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Modeling the impact of anticipated climate change on wheat yields in two different agro-climatic zones of eastern India

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ABSTRACT

Wheat is the major cereal crop of winter season in the Indo-gangetic plains of India. The study is aimed to analyze impact of climate change on wheat varieties viz. K-9107 and HD-2733, under two different agroclimatic zones using simulation model InfoCrop. Model was calibrated and validated for Patna and Ranchi centres. Sensitivity analysis indicated declining yield trend with increase in temperature. Wheat yields simulated for future climate change scenario HADCM3 A2 for different time periods viz. 2020, 2050 and 2080. Simulated wheat yield showed decline from 3 to 38 percent for Patna and 3 to 28 percent for Ranchi. Due to higher temperature in future scenario the days to anthesis, days to maturity and grain number showed decline for both the locations.

Key words: Climate change, scenarios, simulation study, wheat, agroclimatic zones,

Climate change refers to the variation in the earth's global climate or in regional climates over large time scales, evident from the observations of increase in global average air temperature, extreme weather events, melting of snow and ice, sea surface temperature increase etc. It is expected that the increasing concentration of greenhouse gases in the atmosphere would affect the climate; global mean surface temperature is projected to increase by 2.0 to 5.4^{0}C for A2 scenario during 2090 to 2099 relative to 1980-1999 (Intergovernmental Panel on Climate Change, 2007). Regional weather remains the dynamic force in agricultural production and meteorological variables (precipitation. regimes, increasing temperatures etc.) and CO_2 levels affects crop production biophysically. Although increasing level of CO_2 may increase the net primary productivity of crops, changes in meteorological variables may lead to increased or decreased gross production of crops. In India major part of the population is engaged in agriculture or agriculture based enterprises so, changing climate may impair India's food security by hampering agricultural production in more than one ways. To overcome the negative effects of climate change, a pre-assessment of the approaching situation can be quite helpful in managing the change for benefit. The direct effect of increased levels of CO_2 are generally beneficial to vegetation, though global warming and other climatic changes may have a range of negative and positive impacts depending on complex interactions among managed and unmanaged ecosystems (Watson *et al.,* 1995). Dynamic crop growth models are widely used to project the effects of rising atmospheric CO_2 concentration and associated climate change on crop yields. Although these models are far from perfect and sometimes rely on assumptions that have not been fully tested, they are the best tool we have at present to investigate the effects of likely climate changes on agricultural production. Pathak *et al*. (2003) observed decreasing trends of potential yields of rice and wheat in Indo-Gangetic plains of India with increasing minimum temperature and decrease in solar radiations. An increase in minimum temperature by 2°C could decrease rice yield by about 0.75 t h^{-1} in the high yield areas and about 0.06 ton/hectare in the low yield coastal regions of India (Sinha and Swaminathan, 1991).Simulation studies for rice (MTU-7029) at Patna showed decline in yield by as much as 31% for 2080 scenario (Haris *et al.,* 2010). Wheat crop matured 10-20 days earlier and wheat production declined by more than 4 million tonnes in Indo–Gangetic plains when temperature increased by 3-6ºC in March 2004 equivalent to average 1ºC per day rise in the crop season (Aggarwal, 2008). Fifty one percent decrease in the most favorable and high yielding regions of India due to heat stress, likely to reduce wheat yield (Govindasamy *et al.,* 2003).

This study was undertaken at ICAR-Research Complex for Eastern Region, Patna as part of the "Network Project on Climate Change" to assess the impacts of probable changes in climate with time, on the wheat yield grown in Bihar and Jharkhand.

MATERIALS AND METHODS

Location

In this study, Ranchi in Jharkhand and Patna in Bihar are selected, on the basis of availability of data, to simulate the effects of climate change on wheat yield. Bihar is situated in Middle Gangetic Plain Zone (zone 4) and Jharkahand in Eastern Plateau and Hills region (zone 7) based on agroclimatic zones/regions in India. Patna lies in N8Cd5 agro-ecosub region (Avadh Plain and South Bihar Plain) at 25.58°N latitude, 85.25°E longitude and 41m altitude with 700-1000 m rainfall and 24-26°C mean temperature, whereas Ranchi is in J2Cd5 (Eastern Chhotanagpur Plateau and Gujarat Hills

Table 1: Coefficient of efficiency based on validation of InfoCrop model for study area

Variety	Ist Year		IInd Year		IIIrd Year		Coefficient of efficiency
	Observed	Simulated	Observed	Simulated	Observed	Simulated	
K-9107	4210	4455	3768	3827	4360	4404	0.65
HD-2733	2597	2618	3289	3305	2787	2687	0.85

Table 2: Change in phenology (days) and yield (%) for A2 scenarios at Ranchi and Patna

Year	Days to Anthesis		Days to Maturity		Yield	
	Ranchi	Patna	Ranchi	Patna	Ranchi	Patna
2020	-6	-11	-7	-17	-3	-3
2050	-15	-19	-17	-27	-14	-25
2080	-20	-23	-23	-33	-27	-38

hot dry subhumid) agro-ecosub region at 23.19°N latitude, 85.27°E longitude and 650 m with 1200-1600 mm rainfall and 25-27°C mean temperature (Velayutham *et al.* 1999).

