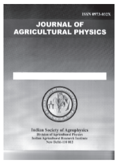
*Vol. 22, No. 1, pp. 99-106 (2022)*
**Journal of Agricultural Physics**
**ISSN 0973-032X**
**http://www.agrophysics.in**



**Research Article**

# Calibration and Validation of CERES-Maize Model under Different Environments for Ludhiana, Punjab

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## ABSTRACT

The field experiment was conducted during *kharif* 2014 and 2015 at the Research farm, School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana to generate the field data on anthesis, maturity, grain yield and biomass yield for the calibration and validation of the CERES-Maize model. The treatment comprised four sowing dates (4th week of May, 2nd week of June, 4th week of June and 2nd week of July) and two maize cultivars (PMH 1 and PMH 2) in a randomized block design. The final genetic coefficients for the PMH 1 and PMH 2 variety were derived by repeated interactions between these coefficients. The d-stat values for the days taken to anthesis, maturity, for grain yield and biomass yield showed good agreement between the observed and simulated values. The results of validation showed that the NRMSE for the days taken to anthesis, maturity, for grain yield and biomass yield was 2.7, 4.2, 19.7 and 17.6%, respectively. The results of NRMSE for the phenology fall in excellent category whereas for grain and biomass yield, in a good category, indicating that model can be used accurately to predict phenology and yield under different environments.

**Key words:** Maize, Calibration, Validation, Anthesis, Maturity, Grain yield, Biomass yield

## Introduction

The phenology, growth and yield of maize is affected by the management practices as well as environmental factors (Kumar and Kaur, 2021). Crop modelling offers an effective way to understand and analyze the consequences of management options under variable climatic conditions. Crop growth models are important tools for agricultural research, development of cropping technologies, exploration of management and policy decisions (Boote *et al.*, 1996) and for studying the interactions between crops and their environment (Jones *et al.*, 2000; Hammer *et al.*, 2002).

The agronomic studies relating the crop growth and yield to different farm conditions are expensive and time consuming. In addition, useful results are not always obtained due to uncontrollable environmental factors that may come into play. Therefore, crop simulation models can be used as an alternate tool to produce reliable data. However, simulation models are not meant to be a replacement of field experimentation but rather, the two are complimentary. Field experiments provide data required to demonstrate the accuracy of simulation models for specific soil management and weather combinations. Based upon model predictions, a decision maker can have a better idea of the consequences of the decisions before even considering conducting field experimentation. Crop simulation models have been applied to a number of

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environments to test the hypothetical impacts of different management practices (Lopez-Cedron *et al.*, 2005) or cultivar characteristics (Boote *et al.*, 2001) on production of biomass, biomass partitioning, and grain yield. Simulation modelling can enhance field experimentation, particularly if research is to be conducted over a short time period in a range of different conditions and also where resources are limiting. DSSAT model has been used by scientists for simulating yield and crop growth parameters after calibration and validation for different regions in India (Patel *et al.,* 2010; Parmar *et al*., 2013).

CERES-Maize is a relatively simple, deterministic crop simulation model that simulates corn growth, development, and yield (Jones and Kiniry, 1986; Adnan *et al*., 2020; Shen *et al*., 2020; Rugira *et al*., 2022). The model simulates daily biomass addition and partitioning among plant organs. Simulation processes are affected by environmental variables such as solar radiation, temperature and cultivar-specific factors and can include water and nitrogen stress when these options are chosen (Jones *et al.*, 2003). CERES-Maize distinguishes five developmental stages: emergence to the end of the juvenile period, the end of the juvenile stage to tassel initiation, tassel initiation to silking, silking to the start of effective grain filling and start of effective grain filling to physiological maturity. Cultivar-specific growth parameters must be specified for each of these stages.

This crop model has been tested and evaluated in different locations in the world. The evaluation of CERES-Maize model in a semi-arid Mediterranean environment under three different soil moisture conditions showed that in well-watered plots, growth and yield were adequately simulated by the model (Nouna *et al.*, 2000). Karthikeyan and Balasubramainyan (2005) and Kumar *et al.* (2010) also validated this model under UP and Tamilnadu conditions. Although CERES-Maize crop model has been tested for various cultivars across a wide range of climate, soil, and management conditions in the world, it has not been calibrated, validated, and evaluated for simulating the maize growth and yield under different combinations of environments for the Punjab region. Therefore, the aim of our research was to evaluate of the CERES-Maize model for simulating growth and yield for two maize hybrids as affected by different sowing dates and cultivars in Punjab.

