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Potential impact of future climate change on maize (*Zea mays L.*) under rainfed condition in central India

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ABSTRACT

A simulation experiment was carried out using Agriculture Production Systems Simulator (APSIM) model to assess the impact of climate change (change in temperature and rainfall patterns) on productivity of maize in the state Madhya Pradesh. Thirty districts with 74 soil profiles from Madhya Pradesh state were considered for the study. However, we are presenting the average results over districts and soil profiles. A well-parameterised and validated APSIM model was used to simulate the effects of temperature and rainfall on maize grain and biomass yield. Increase in temperature having negative effects on both grain and biomass yield of maize. While increasing the temperature from base to 5 ˚C, the grain and biomass yield of maize decreased by 40% and 28%, respectively. Further, increasing the temperature by 1 ˚C could reduce the grain and biomass yield by 10% and 8 %, respectively. A small increase in maize yield was observed by 10% decrease of rainfall from the base. While rainfall increase by 10% or more and decrease by >20% would results in lower maize yield and biomass. The decrease in maize yield due to increase in temperature could be attributed to decrease in duration of the crop. One-degree increase in temperature may decrease the duration of crop by 4.3 days. This study also revealed that agronomic management practices such as delaying of sowing dates could reduce the impact of climate change on crop yield to a considerable extent. By adopting the sowing date between 7th and 14th July, it may be possible to reduce the impact of temperature change on maize grain and biomass yield in central Indian condition.

Key words: Maize, climate change, rainfed, central India

Maize (*Zea mays L.*) is one of the most versatile crops owing to wider adaptability under diverse agro-climatic conditions. Worldwide, it is cultivated on nearly 150 mha in about 160 countries, representing diverse soil, climate, biodiversity, and management practices, and contributes ~36% (782 million tonnes, mt) of global grain production (Singh *et al.,* 2017). In India, maize is the third largest staple food crops in terms of area and contributes nearly 9% in the national food basket. The predominant maize growing states that contributes more than 80% of the total maize production are Andhra Pradesh (20.9%), Karnataka (16.5%), Rajasthan (9.9%), Maharashtra (9.1%), Bihar (8.9%), Uttar Pradesh (6.1%), Madhya Pradesh (5.7%), and Himachal Pradesh (4.4%) (Murdia *et al.,* 2016). Maize is one of the promising options for diversifying agriculture in upland areas of India. The area under maize cultivation in India has gradually expanded over the past few years to about 9.19 million ha in 2014-2015 and produces 24.17 mt (Anonymous, 2016).

The change in climate in terms of rainfall variability and temperature fluctuation projected to have significant impacts on agricultural production (Battude *et al.,* 2016). Worldwide, researchers agree that anthropogenic emissions of greenhouse gases lead to accelerating climate change and their impact on agriculture sector at the local, regional and global scales (Li *et al.,* 2014). The impact of climate change on agriculture vary through the latitudes and from crop to crop (Msowoya *et al.,* 2016). Higher temperatures can reduce crop production in many parts of the world (Gohari *et al.,* 2013) although crop yield could increase in temperate region of the world (Chavas *et al.,* 2009).

Nevertheless, the majority of the past studies have generally reported that negative impact of climate change on crop production (McDermid *et al.,* 2016; Mohanty *et al.,* 2017a). The risks to adverse effects of climate change are expected to be highest in developing countries, particularly in sub-Saharan Africa, South and South-East Asia (Stevens and Madani, 2016). South Asia is projected to experience a warming of 2-6 ºC by the end of the 21st century (Ravindranath, 2007). South Asian countries including India are very vulnerable to the climate change by various reasons: due to its geo-climatic conditions, socio-economic-demographic backgrounds, overwhelming dependence on agriculture and rural sectors for livelihoods, etc. (Islam *et al.,* 2009). India's surface temperature is presently increasing at 0.08°C per decade. Such increase in temperature causes a drastic decline in the agricultural output, exacerbating the problems of food insecurity and rural poverty (Birthal *et al.,* 2014). Allen *et al.* (2003) have shown that 1°C increase in mean annual temperature will reduce productivity by 17% in maize and soybean in south Asian region. Similarly, in central India, Mohanty *et al.* (2015, 2017b) reported a decline in soybean and wheat yield by 10% and 8%, respectively by 1ºC increase in temperature. Thus, assessments and understanding of the possible impacts of climate change on crop in a particular geographical region are essential as they can lead to site-specific recommendations to take advantage of the potential benefits and minimize potential adverse impacts of climate on crop production.

