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Impact assessment of climate change on wheat crop through DSSAT model in Prayagraj region of Uttar Pradesh

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Abstract
Crop production is naturally sensitive to variability in climate. Temperature and Solar radiation are two important parameters related to climate change, which affect productivity and phenology of crop. Crop Environment Resource Synthesis-Rice (CERES-wheat) model was applied to assess the impact of climate change and variability on physiology and productivity of wheat crop at Prayagraj region, Uttar Pradesh. The simulation of anthesis days, maturity days, and grain yield were carried out for the range of temperature -3 °C and +3 °C with an interval of 1 °C temperature from normal, alone or in combination with solar radiation +1 to +3 MJ m-2day-1 while keeping the other climate variables constant. Anthesis days and maturity days reduced with increasing temperature. Grain yield decreased by 6.6% concurrently with an increase in temperature by 3 °C and an increase in solar radiation (up to 3MJ m-2 day-1) in comparison with the normal conditions. The results revealed that grain yield as simulated by the CERES-Wheat model under high temperature regimes showed a gradual decrease in yield, while the lowering the temperature increased the yield. The impact maximum temperature was found to be more than that of minimum temperature.

Keywords: CERES-wheat, simulation, climate change

Introduction
Wheat (*Triticum aestivum* L.) is considered as a classical example of intimate relationship between plants and human beings. It is the second most important food grain crop of India and is associated with the food security of the country. Uttar Pradesh ranks first in respect of wheat crop coverage, with area of 2, 11,378 ha and production of 4, 69,115 MT but average productivity is much lower 2.219 t/ha in Prayagraj district (DAC, 2017-18) [3]. The availability of wheat has increased from about 79 gm capita^{-1} day^{-1} to more than 185 gm capita^{-1} day^{-1} despite the doubling of the population since 1961 (Bhardwaj *et al.*, 2010) [2]. The wheat production in the country is highly variable due to different agro-climatic conditions. Wheat is a cool-season crop. Cool weather during vegetative growth and warm weather for maturity is ideal for wheat crop. Warm temperature during the growth of wheat may retard heading (Reddy and Reddy, 2008) [10]. Day temperature above 25 ºC during the development and grain filling period tends to decrease grain weight.

Agriculture is extremely sensitive to climate change because the CO_2 concentration and meteorological variables (i.e., temperature, precipitation, and solar radiation) determine resource availability and control fundamental processes involved in crop growth and development). Intergovernmental Panel on Climate Change (IPCC) has predicted 3-4 ºC increase in average temperature by 2080 A.D. and winter may be warmer as compared of monsoon period. If so, winter crop production will be adversely affected due to increased temperature. In agricultural system, growth and development of the crop is more often dependent on the integrated responses of temperature, CO2 concentration, agronomic management, etc. However, it is quite difficult to study the impact of these integrations in field condition, but crop simulation models are the needful tools that can be used to enumerate the integrated impact of climate change and their interaction in the system. The model, Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.7 is a software application program that comprises crop simulation models (Hoogenboom *et al.*, 2017). The CERES (Crop Environment REsource Synthesis)-Wheat (Ritchie *et al.*, 1988) [11] is a process-based, management-oriented model that can simulate the growth and development of wheat crop. Looking to the above research, an attempt has been made in the present investigation to analyze the impact of climate change on wheat yield using CERES-Wheat model v4.7.

Materials and Method

Study area: The present study was carried out taking into account the anticipated regional climatic changes for Prayagraj region, Uttar Pradesh. The climate of Prayagraj has a humid subtropical, controlled by south-west monsoon, common to cities in the plains of North India, designated *Cwa* in the Köppen *climate classification*: This region falls in semi-arid to sub-humid type of climate. Praygaraj soils lay alluvial of Indo-Gangetic plain with mostly soil order *Inceptisols.* Generally, soil texture has sandy loam to sandy clay loam (Rai *et al.,* 2011).

