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Assessment of maize (*Zea mays L.*) productivity and yield gap analysis using simulation modelling in subtropical climate of central India

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ABSTRACT

Quantifying the yield potential of maize at any given site is a key to understand the existing yield gaps and to identify the most important constraints in achieving optimal yield and profit. A well parameterized and validated APSIM model was used to assess the productivity and yield gap of maize cv Kanchan 101 from multi-year long-term and completed experiments. A total of 30 districts with 74 soil profiles of Madhya Pradesh were considered for the study. For the 30 selected sites, the rainfed potential yield of maize (*Ywp*) ranged from 3.3 to 5.2 t ha^{-1} whereas the districts mean yield (*Yf*) ranged from 0.7 to 3.1 t ha^{-1} giving yield gaps ranging from 1.7 to 3.1 t ha^{-1}. It was observed from the long-term simulation study that there is a good potential to improve the grain yield of maize crop by 3.0 t ha^{-1} provided optimum dates of sowing and good management practices are followed in the state.

Key words: Maize, vertisols, yield gap analysis, simulation modelling, APSIM

Maize (*Zea mays* L.) is cultivated widely throughout the world and has the highest production of all the cereals. Worldwide, production of maize was more than 960 MT in 2013-14. It is an important staple food in many countries and also used as animal feed and has many industrial applications. Owing to its tremendous genetic variability, the maize crop thrives well in a wide range of environments from tropical to temperate climate (Anonymous, 2014).

Maize can be grown successfully in a variety of soils ranging from loamy sand to clay loam. However, soils with good organic matter content having high water holding capacity with neutral pH are considered to be good for higher productivity. Quantifying the yield potential of maize for a region is a key to understand the yield gaps and identify the important constraints to achieve optimum yield. However, understanding the causes of yield gaps allows farmers to prioritize their strategies in improving yield and profit in a sustainable and eco-friendly manner and maximizes their return on the investment (Van Ittersum *et al*., 2013). In general, yield gaps are analyzed stepwise by estimating the potential yield, the attainable yield/experimental yield and the actual yield in farmers' fields.

Potential yield is defined as the yield of a cultivar when grown in environments to which it is adapted, with an unlimited supply of nutrients and water without the infestation of pests and diseases. The crop model often provides a reasonable estimate of potential yield when historical climate data are available. In India, potential yield and yield gap analysis of various crops including rice, wheat have been reported by many researchers (Patel *et al.,* 2008; Singh *et al.,* 2015). But the information regarding potential yields and yield gap analysis of maize crops in India is lacking. Keeping this in view, the present study has been undertaken to generate information on potential yield of maize crop to address the yield gaps using credible crop simulation modelling approach.

MATERIALS AND METHOD

Model used

The APSIM is a dynamic daily step crop growth simulation model that combines biophysical and management modules within a central engine to simulate crops and cropping systems (Keating *et al.,* 2003,). APSIM has been successfully used for simulating efficient production, improved risk management, crop adaptation, and sustainable production and climate change and impact assessment (Mohanty *et al*., 2015, 2017).

A well-parameterized and validated APSIM maize

Table 1: Parameterization of crop coefficients used in the model for maize simulation

Parameters or variables	Explanation	Value	Units
Cultivar name	Kanchan		
Phenology			
est_days_endjuv_to_init	Estimated days from end juvenile	15	days
tt_emerg_to_endjuv	Thermal time from emergence to end of juvenile stage	250	°C days
tt_flower_to_maturity	Thermal time from silking to physiological maturity	900	°C days
head_grain_no_max	Potential kernel number per ear	550	_
grain_gth_rate	Grain growth rate	12	g plant^{-1} d^{-1}
tt_flag_to_flower	Thermal time from flag leaf to silking	25	°C days
tt_flower_to_start_grain	Thermal time from silking to start of grain fill period	100	°C days
tt_maturity_to_ripe	Thermal time from maturity to ripe	10	°C days
x_stem_wt	Plant weights	80	g
y_height	Plant heights	1800	mm

module was used for the long-term simulation studies and for yield gap analysis. The crop coefficients for the maize cultivar KH-101 used for parameterization of the maize module of APSIM (Table 1) was adopted from Patidar (2015). The performance of the model was validated with datasets obtained from the various ongoing long-term experiments at ICAR- Indian Institute of Soil Science, Bhopal. The crop variables which were validated for the model include crop biomass and grain yield. The observed and simulated crop biomass and grain yield are presented in Fig. 1 (a & b), which exhibits good agreement between observed and simulated values as presented by the coefficient of determination (R^2) of 0.80 and 0.72 in case of grain and biomass yield, respectively. The average predicted grain yield simulated by the model was 3.66 t ha^{-1} as against the average observed yield of 3.61 t ha^{-1}. Similarly, the average predicted biomass yield as simulated by the model was 8.66 t ha^{-1} as against mean observed biomass yield of 9.39 t ha^{-1}.