## Material and Methods

*Experimental site:* The crop and weather data of Ludhiana, Punjab, India situated at 30°54′ N latitude and 75°48′ E longitude with an altitude of 247 m above the mean sea level. The Ludhiana has sub-tropical and semi-arid climate with very hot and dry summer (April to June), hot and humid conditions from July to September, cold winters from November to January and mild climate during February and March. The summer temperature exceeds above 38°C and reaches 47°C with dry summer spells, while frost occurs during December and January and minimum temperature during winters goes below 0.5°C. The average annual rainfall in Ludhiana is 750 mm.

*Crop growth model:* A dynamic crop simulation model CERES-Maize (Jones *et al.*, 1986) was selected for the study due to its capability to simulate daily crop growth, phenology, development and yield under diverse climatic and soil conditions with different agronomic managements. The model comprises six genetic coefficients (P1, P2, P5, G1, G2 and PHINT) for maize cultivars. There are six genetic coefficients in CERES-maize; degree days (base 8°C) from emergence to the end of the juvenile phase (P1), coefficient of photoperiod sensitivity (P2), from silking to physiological maturity in degree days (base 8°C) (P5), the number of potential kernels (G2), the rate of potential kernel growth mg/(kernel d)(G3), and PHINT, degree days it takes for a leaf tip to emerge (phyllochron interval) (°C d). The coefficients P1, P2, P5 and PHINT deal with vegetative growth and phenology of plant, whereas G1 and G2 describe grain number per cob and grain filling rate respectively.

*Field experiment:* The model was calibrated and validated using data from field experiment comprising four sowing dates (4th week of May, 2nd week of June, 4th week of June and 2nd week of July), and two maize cultivars (PMH 1 and PMH 2). The experiment was conducted in a randomized block design at Research farm, School of Climate Change and Agricultural Meteorology Punjab Agricultural University, Ludhiana during *kharif*, 2014 and 2015.

*Calibration, validation and sensitivity analysis of crop growth model:* For calibration, the genetic coefficients for both cultivars were changed and checked till the model predicted phenology and yield closer to the observed data. The model was calibrated with phenology, grain, biomass, and yield data collected during 2015 for both the cultivars (PMH 1 and PMH 2).

The model was validated using the field data of year 2014 using genetic coefficients obtained after the calibration.

The sensitivity analysis was done by increasing and decreasing the values of genetic coefficients to check which input parameter is affecting the model output.

*Statistical analysis of model performance:* Simulation performance was evaluated by calculating different statistic indices like root mean square error (RMSE) (Wallach and Goffinet, 1989), d-stat, $R^2$ and NRMSE. Model performance improved as $R^2$ and d-stat value approaches to unity while RMSE proceed to zero.

Regression analysis in combination with the 1:1 line graphs were used to evaluate model accuracy. Graphical analysis was used to provide qualitative evaluation of model trends, distribution and inaccuracies.

The normalized root mean square error values in percent were calculated for the observed and simulated data. Normalized RMSE gives a measure (%) of the relative difference of simulated versus observed data. The simulation is considered excellent with a normalized RMSE less than 10%, good if the normalized RMSE is greater than 10 and less than 20%, fair if the normalized RMSE is greater than 20% and less than 30%, and poor if the normalized RMSE is greater than 30% (Jamieson *et al.*, 1991). The NRMSE was calculated by using the formula (Loague and Green, 1991):

$$NRMSE = \sqrt{\frac{\sum_{i=1}^{n}(Pi - Oi)^2}{n}} * \frac{100}{M}$$

Where,

*Pi* and *Oi* refer to predicted and observed values for the studied variables, respectively.

n refers number of observations in a dataset.

M refers the mean of the observed variable.

