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Modeling the Impact of Increased CO_2 Levels on Wheat and Rabi Maize for Different Climate Change Scenarios in Selected Locations of Bihar

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Abstract

Agriculture remains dependent on climate and climatic resources, uneven distribution of monsoonal rainfall, due to climate change, around the country may result in some parts getting flooded while others facing drought, leading to mass migration of people and insecurity of availability of food to all. Timely assessment of climate change effects on agriculture might help to adapt suitable farming techniques to maximize agricultural production. The response of C_3 and C_4 crops to elevated CO_2 levels when exposed frequently to water stress or changes in climatic factors such as temperature or rainfall may provide variable results. Current crop growth models, simulate not only the effect of increased temperature but, also consider the effect of increased CO_2 on morphology and phenology of crop. Simulated yield of wheat (HUW 468) decreases from the baseline in 2050 and 2080 while, a meager increase of 3% may occur in 2020 at Pusa. At Madhepura, a decline of 21% in simulated yield of wheat (HD 2733) from the baseline may be observed for 2080. Patna and Sabour may show a decrease in simulated yield of almost 40 % upto 2080s. Simulated yield of rabi maize may increase to 11 %, 25% and 77 % upto 2020, 2050 and 2080 respectively for the stations under study. Reduction in simulated yield of wheat without CO_2 increase is higher than simulation with CO_2 increase for all stations and scenarios. For 2020s difference in reduction percentage between simulated yield with and without CO_2 increment is less as compared to 2050s and 2080s. While, in case of maize an increase in yield is observed with or without CO_2 increase but the increase is more at enhanced CO_2.

Introduction

Climate change refers to the variation in earth's global climate or in regional climates over timescales ranging from decades to millions of years. Greenhouse gases (GHG's), are effective in trapping heat at the earth's surface, without GHG's, most of the currently cultivated regions of the earth would be too cold for agricultural production. However, human activity is contributing to increases in GHG concentrations in the atmosphere and the increases are causing potentially detrimental changes in temperature and other aspects of climate. The atmospheric concentration of CO_2 in 2005 was 379 ppm compared to the pre-industrial levels of 280 ppm (IPCC 2007). Global annual-mean surface temperature has shown a rapid and widespread increase of 1.4º F (0.7ºC) since the early 20th century with about 0.9º F of that increase occurring after 1978. It is also estimated that by 2100, average temperatures will increase by between 1.4° and 5.8°C (IPCC). Agricultural productivity and production is predicted to decline due to climatic changes. 0.5°C rise in winter temperature would reduce wheat yield by 0.45 tonnes per hectare in India (Lal et al., 1998; Kalra et al., 2003). 2 to 5% decrease in yield potential of wheat and kharif maize for a temperature rise of 0.5 to 1.5°C in India (Aggarwal, 2003).

State of Bihar lies between 24^0 to 27^0N, 83^0 to 88^0E with a height of 52.73 m above mean sea level Bihar is having total geographical area of 9.36 million hectares with cultivable land of 0.58 lakh hectares, with normal rainfall of 1176.4 mm (anonymous 2007). The state falls in the middle-Gangetic plains region. It is sub-divided into three agro-ecological zones. These are, Northwest Alluvial Plains (Zone-I), North-East Alluvial Plains (Zone-II) and South Bihar Alluvial Plains (Zone-III A and III B). Major crops grown in agro-ecological zones of Bihar are depicted in table1. Gross cropped area is maximum (30.07 lakh hectares) for zone I and minimum (6.21 lakh hectares) for zone III B, irrigated area ranges from 3.68 lakh hectares to 18.41 lakh hectares, Zone II receives highest annual rainfall (1387 mm) and is also the coldest among the three zones (average temperature: 21.3^0C). Zone III receives least rainfall (1104 mm) and is also the warmest of the zones of Bihar (average temperature: 22.45 ^{0}C).

