegrowth and yield of maize under current weather and CO_2 condition as well as under different changing scenarios with rise in temperature, solar radiation and CO_2 was simulated using CERES-maize model. Modifications were introduced to CERES-Maize in order to account for the effect of rising temperature, solar radiation and atmospheric CO_2 on crop growth. Initial CO_2 was fixed at 330 ppm. The model simulations were run at three level of rise in CO_2 (440, 550 and 660 ppm), temperature (1, 3 and 5^0C) and solar radiation(1, 3 and 5MJ m^{-2} day^{-1}) relate to present scenario.

Simulation analyses

Simulations were run with the sowing dates set to 10^{th} June, corresponding to the 161 Julianday of the year. The sowing date corresponds with traditional crop management in the study zone. The effects of temperature, solar radiation and CO_2-induced climate change on crop production, expressed as the relative changes in yields between the baseline and rise in climatic variables, are presented as percentage changes in average yield and other crop growth variables from the baseline.

RESULTS AND DISCUSSION

Impact of elevated temperature

The rise in temperature showed a general tendency towards diminishing future maize yields in the experimental field (Table 1). The yield reduction of maize crop ranged from 9 to 62 percent with subsequent reduction in LAI (1 to 60 percent), biomass

(4 to 64 percent) and grain number (5 to 53 percent).The elevated temperature up to 1^{o}C did not show the marginal effect on grain yield where as significant yield reduction was observed at 3 and 5^{o}C. Under irrigated conditions the reduction was slightly higher than rainfed conditions.The negative effect of rising temperature on yield may be due to the fact that warmer temperatures speed plant development during the earlier part of the season, potentially causing the flowering stage to begin earlier. The increased temperatures during a plant's reproductive period, when grain filling occurs, indirectly cause yield reductions because increased temperatures decrease the reproductive period duration and prevent grains from reaching their potential size by accelerating a maize plant's development (Horie *et al.*, 1995). High temperature caused significantly declines in shoot dry mass, relative growth rate and net assimilation rate in maize, though leaf expansion minimally effected (Ashraf and Hafeez,2004).

Impact of elevated solar radiation

Rise in solar radiation showed gradual yield enhancement (Table 1). The magnitude of increase in yield was 4.40, 12.75 and 17.43 percent under rainfed conditions where as it was 4.65, 13.58 and 22.28 percent under irrigated conditions against different level i.e.1, 3, 5 MJ m^{-2} day^{-1} of solar radiation, respectively. The enhancement of yield was higher under irrigated conditions as compared to rainfed conditions. The other parameters i.e. LAI, biomass and grain number showed the same trend. Increasing solar radiation simulates the leaf assimilation (Wolf and van Diepen, 1995) thereby increasing the yields (Maytin *et al.*, 1995; Brown and Rosenberg, 1997). However, as the increased solar radiation stimulates evapotranspiration, the yields may decrease due to a deepened water stress if the water supply is at its critical level

Impact of elevated CO_2

Elevation of CO_2 in the level of 440, 550 and 660 ppm showed gradual yield increment of 2.01, 3.92 and 5.37 percent under rainfed conditions and 2.33, 4.52 and 7.41 percent under irrigated conditions, respectively (Table 1). The LAI, biomass and grain number was increased by 0.81 to 1.61, 1.82 to 4.36 and 2.01 to 5.35 per cent under rainfed conditions and 1.04 to 2.09, 2.21 to 5.98 and 2.35 to 7.43 percent under irrigated conditions against increased CO_2 level from 440 to 660 ppm, respectively.This may be due to the positive effect of CO_2 on maize growth and yield. Co_2 affects the maize plant by eliciting two direct physiological responses viz. enhanced rates of photosynthesis and reduced stomatal conductance. Greater photosynthesis allows greater carbon gain and biomass accumulation, while reduced stomatal conductance leads to lower transpiration and lower soil moisture depletion, which can delay the water deficit (Leakey *et al.*, 2009). Both aspects enhance the water use efficiency of maize causing increased growth.