The deviation between the model simulated and actual field observed values for phenology, growth and yield of maize cultivars was calculated as given below:

## Results and Discussion

### Calibration of CERES-Maize model

Crop simulation models need some calibration before they can be used in an area other than where they were originally made, especially when the model is to be used to predict future climate change scenarios. The CERES-Maize model was calibrated for the maize crop cultivars *i.e.,* PMH 1 and PMH 2 for the first date of sowing. The model simulated and field observed value for anthesis and physiological maturity dates, grain yield and biomass yield were tabulated and the differences between the two values were compared. CERES-Maize requires a set of six genetic coefficients for simulation of phenology, growth and grain yield of cultivars. Since such data were not available, the genetic coefficients of different hybrids were estimated by repeated iterations until a close match between simulated and observed phenology, growth and yield was obtained. The value of each genetic coefficient which minimized the differences between the observed and simulated values were selected for using in the model separately for the two cultivars. The calibrated values of the genetic coefficients for maize cultivars have been given in Table 2. The cv. PMH 1 had higher value for P1 and P5 *i.e.,* 350 (°C day) and 710 (°C day), respectively that indicates it was longer duration hybrid as compared to PMH 2. Minor differences were recorded in P2 values that were 0.4, 0.3 (day) PMH 1 and PMH 2. The value of G2 was 1190 and 1180 for PMH 1and PMH 2, respectively. PMH 1 had lower kernel filling rate (G3) *i.e.* 23.0 mg day$^{-1}$ as compared to PMH 2 (25.5 mg day$^{-1}$). PHINT (Phyllochron interval) value varied from 33.0°C day PMH 1 35.0°C day for PMH 2.

### Validation of CERES-Maize model

The validation describes the comparison of CERES-Maize model simulated parameters with actual observations for growth development and yield of maize cultivars. The comparison of the observed and simulated results of the phenological events and yield of maize cultivars sown under four dates of sowing and for two crop years have been given in Table 3. The CERES-Maize model was able to simulate phenological events i.e. anthesis date (RMSE= 3.5 day, d-stat=0.752), maturity date (RMSE= 1.4 day, d-stat=0.908); yield parameters i.e. grain yield (RMSE= 956 kg/ha day, d-stat=0.592) and biomass yield (RMSE= 1880 kg/ha, d-stat=0.628) for maize cultivars under different sowing dates during the two crop years.

### *Sensitivity analysis of CERES-Maize model*

The sensitivity analysis was performed for 6 cultivar specific coefficients (P1, P2, P5, G2, G3 and PHINT) which control the phenological development and yield of the maize crop by changing (increasing or decreasing) their values to determine their effect on the grain yield. The data presented in Table 1 indicates the sensitivity of model to these genetic coefficients. The anthesis and maturity days were sensitive to the P1 and P5 genetic coefficients. The grain yield was sensitive to the P5 and PHINT genetic coefficient.

### *Crop phenology*

The 1:1 line graph between dates of phenological stages simulated by CERES-maize model and actually observed for maize cultivars PMH 1 and PMH 2 under different environments have been shown in and Fig. 1. The evaluation of the CERES-Maize model for simulating the duration from

**Table 1.** Sensitivity test results for the genetic coefficients of maize for CERES-maize model

| S. no. | Genetic coefficients | Range | Anthesis (days) | Maturity (days) | Grain yield (kg/ha) |
|---|---|---|---|---|---|
| 1 | P1 | 335 | 54 | 86 | 4686 |
| | | 310* | 52 | 83 | 4751 |
| | | 285 | 50 | 81 | 4881 |
| 2 | P2 | 0.4 | 54 | 86 | 4660 |
| | | 0.3* | 52 | 83 | 4751 |
| | | 0.2 | 52 | 83 | 4751 |
| 3 | P5 | 705 | 52 | 84 | 4726 |
| | | 690* | 52 | 83 | 4751 |
| | | 675 | 52 | 82 | 4687 |
| 4 | G2 | 1280 | 52 | 83 | 4718 |
| | | 1180* | 52 | 83 | 4751 |
| | | 1080 | 52 | 83 | 4789 |
| 5 | G3 | 27.0 | 52 | 83 | 4731 |
| | | 25.0* | 52 | 83 | 4751 |
| | | 23.0 | 52 | 83 | 4768 |
| 6 | PHINT | 37.0 | 52 | 84 | 4690 |
| | | 35.0* | 52 | 83 | 4751 |
| | | 33.0 | 51 | 83 | 4631 |