Total 74 soil profiles from the 30 districts of Madhya Pradesh were considered for the study. The soil profile data were collected from the soil series of Madhya Pradesh, published by NBSSLUP, Nagpur (Tamgadge *et al.,* 1999). The input weather data required to run the APSIM model included daily maximum and minimum temperature, solar radiation and rainfall. The weather data collected during multi-year and multi-locations (district wise) from the India Meteorological Department, Pune for the state Madhya Pradesh was used for this study. For those simulations, where climate data were not available, the nearest district weather data was used for the study.

Long-term simulation study using APSIM model

The simulations were performed for a sowing window of 10 June to 10 July, a common planting date for maize in the state. Simulated plant populations and sowing depth for the maize were 8 plants m^{-2} and 50 mm, respectively. The model executes sowing event on a day when the soil moisture content in the top 30-cm soil depth reached at least 40% of the extractable water holding capacity or there is 30 mm rain continuously for 3 days if not, sowing was not performed. The model outputs for each year were sowing and harvest dates and grain yields. The simulation was carried out on daily time step and predicted values for grain yield was used in yield gap analysis. The simulation was run for the period of 30 years and the average grain yield of 30 years was used for yield gap analysis. In the present study, yield gap was estimated from the difference between water limited rainfed potential yield of maize (*Ywp*), experimental station yield***s*** (*Ya*) and districts mean yields (*Yf*) of the particular locations.

In general, potential yield is the yield of any crop cultivar when grown under stress-free and non-limiting condition. However, the term "water-limited potential yield (*Ywp*)" is mainly used for the rainfed crop, where the crop growth can be limited by water availability. In this study, we have used model predicted *Ywp* to calculate the yield gap. It is because most of the *rainfed* crops suffer water deficit at some point of time during the growing season.

Experimental station yields (Ya) is the maximum possible yield of a cultivar usually obtained at the experimental fields of the research station. We assume that crops at the research station were under good care and

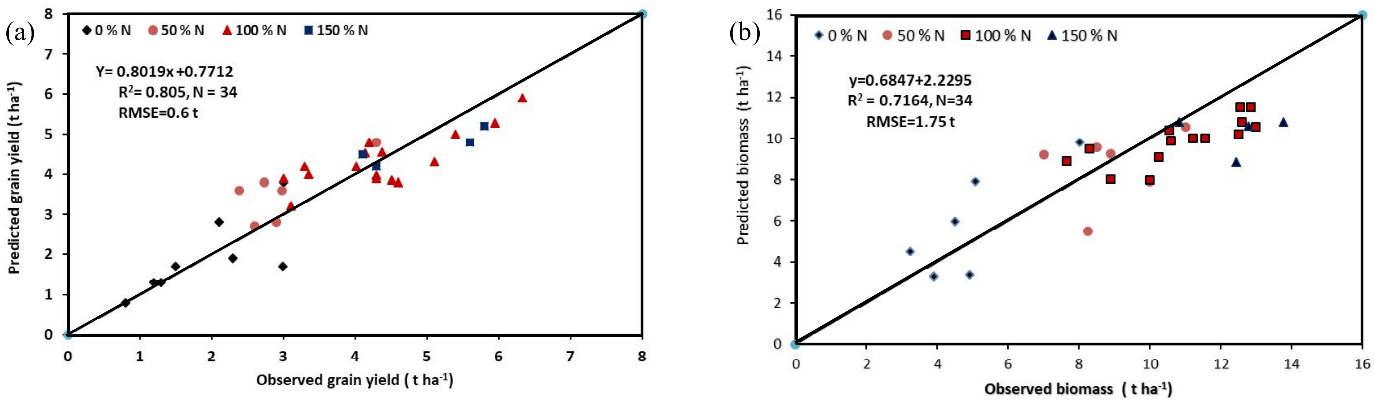

Fig. 1: Observed and predicted (a) grain yield and (b) biomass with model validation statistics index

