RESEARCH ARTICLE Agricultural Science Digest, Volume 41 Issue 1: 56-60 (March 2021)

Simulating the Impact of Climate Change on Maize Productivity in Trans-gangetic Plains using Info Crop Model

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10.18805/ag.D-5079

ABSTRACT

Background: Climate change is a nonpareil threat to the food security of hundred millions of people who depends on agriculture for their livelihood. A change in climate affects agricultural production as climate and agriculture are intensely interrelated global processes. Global warming is one of such changes which is projected to have significant impacts on environment affecting agriculture. Agriculture is the mainstay economy in trans-gangetic plains of India and maize is the third most important crop after wheat and rice. Heat stress in maize cause several changes *viz.* morphological, anatomical and physiological and biochemical changes.

Methods: In this study during 2014-2018, impact of climate change on maize yield in future scenarios was simulated using the InfoCrop model. Average maize yield from 2001-15 was collected for Punjab, Haryana and Delhi to calibrate and validate the model. Future climatic data set from 2020 to 2050 was used in the study to analyse the trends in climatic parameters.

Result: Analysis of future data revealed increasing trends in maximum temperature and minimum temperature. Rainfall would likely follow the erratic behaviour in Punjab, Haryana and Delhi. Increase in temperature was predicted to have negative impact on maize yield under future climatic scenario.

Key words: Climate change, Info crop, Maize, Scenario, Temperature.

INTRODUCTION

Climate change is an unrivaled threat to the food security of hundred millions of people who depends on agriculture for their livelihood. Global mean temperature would increase by 0.3°C to 1.7°C, 1.1°C to 2.6°C, 1.4°C to 3.1°C and 2.6°C to 4.8°C under Representative Concentration Pathways (RCP) 2.6, RCP4.5, RCP6.0 and under RCP8.5. It is incontrovertible that hot and cold extremes over the land areas would occur frequently on daily and seasonal basis as a result of increase in global mean temperature (IPCC 2014). India ranked 46 in Global Climate Risk Index in 2012 but during the year 2013 series of cyclonic storms occurred over Bay of Bengal which resulted in heavy loss both in terms of agriculture and mankind (IMD 2013). A change in climate affects agricultural production as climate and agriculture are intensely interrelated global processes. Global warming is one of such changes which is projected to have significant impacts on environment affecting agriculture, including higher carbon dioxide emission, rise in atmospheric temperature, higher glacial run-off, changed precipitation and the interaction of these elements (Singh *et al.*, 2017). Reduction in potential yield of crops is linked to negative trends in solar radiation and increasing trends in minimum temperature in Indo Gangetic Plain (Pathak 2003). Maize production for World was 1,147 million thousand tonnes and in India, production of maize was 21,810 thousand tonnes (APEDA, 2016). Maize demand will double in the developing countries by 2050. Temperature increases have multiple effects on crop growth, development and yield depending on the crop growth stage. Higher temperatures usually accelerate rates of crop development and this results in a shortened growing period and typically but not always in lower crop yields (Rötter and Höhn, 2015; Rötter *et al*., 2015). Heat stress in maize cause several changes *viz.* morphological, anatomical and physiological and biochemical changes (Commuri and Jones 2001).

The yields of various cereals likely to be decrease under future scenarios (Pathak, 2003). A study therefore, has been planned to look into the climate change, its impacts on crop yield in future scenarios in trans-gangetic plain region with the objective (i) to analyse the trends in climatic parameters under future climatic scenario and (ii) prediction of maize yield under future climatic scenario.

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How to cite this article: Kaur, B., Singh, S.P. and Kingra, P.K. (2021). Simulating the Impact of Climate Change on Maize Productivity in Trans-gangetic Plains using Info Crop Model. Agricultural Science Digest. 41(1): 56-60. DOI: 10.18805/ag.D-5079.

Submitted: 08-11-2019 **Accepted:** 15-10-2020 **Online:** 30-12-2020

MATERIALS AND METHODS

Location of study

The present study was carried out at Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, Punjab during 2014-18.

Study area

The study area comprise of maize growing regions of trans-

gangetic plains which includes Punjab, Haryana, Delhi and northern Rajasthan. Punjab lies between 31.1°N and 75.3°E, whereas Haryana lies between 29.0°N and 76.1°E. The coordinates of Delhi are 28.7°N and 77.1°E. Northern parts of Rajasthan were not taken in present study due to non-significant maize area and yield.

