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# Impact of elevated temperature and $CO_2$ on yield of wheat in Bihar

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## ABSTRACT

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 was made to assess the impact of these parameters on the productivity of wheat crop in Bihar. For this purpose CROPSIM-CERES-Wheat model 4.6 was used in which weather data of 1981-2010 was used as baseline to assess the change in wheat yield under different climate change scenarios for four locations viz. Pusa (zone I), Purnia (zone II), Sabour (zone III A) and Patna (zone III B) in Bihar. The model was run for the scenarios like 1°, 2°, 3° and 4 ° C increase in mean temperature keeping all parameters normal. Similarly change in yield of wheat at increased $CO_2$ at 700 ppm and 850 ppm was studied. The effect of different combinations of increased temperature and $CO_2$ on wheat yield was also studied. Simulated wheat productivity revealed the reduction in grain yield by 7.4 to 38.6 per cent in response to temperature rise up to $4^0$ C at all locations. The elevated $CO_2$ (from 350 ppm up to 850 ppm) increased the yield by 39.1 per cent. Increased temperature with combination of increased $CO_2$ concentration reduced the yield by 2.1-16.0 per cent for different combinations at different locations. The maximum reduction in simulated wheat yield was observed at combination of 2 ° C increase in temperature with 450 ppm $CO_2$ concentration at all locations in Bihar.

***Key words:*** Climate change, CROPSIM Wheat model, temperature rise, $CO_2$ conc., wheat

Climate change is one of the primary concerns for humanity in the 21st century. Inter-Governmental Panel on Climate change (IPCC) Fifth Assessment Report concludes that increasing numbers of warm days and decreasing numbers of cold days have been observed, with the warming trend continuing into the new millennium. Increasing annual mean temperature trends at the country scale in East and South Asia have been observed during the 20th century. Ensemble-mean changes in mean annual temperature exceed 2°C above the late-20th-century baseline over most land areas in the mid-21st-century under RCP8.5, and range from greater than 3°C over South and Southeast Asia to greater than 6°Cover high latitudes in the late-21st century (IPCC, 2014). In the Indo-Gangetic Plains of South Asia there could be a decrease of about 50 per cent in the most favourable and high-yielding wheat area as a result of heat stress at two times $CO_2$ (IPCC, 2014). High $CO_2$ and other GHGs tend to warm up the atmosphere, besides affecting other meteorological variables.

Climate change is expected to impact crop yield both in positive and negative ways, though the magnitude may vary from place to place. Significant increasing trend of annual maximum and minimum temperatures have been reported from Bihar (Kumar and Kumar, 2017). Although increase in atmospheric $CO_2$ has a fertilization effect on crops with $C_3$ photo synthetic pathway and thus promotes their growth and productivity, on the other hand, it can reduce crop duration. Changes in temperature play a crucial role in determining crop productivity (Fiscus *et al.,* 1997). Small changes in growing season temperature over the years appear to be the key aspect of weather affecting yearly wheat yield fluctuations (Mall *et al.,* 2000). With subsequent rise in temperature reduced the yield of wheat and enhanced $CO_2$ was unable to counter balance the decline in wheat yield (Vahab *et al.,* 2013). Kumar *et al*., (2013) reported the reduction in wheat yield in Haryana by 16-18 per cent by increasing the maximum and minimum temperature up to 2.5 °C from baseline temperature. Keeping the above in view, an attempt was made to assess the impact of climate change in respect of temperature and $CO_2$ concentration on the productivity of wheat by comparing model crop yields simulated with use of weather series representing the present climate and changed climate.

## MATERIALS AND METHODS

### *Study sites*

Four stations were selected representing different zones viz. Pusa (zone I), Purnea (zone II), Sabour (zone III A), Patna (zone III B). The soil belongs to the major group of Indo-Gangetic alluvium and is sandy loam in texture in zone I and II, whereas sandy clay loam in zone III A and III B.

**Table 1:** Different emission scenarios as per IPCC fourth and fifth assessment report

| Emission scenarios | Description | $CO_2$ equivalent by 2100 in (ppm) | Projected changes in global mean surface air temperature 2046-2065 | 2081-2100 | SRES equivalent |
|---|---|---|---|---|---|
| RCP8.5 | Rising radiative forcing pathway leading to 8.5 $Wm^{-2}$ in 2100 | 1370 | 2.0 (1.4-2.6) | 3.7 (2.6-4.8) | $A_1F_1$ |
| RCP6.0 | Stabilization without overshoot pathway to 6.0 $Wm^{-2}$ at 2100 | 850 | 1.3 (0.8-1.8) | 2.2 (1.4-3.1) | $B_2$ |
| RCP4.5 | Stabilization without overshoot pathway to 4.5 $Wm^{-2}$ | 650 | 1.4 (0.9-2.0) | 1.8 (1.1-2.6) | $B_1$ |
| RCP2.6 | Peak in radiative forcing at ~3 $Wm^{-2}$ before 2100, afterwards decline | 490 | 1.0 (0.4-1.6) | 1.0 (0.3-1.7) | None |

RCP: Representative Concentration Pathways, specific emission trajectory suggested by IPCC fifth assessment report.