Climate change may drastically modify precipitation, temperature, soil water, runoff, and may reduce crop maturation period and increase yield variability and could reduce areas suitable for the production of many crops (Olesen and Bindi, 2002). In the context of climate change impacts, the contribution of rainfed agriculture for food security should not be underestimated as it currently supplies some 44% of food grains and supporting 40% of the population in India. In central India, particularly in Madhya Pradesh, maize is mostly grown as rainfed crop, and its productivity tends to be affected by unpredictable climatic scenarios. In a world where the population is continuously increasing, it is necessary to maintain sufficient levels of crop production to ensure food security in changing climate scenarios. Therefore, this study was aimed to evaluate and assess the possible impacts of climate change on maize production in rainfed region of central India and develop adaptation strategies measures to offset its adverse impact.

MATERIALS AND METHODS

Study area

This study was conducted over Madhya Pradesh state, which is geographically located between latitude 21.2–26.87 °N and longitude 74°59'–82°06' E. The state administratively divided into 51 districts, out of this, 30 districts were selected for this study (Fig. 1). The mean minimum and maximum temperature for 31 years vary among selected districts are 17.2-21.4 ºC and 30.4-34.8 ºC, respectively. The long-term annual average precipitation varies between 755-1487 mm within the study area. The dominant soil types of the study area are Vertisols, Inceptisols, and Entisols. The sand, silt, and clay content were varied between 5%–79%, 3%–37%, and 15–70%, respectively within the study region. The soil-water characteristic such as permanent wilting point and field capacity of different locations are in the range of 11-33% and 19-52%, respectively. While the bulk density varies from 1.19 to 1.61 Mg m^{-3}.

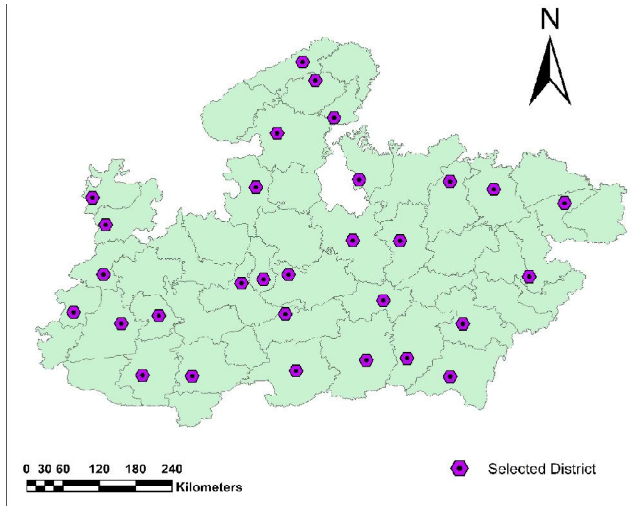

Fig. 1: Location map of the study area

Climatic Scenarios

The long-term (1980–2010) baseline data that included minimum and maximum temperatures, daily precipitation for different locations of Madhya Pradesh state were obtained from India Meteorological Department (IMD), Pune. Gaps in meteorological data point were filled with data from the NASA prediction of world wide energy resources (https://power.larc.nasa.gov/). In this study, simulations of future climate scenarios were based upon the observed baseline climate. For simulating future climate scenarios in line with different representative concentration pathway (RCP), the stepwise increment of 0.5ºC up to 5ºC and deviations in rainfall from –30% to +30% over the baseline climate were considered in the model itself. This ranges utmost covers the estimation of RCPs for the study area (Mohanty *et al.,* 2017a,b). In this study, the 'CO_2

fertilizer effect' is assumed to have no enhancing effect on maize output as the interaction of carbon dioxide with other environmental variables remains uncertain and continues to be debated among scientists.