Crop model used

In this study InfoCrop model developed at IARI, Pusa by Aggarwal *et al,* (2004) was used. The inputs required by the model include soil data (soil texture, pH, organic matter, bulk density and soil hydraulic characteristics etc.), crop management data (sowing date, sowing depth amount and time of application of irrigation, fertilizer, etc.), daily weather data (maximum temperature, minimum temperature, rainfall, solar radiation, wind speed and vapour pressure) and variety specific genetic coefficients data. The daily meteorological data, crop and soil data were collected from, ICAR-Research Complex for Eastern Region, Patna and from Birsa Agricultural University, Ranchi.

Crop specific generic variables characterize the difference in performance among varieties. Initial values for coefficients were first supplied to run the model according to cultivar characteristics, then trial and error type hypothesis method was used to reduce the difference between simulated and observed grain yield and crop duration, the most matching values were worked out.

In the present study, varieties HD-2733 and K-9107 are selected for Patna and Ranchi respectively. The accuracy of the model was evaluated by calculating the coefficient of efficiency based on the model adopted from Hubbard *et al*., (2003). After calibrating, the model was run for the baseline and scenarios based on the practices used for validation purposes.

Climate change scenarios

The IPCC's Special Report on Emission Scenario (SRES) describes future scenarios projecting greenhouse gas emissions. The SRES scenarios set comprises of four scenario families, viz. A1, A2, B1, B2 (Yao *et al.,* 2007). A2 scenario is selected for the current study, which is a high emission level. The CO_2 concentration for SRES A2 scenario increases from 370 ppm to 682 ppm for 2080. The General Circulation Model (GCM) projections of Hadley Center for Climate Prediction and Research, Model ver.3 (HADCM3) were used in this study. Factors for maximum temperature, minimum temperature and rainfall from A2 scenario were incorporated individually, into each year of historical weather data i.e. baseline (1961-1990) to generate 2020, 2050 and 2080 climate scenarios and this data is later used to simulate wheat yields for two centers.

Expected changes in Temperature = Baseline temperature + Expected change in temperature obtained from HADCM3 outputs

Expected changes in Precipitation = Baseline daily rainfall x (1+ % change in rainfall)

Impact on wheat

Yields of wheat was first simulated at 370 ppm of CO_2 for the baseline period (1961-1990). The concentration of CO_2 was then increased to 414, 522 and 682 ppm to simulate the yields. Impact of climate change on wheat was simulated using factors for HADCM3 A2 scenario and concomitant CO_2 increase as described earlier.

RESULTS AND DISCUSSION

Crop model validation

Model was tested and validated for two varieties of wheat and coefficient of efficiency arrived ranged between 65 to 85% (Table 1). In general, the model effectively simulates grain yield and duration except for unusually high or low yield experiments may be due to faulty observations, pest damage or some weather extremes experienced during critical stages.

Impacts of climate change on wheat

Sensitivity analysis revealed that yield of wheat decreased from the current levels on increasing the maximum and minimum temperatures. In Ranchi region, wheat yield decreased by 3% in 2020, 14% in 2050 and 27 % in 2080 A2 scenario from the baseline yield (Table 2). Days to anthesis and days to maturity decreased by 6, 15, 20 and 7, 17, 23 days for 2020, 2050 and 2080 respectively from baseline. Yield of wheat declined by 3, 25 and 38 % in 2020, 2050 and 2080 respectively for A2 scenarios at Patna. Days to anthesis and days to maturity decreased by 11, 19, 23 and 17, 27, 33 days for 2020, 2050 and 2080 respectively from baseline. Number of grains for both locations showed decline with increasing temperature in future time periods. Projected yield decline was more in the case of Patna than Ranchi under A2 scenario.

These results indicate that future climate changes are likely to cause decline in wheat yields. Similar results were also obtained in nine out of 11 districts in upper gangetic plains.

CONCLUSION

From the above study, it can be concluded that the yield of wheat may decrease over the present yields with the current cultivars and ongoing practices. The yield, days to anthesis and maturity is showing a declining trend may be due to increased temperature during the crop growth period. Decline in number of grains could be attributed to thermal stress faced by crop during grain filling stages leading to spikelet sterility. A pre-assessment of the effects of climate change on wheat yield can help in developing management strategies to overcome the negative effects of anticipated changes in climate.

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