SRES: Specific Report on emission Scenarios, as suggested by IPCC fourth assessment report

***Data requirement for DSSAT simulation model***

To investigate physiological responses of wheat crop to changes in climate, crop growth model CROPSIM-CERES-Wheat version 4.6 in DSSAT v. 4.6 was used in this study. For calibration and validation of the model, observed weather data were obtained from India Meteorological Department, Pune for Pusa, Purnia, Sabour and Patna stations. The experimental data of wheat cultivar HD2733 were used for the genetic coefficient and crop management. The calibrated genetic coefficient of wheat was used for simulation of baseline and projected yield for different locations in the region.

***Climate change scenarios***

The yield of wheat under current weather and $CO_2$ condition as well as under different changing scenarios with rise in temperature and $CO_2$ was simulated using CROPSIM-CERES-Wheat model. The range of temperature and $CO_2$ concentrations used in the model, were based on the IPCC fifth assessment report (AR 5, 2013) which is presented in Table 1. Unmodified current climate data of 30 years (1981-2010) was considered as baseline. The model was run for 12 assumed scenarios keeping other factors constant (Table 2). The change in yield of the wheat crop from baseline mean yield was calculated in different scenarios.

## RESULTS AND DISCUSSION

***Impact of elevated temperature and $CO_2$***

The yield reduction of 7.4 to 38.6 per cent was observed with increase in mean temperature by 1 to 4 °C at all the locationsand maximum yield reduction was observed at Sabour (Table 2). 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. Pandey *et al.* (2007) have reported that increase in temperature by 1 to 3 °C caused reduction in wheat yield by 8 to 31 per cent in Gujarat.

With doubling the carbon dioxide concentration from 350 to 700 ppm, the yield of wheat was increased by 22 to 27.7 per cent at different locations (Table 2). A doubling of $CO_2$ concentration generally increases photosynthesis and can lead to a substantial increase in wheat growth and yield (Annette, 2003).

***Combined effect of elevated temperature and $CO_2$***

It was observed that by increasing 1°C mean temperature at $CO_2$ concentration of 400 ppm the wheat yield decreased at all the locations by 6 to 8.8 per cent. The combination of 450 ppm $CO_2$ and 2 °C temperature increase resulted in reduction of wheat yield by 11.5 to 16.0 per cent. Even the combination of 500 ppm $CO_2$ and 2 °C increase in mean temperature also resulted in reduction in the wheat yield by 7.8 to 12.2 per cent. Further increase in temperature by 3 °C and $CO_2$ at 700 ppm reduced the yield by 4.5 to 10.2 per cent. The maximum reduction in simulated wheat yield was observed at combination of 2°C increase in temperature with 450 ppm $CO_2$ concentration at all locations. Results of simulated yield clearly indicates that the decline in yield due to temperature stress was compensated through increase in $CO_2$ level at certain level only. This clearly indicates that the negative effects on crop yields of warmer temperatures in the changed climate were stronger than the positive effect of elevated $CO_2$. The combined simulation of increased temperature and $CO_2$ on grain yield revealed that at increased temperature and $CO_2$ decreased the yield in all the scenarios

**Table 2:** Change in yield (%) of wheat crop in different scenarios of climate change at different stations representing different agro-ecological zones of Bihar

| Climate change scenarios | Pusa | Purnea | Sabour | Patna |
|---|---|---|---|---|
| Mean temperature + 1°C | -7.4 | -8.8 | -10.4 | -7.6 |
| Mean temperature +2°C | -16.3 | -18.4 | -21.2 | -15.3 |
| Mean temperature +3°C | -24.4 | -27.0 | -30.9 | -21.6 |
| Mean temperature +4°C | -31.1 | -34.9 | -38.6 | -26.9 |
| No change in temperature &$CO_2$ 700 ppm | 22.0 | 23.1 | 27.7 | 26.0 |
| No Change in temperature &$CO_2$ 850 ppm | 28.7 | 30.0 | 39.1 | 35.0 |
| Mean temperature +1°C& $CO_2$ 400 ppm | -6.0 | -7.3 | -8.8 | -6.2 |
| Mean temperature +1°C&$CO_2$ 450 ppm | -2.4 | -3.7 | -4.9 | -2.7 |
| Mean temperature +2°C&$CO_2$ 450 ppm | -11.5 | -13.5 | -16.0 | -10.8 |
| Mean temperature +2°C&$CO_2$ 500 ppm | -7.8 | -9.6 | -12.2 | -7.3 |
| Mean temperature + 3°C&$CO_2$ 700 ppm | -4.5 | -6.1 | -10.2 | -2.4 |
| Mean temperature +4°C&$CO_2$ 850 ppm | -6.0 | -9.1 | -13.2 | -2.1 |

but loss of yield is less as the $CO_2$ concentration is increased with increased temperature.

## CONCLUSIONS

Future climate change is expected to impact wheat production in Bihar to a greater extent. Wheat yields are expected to decline by 7.4 to 38.6 per cent in response to temperature rise by $1^0$ to $4^0$ C for all locations. In contrast, the doubling of $CO_2$ (from 350 ppm) may increase the yield by 22-27.7 per cent.The negative effect of higher temperature could not be fully compensated by increase in $CO_2$ concentration.The maximum reduction in simulated wheat yield was observed at combination of 2 °C increase in temperature with 450 ppm $CO_2$ concentration at all locations. Among all the zones, zone III B (Patna) is more vulnerable for the same which needs more attention.

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