Data collection

Daily weather data for the period of 2020-2025 was derived from marksim weather generator (https://gismap.ciat.cigar.org/MarksimGCM/) for the climatic scenario RCP8.5. Average maize yield data (2001-2015) for calibration and validation was collected from statistical abstracts of Punjab, Haryana and Delhi.

Future crop yield prediction

The crop yield prediction for maize has been predicted upto mid-century (2020-2050) using InfoCrop model for the whole states of Punjab, Haryana and Delhi. The model was first calibrated using maize yield data from 2001-10 and validated using data of 2010-15 before predicting the changes in future climatic perspectives.

Model Description

InfoCrop model is a generic crop model which simulates the effect of weather, soils, agronomic practices like planting, nitrogen, residues and irrigation and major pests on the crop growth, yield *etc*.

The input requirements of the model are:

- Site information

1. Station name
2. Latitude
3. Longitude
4. Altitude

- Weather data

1. Daily maximum temperature (°C)
2. Daily minimum temperature (°C)
3. Daily precipitation (mm)
4. Daily solar radiation (MJ m^{-2} day^{-1})

- Crop/variety

1. Thermal days
2. Optimum temperature
3. Maximum temperature
4. Base temperature
5. Relative growth rate of leaf
6. Specific leaf area
7. Radiation use efficiency

Model calibration

The process of adjusting model parameters to the local conditions is known as calibration. It is required for generating genetic coefficients for new cultivars used in modeling study. The model was calibrated using maize cultivar PMH 4 as this variety is suitable for Punjab, Haryana and Delhi.

Model validation

The purpose of the validation is to compare simulated and observed yield for year that was not used for model calibration. The data of year 2011 to 2015 was used for validation. Simulation performance was evaluated by calculating different statistic indices like R^2, d-statand ME (model efficiency). Model performance improved as R^2 and d-stat value approaches to unity while model efficiency proceeds to 100.

Modeling efficiency (%)

This is defined as a mathematical measure of how well a model simulation fits the available observations.

$$ME = 1 - \frac{\varepsilon(o_i - s_i)^2}{\varepsilon(o_i - o_{av})^2}$$

Where

O_i and S_i represent the observed and simulated values and O_{av} is the observed average.

R^2

It is the measure of goodness of fit of linear regression. It is a statistic used in the context of statistical models whose main purpose is either the prediction of future outcomes or the testing of hypotheses, on the basis of other related information. The value R^2 is a fraction between 0.0 and 1.0.

RESULTS AND DISCUSSION

Trends in maximum temperature (°C) under future climatic scenario RCP8.5

Climatic data was analyzed to observe the trends during the period 2021-2050. It was observed that maximum and minimum temperature followed significant increasing trend though out the time period (Table 1-3) for whole states of Punjab, Haryana and Delhi. Maximum and minimum temperature showed increasing trend on annual and

Table 1: Annual and seasonal trends in weather parameters in Punjab, Haryana and Delhi.

Weather parameters	Test	Punjab		Haryana		Delhi	
		Kharif	Annual	*Kharif*	Annual	*Kharif*	Annual
Maximum Temperature (°C)	Z	7.78***	7.89***	7.87***	7.89***	7.85***	7.89***
	Sen' slope	0.040***	0.048***	0.045***	0.050***	0.046***	0.051***
Minimum Temperature (°C)	Z	7.89***	7.89***	7.89***	7.89***	7.87***	7.87***
	Sen' slope	0.048***	0.050***	0.049***	0.053***	0.050***	0.054***
Rainfall (mm)	Z	0.96	0.05	0.92	1.70	1.51	1.81
	Sen' slope	0.230	-0.005	-0.015	-0.116	0.36	0.29

Z: Mann-Kendall test, Q: Sen's slope estimator.

***Statistically significant trends at the 0.1% significance level.

seasonal basis. In Punjab, during *Kharif* season, maximum and minimum temperature likely to increase by 0.040°C and 0.048°C; respectively at p=.001. Maximum temperature likely to increase by 0.048°C per year and minimum temperature at 0.050°C per year on annul basis at p=.001. No significant trend was observed in rainfall in Punjab (Table 1).

Table 2: Genetic coefficients used to calibrate the InfoCrop model for maize crop (PMH 4).