Software used: The DSSAT-CERES wheat model is widely used to simulate the effect of weather, soil characteristics, genotype and management factors on the growth and development of dry and wet irrigated wheat.

Methodology: The effects of changes in temperature and solar radiation on phenology (anthesis and maturity days) and productivity (grain yield) of wheat under climatic condition of district Prayagaraj have been studied here using DSSAT-CERES wheat model v4.7. The genetic coefficients of wheat cultivar WH-711 were used. The model was calibrated and validated with conducted field experiment at the College of Forestry farm, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, UP, India of two years 2015-16 and 2016-17. For year 2018-19 climate modification were studied through Environmental modification component of DSSAT. Daily historical weather data of prayagraj (25º 43' N latitude and 81º 84' E longitude and 94 meter above mean sea level) were obtained from College of Forestry, Sam Higginbottom University of Agriculture, Technology and Sciences. The widely accepted approach to analyze possible effects of different climatic parameters on crop growth and yield by specifying the incremental changes to climatic parameter and applying these changes uniformly to baseline/normal climate was also employed in the present study (Hundal and Kaur, 2007). The simulation of anthesis days, maturity days, grain yield were carried out for the range of temperature (maximum and minimum both) -3 °C and +3 °C with an interval of 1 °C temperature from normal, alone or in combination with solar radiation+1 to +3 MJ m-2day-1 while keeping the other climate variables constant. The major reason for using incremental variable scenarios is that they capture a wide range of potential changes. Subsequently, the combination of two variables was used to assess their combination effect on wheat crop.

Results and Discussion

Impact of temperature and solar radiation on phenology of wheat crop

Effect on anthesis day

Results on effects of temperatures and solar radiation on days of anthesis of wheat are presented in Table 2. Days were simulated with combinations and alone of temperature and solar radiation. The anthesis days were simulated at 68 days after sowing in normal weather condition (no environment modification) (Table 1). The simulated anthesis days of wheat by CERES-wheat model under incremental units of temperature (1 to 3 °C) and showed gradual decrease in days ranging from (1 to 4 days). While model under decremental units of temperature (1 to 3 °C) showed gradual increase in number of days ranging from (1 to 3 days). While increasing the temperature by 1 °C, 2 °C and 3 °C along with the combination of solar radiation i.e. +1, +2 and +3 MJ m^{-2} day^{-1} respectively, the anthesis days are proportionally decreased by 1 day, 2 days and 4 days respectively. Patel *et al.* (2017) [8, 9] reported the same result that increasing in temperature above normal decreased the anthesis days. Higher temperatures could also accelerate plant development and therefore, shorten the growth period Lal *et al.* (1998) [6].

Effect on maturity days

The days of maturity were simulated with various combinations of temperature and solar radiation as well as temperature and solar radiation alone. The maturity days were simulated at 104 days after sowing in normal weather condition (no environment modification) (Table 1). While increasing the temperature by 1 °C, 2 °C and 3 °C along with the combination of solar radiation i.e. +1 +2 and +3 MJ m^{-2} day^{-1}, respectively, the maturity days proportionally decreased by 1 day, 2 days and 4 days respectively.

The simulated Maturity days of wheat by CERES-wheat model under incremental units of temperature (1 to 3 °C) showed gradual decrease in days while vice versa with decrease of temperature. While model under incremental units of solar radiation (+1 to +3 MJ m^{-2} day^{-1}) showed gradual increase in days but vice versa with decrease of solar radiation. Patel, *et al.* (2017) [8, 9] reported the same that increasing in temperature below normal decreased the maturity days. Higher temperatures could also accelerate plant development and therefore, shorten the growth period Lal *et al*., (1998) [6].