Table1: Major crops grown in different locations

Sl. No.	Agro-ecological zones	Major crops
1.	Zone-I	Rice, Wheat, Maize, Gram
2.	Zone-II	Rice, Wheat, Maize, Gram, Lentil
3.	Zone-III (A)	Rice, Wheat, Gram, Potato, Onion, Lentil
4.	Zone-III (B)	Rice, Wheat, Gram

Material and methods

For this study four stations (figure 1) are selected, representing each zone, on the basis of availability of meteorological, soil and crop data. The weather data obtained from different centers was analyzed. The existing data on baseline conditions in the selected locations, crop yields and farmers' practices and yields on the basis of recommended practices are collected. The crop, meteorological and soil data for selected centers are collected from BAC, Sabour (Bhagalpur), IARI, Pusa, TDC, Dholi (Muzaffarpur), IRS, Madhepura, RAU, and Pusa. INFOCROP as a dynamic process growth model is validated and calibrated as per the availability of data for Pusa, Sabour and Patna for wheat, rice, maize and chickpea crop. Info crop model is used to simulate impact of different scenarios of climate change on the basis of available climatic data and crop data. For calibration purpose the input data for model simulation is fixed and consecutively parameterized to the model required form. The model simulates the grain yield and simulated yields are compared with observed yields thus validating the model outputs (table2).
The monthly mean change in maximum and minimum temperature and the monthly percentage change in rainfall given in the HADCM3 GCM projections are incorporated into the baseline (historical weather data) to generate scenarios of 2020, 2050, and 2080.

Table2: Validation results for Pusa location

S.No.	Crop	Coefficient of Efficiency (%)	RMSE (kg/ha)	MAE (kg/ha)
1	Wheat (timely sown)	84	166	137
2	Rabi Maize	70	293	238

Results and Discussion

Variability of climatic parameters of selected stations during rabi season (Nov-April)
Analysis of weather data during the study period showed (table.3) interannual variation in weather variables. Rainfall ranges from 7 to 221.6 mm, 5.8 to 124.1mm, 33.2 to 276.5 mm and 11.8 to 216 mm for Pusa, Patna, Madhepura and Sabour respectively. Rainfall showed almost no significant trend over 30 year period for any station. Rainfall trend shows a decrease in zone I and zone II by 0.46 and 0.42 mm per year respectively, and for zone III A and IIIB, an increase in rainfall by 0.38 and 0.97 per year respectively.

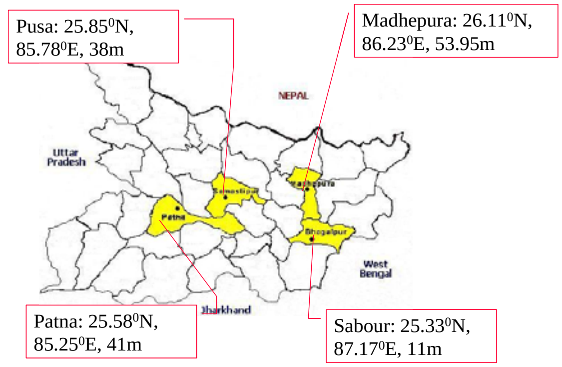

Fig1: selected locations for study

Impacts of climate change on wheat and rabi maize With increased CO_2 levels from 370 (414, 522 and 682ppm) and changing temperature
With the current cultivars, cultivation and management practices, the impacts of climate change on three varieties of wheat namely HD 2733, HUW 468, RW 346 and a variety of maize Ganga-11 under A2 scenario are explored at the selected centers
All the results (figure 2) are taken by comparing the yields between A2 climate change scenario time scales, i.e. 2020, 2050 and 2080, and baseline (1961-1990)
Wheat
Simulated yield of wheat (HUW 468) decreases from the baseline in 2050 and 2080 to 4 and 14% respectively while, a meager increase of 3% may happen upto 2020 at Pusa. At Madhepura, a decline of 5, 13 and 21% in simulated yield of wheat (HD 2733) from the baseline may be observed for 2020, 2050 and 2080 respectively. Patna and Sabour may show a decrease in simulated yield of almost 40 % upto 2080s
Rabi Maize
Simulated yield of rabi maize may increase from 8 to 11 %, 14 to 25 % and 24to 77 % upto 2020, 2050 and 2080 respectively for the stations under study for all the three scenarios from the baseline yield. Maximum increase is observed in Sabour may be due to low baseline yield
With current level of CO_2 but changing temperature
Wheat
Reduction in simulated yield of wheat without CO_2 increase is higher than simulation with CO2 increase for all stations and scenarios. For 2020s difference in reduction percentage between simulated yield with and without CO_2 increase is less as compared to 2050s and 2080s, considering increase in CO_2 while simulating, has a beneficial effect on the yield upto 10% for 2080 scenario.