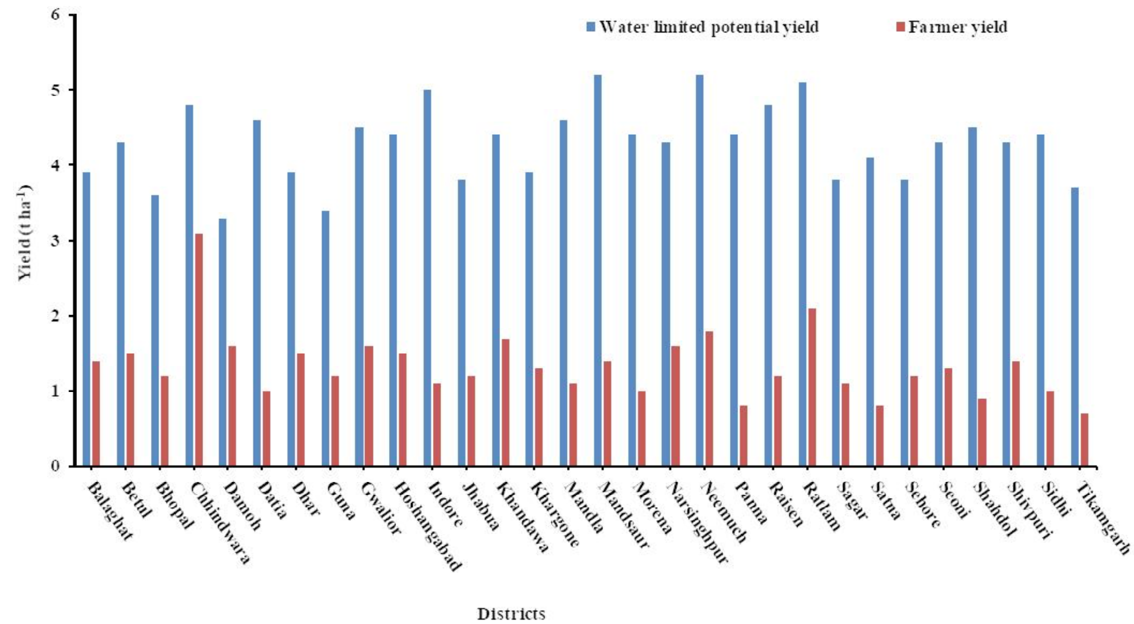

Fig. 2: Potential and average grain yield of different districts of Madhya Pradesh

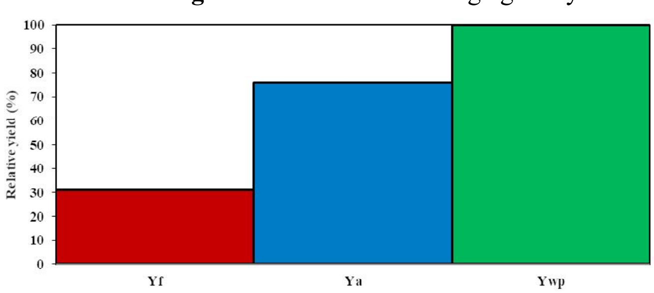

Fig. 3: Yield gap analysis of maize for the state Madhya Pradesh; Yf = farmers' yield; Ya = station yield and Ywp= water limited rainfed potential yield.

supervision and the factors other than water availability has minimal effect on crop growth. For this study, maize yield was collected during the period of 2003-04 to 2014-15 from the annual reports of ICAR-Indian Institute of Soil Science, Bhopal, ICAR- Central Institute of Agricultural Engineering, Bhopal, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur. The yields obtained for the all the entries of maize were averaged over a year at each location to calculate the *Ya* of each district.

District mean yields (Yf) were determined from the area and production data of the crop for each district in the state for the period of 2003-04 to 2014-15 (Anonymous, 2016). Then mean yields were averaged over the years to obtain the *Yf*.

RESULTS AND DISCUSSION

Yield gap analysis of maize

As a rainfed crop, the sowing of maize in India depends on the onset of the monsoon season. The seasonal commencement of the monsoon in the region is between 10th and 30th June. Depending on the weather conditions over 30 years, considerable variation in simulated maize yield was observed. Simulated yields showed year-to-year variation caused by weather variability. There was a large difference between the maximum obtainable yield and the minimum yields for the studied locations. Mean Ywp obtained for a location was compared with the mean *Yf* to calculate the yield gap. The maximum *Ywp* of 7.6 t ha^{-1} was recorded in Mandsaur district while the minimum *Ywp* of 2.8 t ha^{-1} was recorded in Damoh district. When averaged over the simulation period, the mean grain yield ranged from 3.3 to 5.2 t ha^{-1} for the different soils and area. The yield gap was minimum for Chhindwara and Damoh districts, while it was maximum in Indore and Mandsaur districts.

From the study, the *Yf* was far below than *Ywp* in all the districts and the state as a whole (Fig. 2). The *Yf* is just about 30% of the *Ywp* and *Ya* is about 47% of the *Ywp* (Fig. 3). This indicates a great scope for intensification of cereal systems in the state in the rainy season. At the same time, it raises the question why this yield gap is still so significant.

CONCLUSIONS

We made an attempt to understand the yield gap potential through crop simulation modeling in farmers' field across different districts of Madhya Pradesh. The analysis of yield gaps in farmers' fields allowed a comparative understanding of the magnitude of yield gap. Our study indicated that there is a potential scope to improve grain yield of maize by 3 t ha^{-1} with the optimum date of sowing coupled with good management practices for the region.

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