Crop simulation model: Model calibration and validation, and crop management practices

Crop models such as Agricultural Production Systems sIMulator (APSIM) are tools for translating the climate information together with soil, and crop management practices into crop yield. The APSIM is a modular modelling framework, has the capability to simulate yield and biomass of different crops. In this study, APSIM model was applied to simulate maize yield and biomass under different climatic scenarios over the Madhya Pradesh state. Experimental data from the research farm of ICAR-Indian Institute of Soil Science, Bhopal were used to calibrate and evaluate the model, so that model parameters truly represent crop responses to soil and atmospheric conditions, and management practices within the study region. APSIM model calibration and some of the validation results for the maize crop in the same study region have been presented in Mohanty *et al.* (2017a). However, model was further validated using leaf area index (LAI) and maize biomass to exhibit model capabilities to predict these variables. Following climate, management, and soils of all selected districts of the state were put as input in the APSIM to simulate maize yield and biomass under different climatic scenarios. The soil information of different locations was taken from soils of Madhya Pradesh (NBSS & LUP, 1999). Further, the model was instructed to sow maize on 30th June of every year. The plant population, sowing depth and row spacing was set as eight plants m^{-2}, 50 mm and 600 mm, respectively. The nitrogenous fertilizer was applied as urea nitrogen form @ 120 N kg ha^{-1} in the model, which is a common practice in the study area.

RESULTS AND DISCUSSION

Validation of maize cultivar

The APSIM maize module was validated using periodic leaf area index (LAI) and maize biomass data. Three statistical parameters *viz* coefficient of determination (R^2), root mean square error (RMSE) and model efficiency (ME) were used to perform the validation test. Higher value of R^2 (for LAI= 0.74 and biomass = 0.91), ME (for LAI= 0.89 and biomass = 0.99) and lower value of RMSE (for LAI= 0.30 m^2 m^{-2} and biomass = 173 kg ha^{-1}) shows validation results are quantitatively good and show a close relation between simulated and observed LAI and biomass (Fig. 2a,b). However, the differences between observed and predicted values may be attributed to the variability in the field experimentation.

Impacts of elevated temperatures on maize yield and biomass

The simulated results showed that maize yield and biomass decreased under the influence of higher temperature. The increase in temperature by 1°C from baseline resulted in a decrease in grain and biomass by 9.5% and 8.1%, respectively (Fig 3 a,b). Further, an increase of 5°C from baseline temperature resulted in 36.9% and 27.7% decreased in grain and biomass, respectively, over the Madhya Pradesh state. Several studies showed that the grain yields of maize crops continue to decrease due to projected higher temperature during remainder of 21st century (Travasso *et al.,* 2009; Hatfield *et al.,* 2011; Lobell *et al.,* 2011). The increased temperature induces stress during crop growing season that adversely affects plant growth, pollination, and reproductive processes (Sacks and Kucharik, 2011). However, as air temperatures rise beyond the optimum level, instead of falling at a rate commensurate with the temperature increase, crop yield losses accelerate (Hatfield and Prueger, 2015). Meza and Silva (2009) attributed the reduction in yield to the shortening of the growth period of maize under the elevated temperature. It is also reported that temperature beyond 30 °C induces pollen shedding much ahead of silks emergence, while silking is delayed so that silking period does not match to anthesis/ tasselling stage, resulting in poor synchronization of flowering (asynchrony). Further, rise in temperature reduces the pollen viability and silk receptivity resulting in poor seed set and reduced yield (Shreshta *et al.,* 2015). The high temperature also leads to embryo abortion in maize, which is related to the inhibition of photosynthesis which results in reduction in assimilates available for kernel development (Sehgal *et al.,* 2018).

Impacts of rainfall variability on maize yield and biomass

Maize yield and biomass are also influenced by rainfall amount and distribution pattern. It was observed that the maize grain and biomass yield increased with decrease in rainfall to 10% and 20% from the baseline. Further decrease in the rainfall to 30%, the maize grain, and biomass yield decreased by 9% and 6%, respectively. However, increase in rainfall from the base lead to decrease in maize grain and biomass yield. There was 10% decrease in grain and biomass yield by increasing the rainfall to 30%. Rainfall variability from season to season significantly affects soil water availability to crops, and thus pose adverse effect on crop