Combined effect of doubling CO_2 and rise in temperature

Results of simulated yield and growth parameters clearly indicates that the decline in yield due to temperature stress was compensated through doubling the CO_2 level to 660 ppm, though the range is different at different temperature rise scenarios (Table 2). The double CO_2 compensated the yield reduction due to the temperature rise up to 1^0C. Beyond 1^0C, the rising CO_2 could not completely mitigate the adverse effect of rising temperature in maize. Decrease of yield following rise in temperature up to 3^0C coupled with doubling of CO_2 was 25.68 and 27.44 percent in rainfed and irrigated condition, respectively. This clearly indicates that the negative effects on crop yields of warmer temperatures in the changed climate were stronger than the positive effects of elevated CO_2. The biomass, LAI and grain number decreased similarly as biomass and yield does.

Combined effect of rise in temperature and solar radiation

The effect of rise in temperature and solar radiation on simulated crop yield, LAI, biomass and grain number is shown in the Table 3. Results revealed the increase in yield and other parameters under 1 unit increment in temperature and solar radiation. After that there was a decreasing trend.

CONCLUSION

To conclude, it may be stated that the results obtained from CERES-Maize model are in good agreement with the rules governing the growth and development. Simulated yield was found to be sensitive to changes in atmospheric CO_2, temperature and solar radiation. The elevated CO_2 concentration enhanced growth and yield of maize crop but the beneficial effects of elevated CO_2 decreased or even nullified with rise in temperature.

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Table1:Effect of rise in mean temperature, solar radiation and CO_2 concentration on yield of maize cultivar *var*. Kanchan.

Parameters	**% Change**			
	Crop yield	**LAI**	**Biomass**	**Grain no.**
Temperature (^{0}C)				
Rainfed				
1	-9.18	-1.06	-4.93	-5.06
3	-34.16	-28.99	-33.31	-27.92
5	-60.50	-59.57	-62.76	-52.16
Irrigated				
1	-9.64	-1.04	-5.48	-5.50
3	-35.89	-30.21	-34.47	-29.80
5	-61.48	-60.42	-63.33	-53.33
Solar radiation (MJ m^{-2} day^{-1})				
Rainfed				
1	4.40	2.42	4.00	4.40
3	12.75	5.11	10.30	12.78
5	17.43	6.72	13.88	17.26
Irrigated				
1	4.65	2.61	4.41	4.68

3	13.58	6.27	11.50	13.59
5	22.28	9.04	16.72	22.32
CO_2 (ppm)				
Rainfed				
440	2.01	0.81	1.82	2.01
550	3.92	1.08	3.29	3.94
660	5.37	1.61	4.36	5.35
Irrigated				
440	2.33	1.04	2.21	2.35
550	4.52	1.57	3.92	4.52
660	7.41	2.09	5.98	7.43

Table 2: **Combined effects of doubling CO_2 concentration (660 ppm) and rise in temperature on crop growth of maize.**

Temperature		**% Change**		
(°C)	**Crop yield**	**LAI**	**Biomass**	**Grain no.**
Rainfed				
1	0.42	1.36	3.23	1.08
3	-25.68	-18.56	-16.94	-21.78
5	-54.05	-44.39	-50.00	-54.55
Irrigated				
1	0.81	0.26	1.41	0.90
3	-27.44	-18.54	-23.20	-20.78
5	-55.34	-51.70	-55.50	-45.90

Table 3: **Combined effect of rise in temperature and solar radiation on crop growth of maize**

Temperature (°C)			**% Change**	
& Solar Radiation	**Crop yield**	**LAI**	**Biomass**	**Grain no.**

(MJ m^{-2} day^{-1})

Rainfed				
1	4.78	2.34	0.17	0.46
3	20.17	12.90	16.30	12.56
5	44.35	40.05	43.00	32.62
Irrigated				
1	4.89	3.44	0.41	0.56
3	22.04	14.10	17.58	14.60
5	45.60	40.99	43.62	34.14