**Table 2.** Genetic coefficients of maize hybrids used for CERES-Maize model

| Cultivar | P1 (°C d) | P2 (d) | P5 (°C d) | G2 (nos Kernel/pl) | G3 (mg $d^{-1}$) | PHINT (°C d) |
|---|---|---|---|---|---|---|
| PMH 1 | 350 | 0.4 | 710 | 1190 | 23.0 | 33 |
| PMH 2 | 310 | 0.3 | 690 | 1180 | 25.5 | 35 |

planting to anthesis with data from 2014 and 2015 experiment revealed similar average values for the maize between observed and predicted values, e.g., 54 days for observed and 53 days for simulated. The coefficient of determination ($R^2$) between the simulated and observed duration from planting to anthesis for the maize was 0.73, d stat was 0.91 and the normalized RMSE was low (2.7%). The coefficient of determination ($R^2$) between the simulated (86) and observed (85) duration from planting to maturity for the maize was 0.37, d-stat was 0.63 and the normalized RMSE was low (4.2%) (Table 3).

The model simulated the phenological stages namely anthesis and physiological maturity of both the cultivars in close agreement with those observed in the field. However, the days taken to anthesis were simulated more realistically by the model. The linear regression model between observed and simulated anthesis date could account for 72% variations (Fig. 1a) while that for developed for physiological maturity could account for 37% variations (Fig. 1b). Out of 16 environments, CERES-Maize model overestimated and underestimated for anthesis date for 4 and 6 environments (Fig. 1a), respectively; and for physiological maturity for 8 and 6 environments, respectively (Fig. 1b).

### *Yield*

The 1:1 line graph between simulated and observed grain and biomass yield of the maize cultivars under different sowing dates has been given in Fig. 2. The deviation between the simulated and observed grain yield and biomass yield of the maize crop was -31.9 to +30.1 to% and -31.9 to +28.7%, respectively. The coefficient of determination ($R^2$), d stat and normalized RMSE between the simulated and observed grain yield and biomass yield for the maize was 0.17 and 0.34, 0.59 and 0.75 and 19.7 and 17.6%, respectively (Table 3). All these statistical tools indicate that the CERES-Maize model can be used to work out simulation guided management practices for yield maximization of maize under climate change conditions. Chisanga *et al.* (2015) also simulated grain yield with fair (NRMSE = 21.4%) results.

**Table 3.** Statistics of the observed and simulated phenology and yield of maize (Pooled data of *kharif* 2014 and 2015)

| Variable name | Mean | | | Standard deviation | | R-Square | RMSE | d-Stat. | Used | Total | NRMSE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Observed | Simulated | Ratio | Observed | Simulated | | | | Obs. | obs. | |
| Anthesis day | 54 | 53 | 0.992 | 2.3 | 2.6 | 0.726 | 1.4 | 0.908 | 16 | 16 | 2.7 |
| Maturity day | 85 | 86 | 1.012 | 4.3 | 3.3 | 0.376 | 3.5 | 0.752 | 16 | 16 | 4.2 |
| Grain yield (kg/ha) | 4840 | 5094 | 1.059 | 610.4 | 988.1 | 0.172 | 955.9 | 0.592 | 16 | 16 | 19.7 |
| Biomass yield (kg/ha) | 10685 | 11069 | 1.033 | 987.4 | 2227.9 | 0.337 | 1879.8 | 0.628 | 16 | 16 | 17.6 |