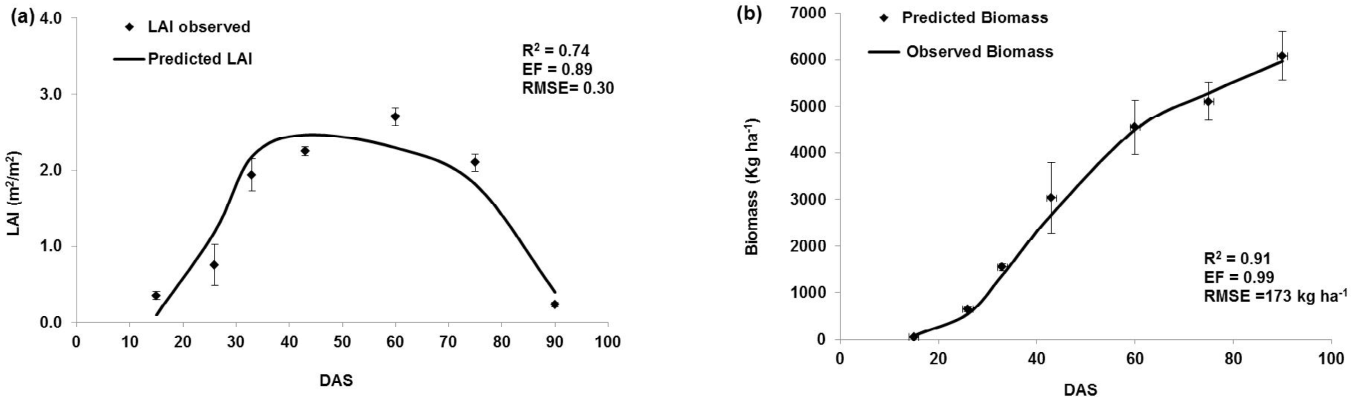

Fig. 2: Validation of APSIM model for Maize cultivar (Kanchan-101) showing observed and predicted (a) leaf area index (LAI) and (b) biomass

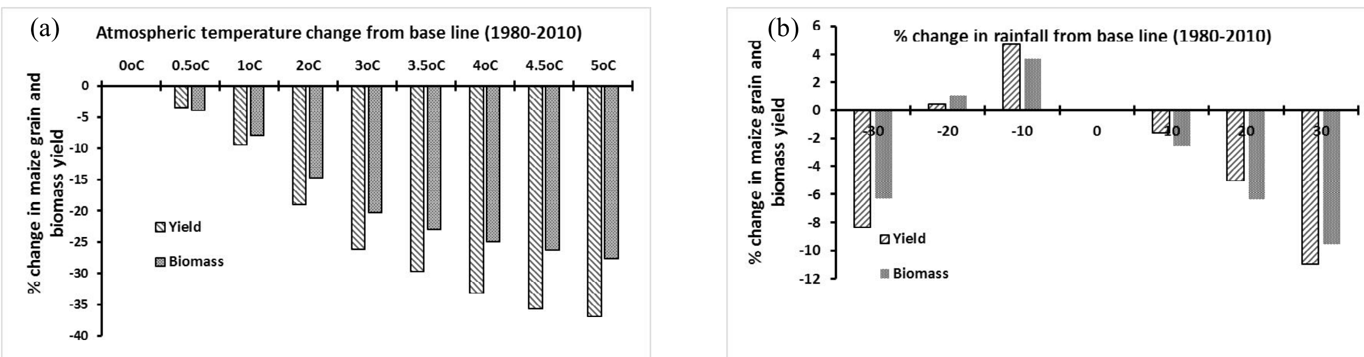

Fig.3: Effect of change in (a) temperature and (b) rainfall on maize yield and biomass