Table 1: Days after Showing (DAS) to simulate anthesis days and maturity days with grain yield and straw yield under normal weather condition (no modification in weather data)

Anthesis days (DAS)	Maturity days (DAS)	Grain yield (Kg^{-1})	Straw yield (Kg^{-1})
68	104	3835	6570

Impact of temperature and solar radiation on productivity of wheat crop

Effect on grain yield

The grain yield was simulated 3835 kg ha-1 under normal weather parameters (no environment modification) (Table 1). The decrease in temperature from 1 to 3 °C increased productivity by 4 to 8.8% i.e.:- 3990 - 4169 kg ha^{-1} (Table 2). Contrary to this, increase in temperature from 1 to 3 °C decreased productivity by 4 to 6.6% i.e.:- 3678-3582 kg ha^{-1}. Increase in radiation from 1 to 3 MJ m-2 day-1 increased productivity by 4.9 to 9.5% i.e.:- 4007- 4189 kg ha^{-1}. Contrary to this, decrease in radiation from 1 to 3 MJ m-2 day-1 decrease productivity by to 4.3 to 13.3% i.e.:- 3677 -3323 kg ha^{-1}.

The changes in temperature and solar radiation simultaneously below and above normal weather condition have affected grain yield. In case of increasing temperature as well as increasing solar radiation with different combinations simultaneously above the normal condition decreased grain yield by 2.4 to 3.6% ie:-. While, in case of decreasing temperature as well as decreasing solar radiation with different combinations decreased grain yield by 1.9 to 7.22%. The reduction in yield was mainly due to reduction in duration of anthesis and grain filling with rise in ambient temperature and vice versa as reported by Aggarwal and Kalra (1994) and Muchow *et al*. (1997).

Similarly, Pathak *et al*. (2003) and Patel (2004) also reported based on the sensitivity analysis of CERES-wheat model that higher maximum temperature decreased wheat yield significantly. This showed that wheat yield was found to be highly sensitive to change in temperature especially if the temperature analomies occurs at grain filling stage. The increase and decrease in maximum and minimum temperature was carried out in grain filling stage of wheat crop.

Table 2: Simulated days of maturity, days of anthesis and grain yield of wheat crop due to alteration in parameters of solar radiation and temperature.

Change in parameters	Days to anthesis	Days to maturity	Simulated grain yield (kg/ha)	% Change from base (3835 kg/ha) yield
Temperture				
+3	64	101	3582	-6.6
+2	65	102	3595	-6.2
+1	67	103	3678	-4.09
-1	69	106	3990	4.04
-2	70	107	3994	4.14
- 3	71	108	4169	8.8
Solar Radiation				
+3	70	106	4196	9.5
+2	69	105	4189	9.3
+1	68	104	4007	4.9
-1	68	104	3677	-4.3
-2	68	103	3494	-8.9
- 3	67	102	3323	-13.3
Combination of temperature and solar radiation				
+1 & 1 °C	67	103	3823	-.3
+2 & 2 °C	65	102	3741	-2.45
+3& 3 °C	64	100	3695	-3.6
-1&-1 °C	68	105	3760	-1.95
-2&-2 °C	69	106	3605	-6
-3&-3 °C	70	107	3558	-7.22

Conclusions

In nutshell, increase in temperature significantly reduced the wheat yield while decrease in temperature increased the yield. The effect of maximum temperature on yield was more than that of minimum temperature. The combined effect of temperature and solar radiation were very marginal at the lower side of yield. Temperature is directly related to plant development. Hence, an increase or decrease in temperature directly affect the length of days of anthesis and maturity. The interactive effects of increasing temperature and solar radiation simultaneously revealed a cumulative adverse effect on productivity of wheat. The results of this simulation indicate that solar radiation directly affects crop yield. Highest potential productivity of a crop is therefore obtained in regions where crop duration is more under relatively low temperatures and more radiation received as compared to the normal. Such simulation studies can guide us in determining the effect of climate variability and changes on productivity of wheat crop and can be used for crop yield forecasting and further policy planning by the government.

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