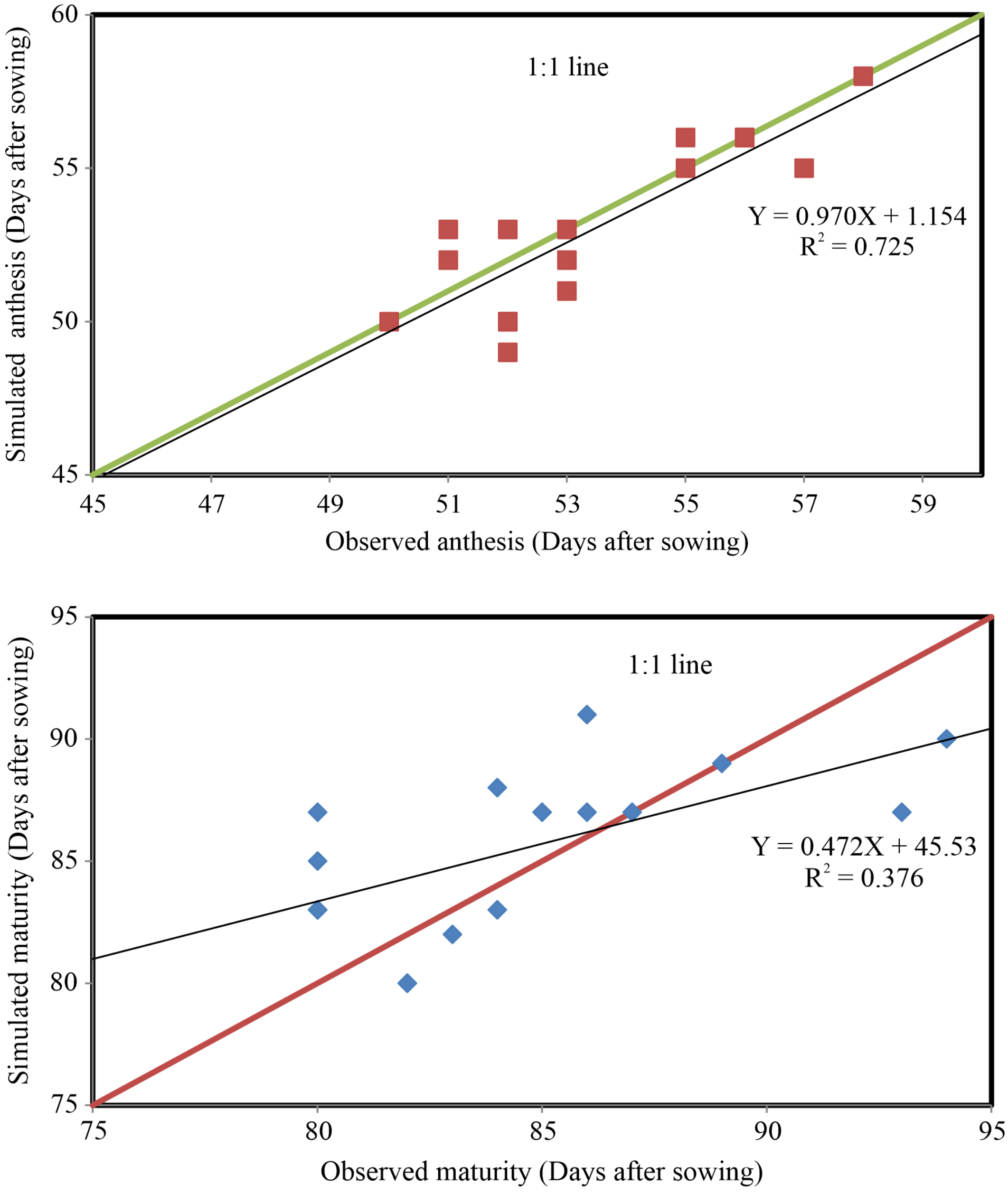

**Fig. 1.** Comparison of simulated and observed anthesis and maturity date (days after sowing) for maize cultivars under different environments, *kharif* 2014 and 2015

The linear regression model between observed and simulated grain yield could account for 17% variations while that for developed for biomass yield could account for 33% variations. Out of 16 environments, CERES-Maize model overestimated and underestimated for grain yield for 9 and 7 (Fig. 2a) environments, respectively; and for biomass yield for 9 and 7 environments (Fig. 2b), respectively.