Genetic Coefficients	Units	Maize
TTGERM	°C/day	55
TTVG	°C/day	730
TTGF	°C/day	950
TBASE	°C	10
TOPT	°C	20
TMAX	°C	40
RUE	g/MJ/day	2.1
RGRL	°C/day	0.008
SLA	dm^2/mg	0.001

Table 3: Test for the evaluation of InfoCrop model for maize grain yield.

Region	Observed (q/acre)	Simulated (q/acre)	R^2	ME	d-stat
Punjab	30.2	31.8	0.84	78	0.92
Haryana	21.6	23.8	0.79	75	0.95
Delhi	19.3	18.9	0.81	80	0.81

In Haryana, annual maximum and minimum temperature likely to increase by 0.050°C and 0.053°C, respectively at p=.001. During *kharif* season, increase in maximum and minimum temperature likely to increase at the rate of 0.045°C and 0.049°C, respectively at p=.001. No trend in rainfall was observed. Similarly, in Delhi maximum and minimum temperature was predicted to increase in future at the rate of 0.046°C and 0.050°C per year at during *kharif* season. On annual basis, maximum temperature likely to increase by 0.051°C and minimum temperature would increase by 0.054°C per year. The increase in temperature likely to significant at p=.001.

Crop productivity predictions in future climate perspectives

Calibration of InfoCrop model

The InfoCrop model for maize was calibrated using the observed yield data during 2001-2010 for Punjab, Haryana and Delhi except northern Rajasthan due to non significant observed yield of maize. The genetic coefficients (Table 2) were derived while calibration and later on these were used in the validation of the model. Thermal days required for germination, vegetative phase and grain filling used to calibrate were 55, 730 and 950°C/day, respectively. Base, optimum and maximum temperature during growth period was 10°C, 20°C and 40°C, respectively. Radiation use efficiency was 2.1 g/MJ/day, relative growth rate of leaves was 0.008 and specific leaf area was 0.001 dm^2/mg.

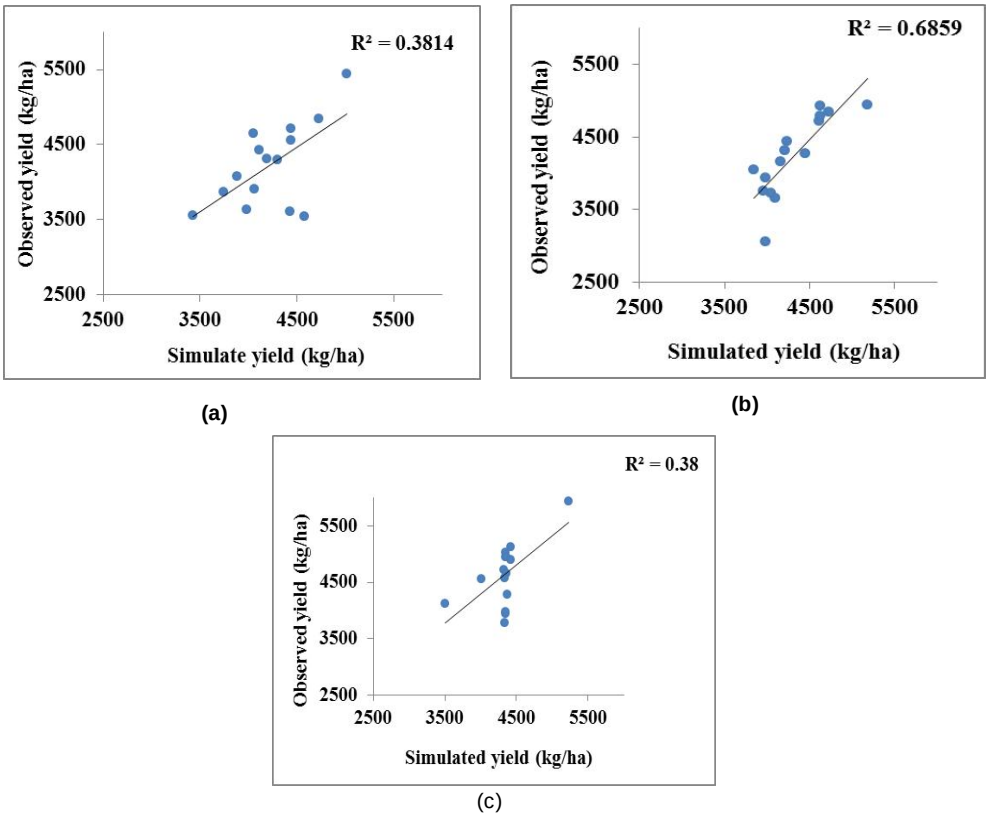


Fig 1: validation of maize yield of (a) Punjab, (b) Haryana and (c) Delhi.