Rabi Maize

An increase in yield is observed with or without CO_2 increase but it is more if CO_2 enhancement is considered. The difference in yield is meager for 2020 and 2050, while the difference between the increase percentage for 2080 with and without CO_2 increase shows a marked difference.

Increasing temperature reduces duration of wheat crop (Midmore et al., 1982). Loss of chlorophyll during grain filling has been associated with reduced field performance of wheat in warm environments (Reynolds et.al., 2000). Fischer (1985) calculated a kernel number reduction rate of 4% per ^{0}C in wheat ranging between 14^{0}C-22^{0}C. Reduced source on yield is confirmed by reduced kernel weight in response to elevated temperature, with kernel weight affected typically by a 2-5% decrease per ^{0}C increase (Wardlaw and Wrigly 1994). These are the possible reasons for reduced yield performance of wheat with increased temperature under different climate change scenarios.

Cultivation of Maize is limited by cold sensitivity as manifested by retardation of growth at temp. 10-15^{0}C (Stamp, 1984; Verheul et al., 1996) as well as by leaf necrosis and plant death at temperatures below 10 °C (Janowiak and Markowski, 1994). Maize is a C4 crop and is remarkably tolerant of high temperatures (Jones and Thornton, 2003). Hardcare and Turnbull (1986) observed that relative growth rate and net assimilation rate of maize increased with temperature in controlled environments from 16 to 28 ^{0}C. Thus maize possibly benefits from increase in minimum temperature and CO_2 under future scenarios. Elevated CO_2 alone tends to increase growth and yield of most agricultural plants by regulating the opening and closing of stomata, reducing transpiration per unit leaf area thus enhancing photosynthesis as well as water use efficiency (Parry et al., 2004).

From this study it can be concluded that increasing temperature may prove harmful for the wheat crop while it is proving beneficial for the maize crop grown during rabi season. Increasing the levels of CO_2 is affecting the wheat and maize crop beneficially, by bringing an increase in yield. Decrease in yield of wheat in different scenarios, may be attributed to the increase in maximum temperature while the increase in maize yield may be because of the higher night temperatures. Maize crop being sensitive to cold temperature stress and also being more tolerant to higher temperatures is able to thrive well in warmer temperatures that might develop in future. The study is based on present varieties and management practices and does not include the possible effect of pest and diseases and changes in soil parameters with increased temperature.

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Table3: Analysis of weather data for baseline period at selected locations

	Pusa (Zone I)			**Madhepura (Zone II)**			**Patna (Zone IIIA)**			**Sabour (Zone IIIB)**		
	TMIN	TMAX	RAIN	TMIN	TMAX	RAIN	TMIN	TMAX	RAIN	TMIN	TMAX	RAIN
MEAN	12.57	28.30	59.75	12.53	27.80	100.47	13.38	28.24	60.05	13.14	28.26	66.2
SD	1.01	0.56	41.30	1.07	0.60	56.26	0.82	0.62	33.08	0.51	0.63	44.3
MAX	15.93	29.65	221.6	14.85	28.36	276.50	14.70	29.22	124.40	13.91	29.25	216
MIN	10.40	26.92	7.00	10.17	26.16	33.20	11.86	26.80	5.80	12.24	27.03	11.8
RANGE	5.53	2.73	214.6	4.68	2.20	243.30	2.84	2.42	118.60	1.67	2.21	204