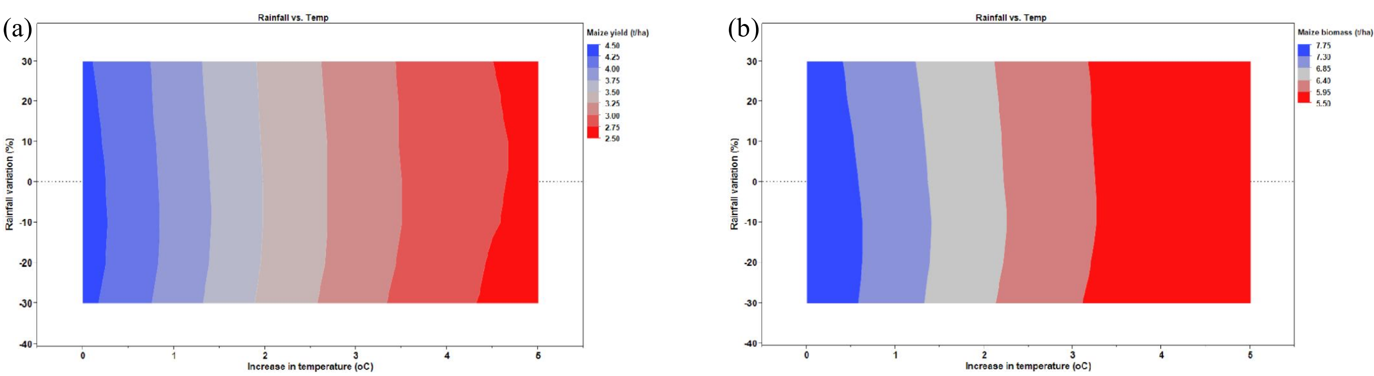

Fig. 4: Interaction effect of change in temperature and rainfall on maize yield and biomass (t ha^{-1})

production. Omoyo *et al.* (2015) mentioned that maize crop is very sensitive to water availability during its critical period i.e. from flowering to beginning of grain filling, due to high water requirement, in terms of evapotranspiration and high physiological sensitivity when determining its main yield components such as the number of ears per plant and number of kernels per ear. A usual maize crop requires 700 mm rain to complete the life cycle with good production. Increase of decrease from the 700 mm of rainfall will adversely affect the crop growth and yield. In our study site, rainfall varies between 755-1487 mm, which leads to increase in maize yield by 10%-20% decrease in rainfall. However, increase in rainfall from the baseline resulted in reduction in crop growth and yield. The reason could be that most of the study area receives a decent amount of rainfall, which is sufficient for field crops in any regular season. However, further increasing the rainfall will provide a negative impact as studied from the simulation of the maize crop.

Interactive effect of temperatures × rainfall on maize yield and biomass

The interaction effect of change in temperature and rainfall on maize yield and biomass were also quantified

Table 1: Effect of change in date of sowing on maize yield with temperature change

Date	Temperature Changes			
	1 °C	2 °C	3 °C	4 °C
22 June	11	20	27	30
30 June	8.1	15	20	25
07 July	7.5	12	16	20
14 July	7.0	10	14	18
21 July	12	18	22	26
31 July	15	25	32	37

using the APSIM model. The results of this analysis are given in Fig. 4 a&b. The maize yield and biomass at a given temperature did not vary much with variation in rainfall (± 10 to 30%). It showed that effect of rainfall had less impact on maize grain and biomass yield than temperature. Lobell and Burke (2008) have also found that uncertainties related to temperature have higher significant contribution to climate change impact than precipitation.

Adaptation strategies

The increased temperature to the tune of 1 °C resulted in the reduction in grain yield by 8 % when the sowing date of maize was the 30th June (Table 1). However, by advancing the sowing date beyond the 30th of June, i.e. 7th July and 14th July, it was observed that the reduction in yield was in the range of 7.5 to 7 % from the normal. Therefore, by adopting the sowing date between 7th to 14th July can possibly reduce the impact of temperature change on maize yield. Sowing after the 21st July did not have any mitigating effect due to temperature change on maize yield. A similar trend in reduction in grain yield of maize was observed when the temperature increased by 2, 3 and 4 °C. So, sowing in between 7–14 July was found to be a good adaptive strategy to combat the adverse impact of climate change. Similar results have also been reported for rice, wheat and soybean crops (Jalota *et al.,* 2012; Balvanshi and Tiwari, 2019). Offsetting the effect of climate change through delaying sowing dates is mainly due to shift of crop water requirement, which is in tune with the peak of seasonal rainfall. This would lessen exposure to drought during silking- tasseling stage and provide some escape from the observed and projected warming concentrated mainly during the early part of crop growth.

CONCLUSION

In this study, APSIM model was used to quantify the potential impact of future climate change on maize grain and biomass yield under rainfed conditions in central India. The study showed that increasing the temperature by 1°C might reduce the maize grain and biomass yield by 10% and 8%, respectively. Increase in rainfall also resulted in decrease in maize yield and biomass. It was also found that agronomic management practices such as advancing the sowing dates could reduce the impact of climate change on crop yield to a considerable extent.

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