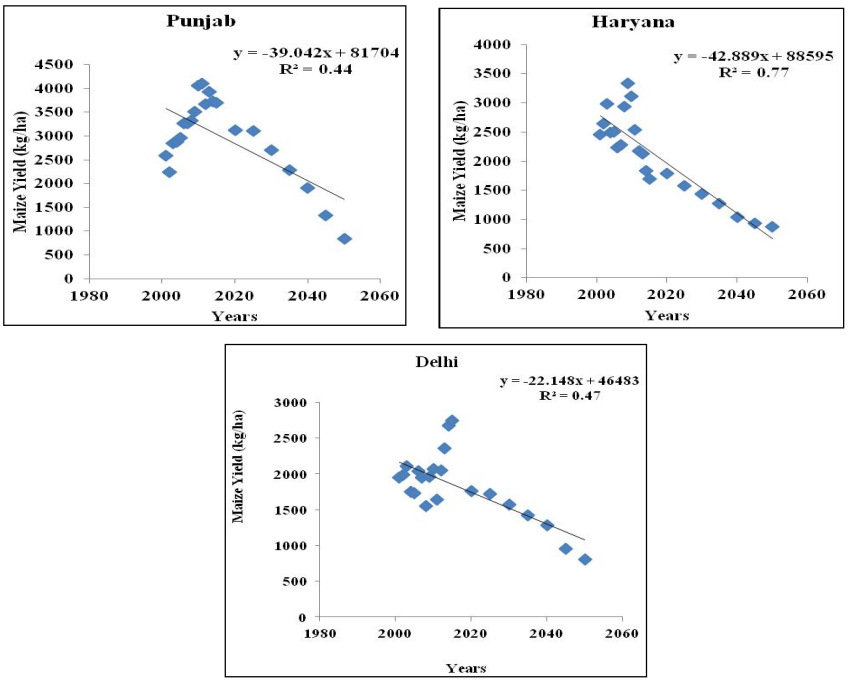


Fig 2: Trends in maize yield under future climatic scenario RCP8.5.

Validation of Info Crop model

After calibration, **t**he model was validated for maize yield during 2011 to 2015 (Fig 1). The validated yield of maize by the model was observed to be closely fit with the observed maize grain yield. The model was then tested to quantify the goodness of fit between observed and simulated yield as model efficiency (ME), R^2 and d-stat (Table 3). R^2 values were 0.84, 0.79 and 0.81; ME values were 78, 75 and 80; and d-stat values were 0.92, 0.95 and 0.81; respectively for Punjab, Haryana and Delhi. The results showed model performance was good.

Prediction of maize yield under future climatic scenario RCP8.5

The validated model was used to simulate maize yield under future climatic scenario with the weather data of corresponding period. Prediction of maize yield in future climatic perspectives showed that maize yield likely to followed declining trend from 2020 to 2050. Maize yield was observed to decrease at the rate of 39.04 kg/ha with R^2 value of 0.44, 42.88 kg/ha with R^2 value 0.77 and 22.14 kg/ha with R^2 = 0.47 in Punjab, Haryana and Delhi; respectively (Fig 2). More declines in maize predicted in Haryana under future climatic scenario. Hundal and Kaur (1996) also reported reduction in maize yield by 10.4, 14.6 and 21.4 per cent due to temperature increase of 1.0, 2.0 and 3.0°C, respectively.

The high temperature during kharif season increased the rate of evapo-transpiration, which increased the stress factor in plants. The water stress accompanied by the nutrient stress would result in less growth and low grain yield (Chatterjee, 1998). Similar findings on the reduction in grain yield of maize due shortening of the growing period have also been reported by Makadho (1996) and Vucetic (2011).

CONCLUSION

It is concluded that by the end of 2050, maximum and minimum temperature would likely to increase. However, rate of increase in minimum temperature is more than that of maximum temperature. Rainfall likely to show erratic behavior. Further, maize grain yield would likely to decrease under future scenarios. This decrease is mainly due to the increase in temperatures that fasten maturity and hence decrease in yields.

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