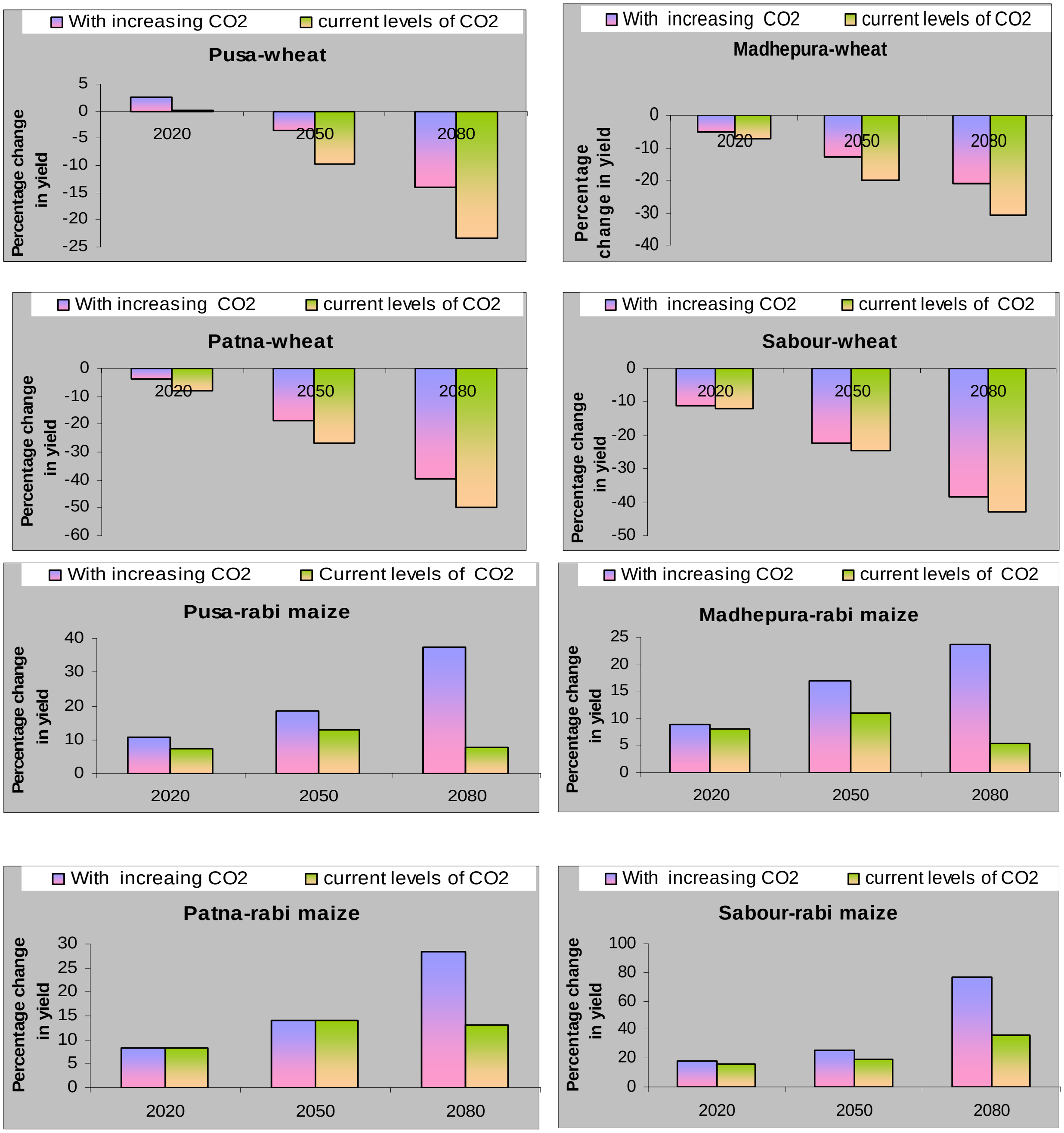

Figure2: Impact of climate change on yield of timely sown wheat and rabi maize at selected centers with increasing CO_2 and without increase in CO_2