## Conclusion

The CERES-Maize model was able to satisfactorily simulate phenology and yield for the maize hybrids grown under the different environments over two years in Punjab. This study also showed that the CERES-Maize model can be a promising research tool for yield forecasting as well a grower's tool for before sowing and within season

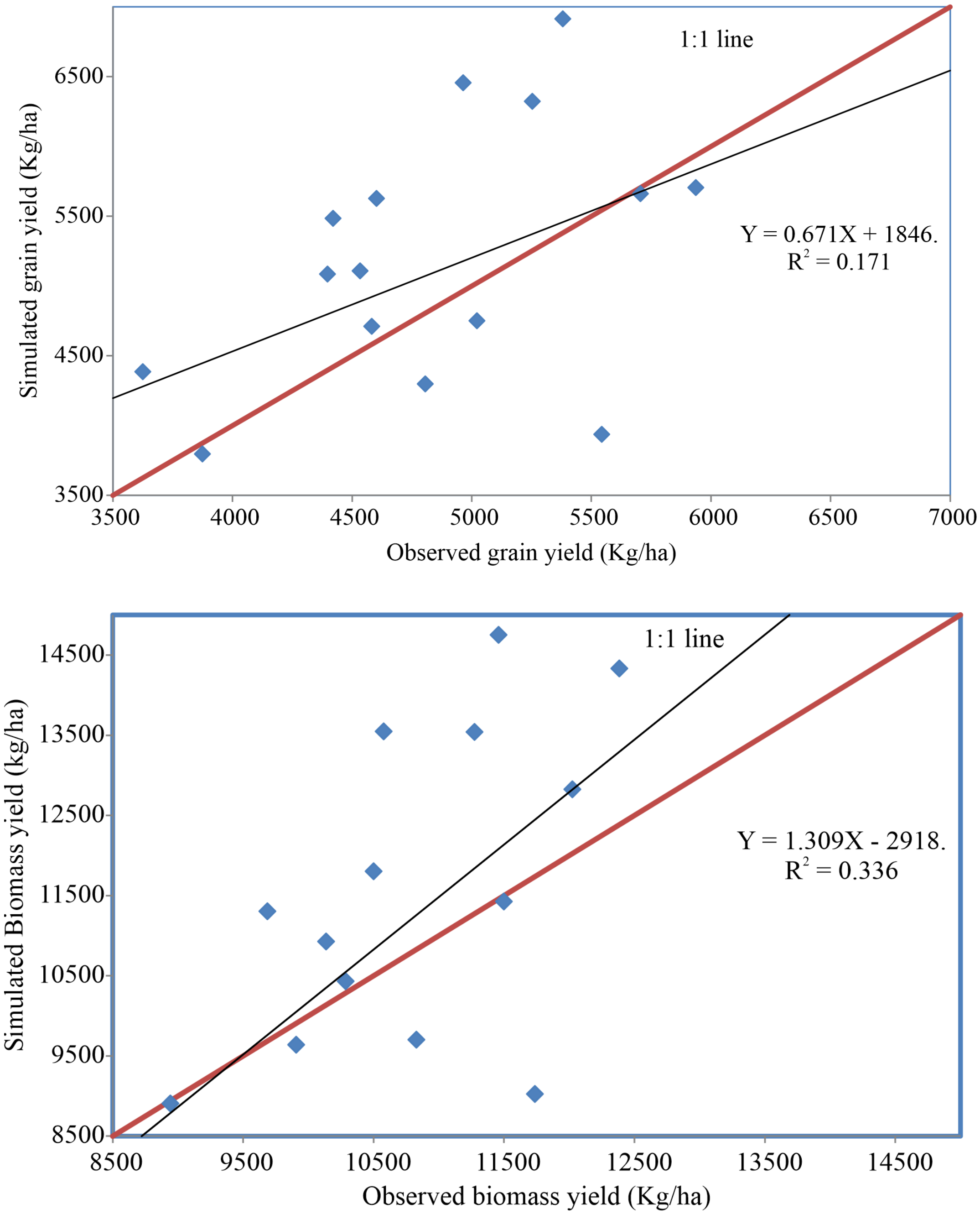

**Fig. 2.** Comparison of simulated and observed grain and biomass yield (kg/ha) for maize cultivars under different environments, *kharif* 2014 and 2015

management decisions for maize hybrids under different environments.

## Acknowledgement

The financial assistance provided by the UGC, New Delhi during Ph.D programme in form of Maulana Azad National Fellowship for post graduate studies has been fully acknowledged.

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Received: March 13, 2022; Accepted: June 4, 2022