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**Research Article**

# Evaluation of CROPGRO-Pigeonpea Model in North-West India

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**ABSTRACT**

Crop simulation models need to be evaluated for their abilities to accurately simulate the crop growth and yield under different conditions. The CROPGRO-Pigeonpea model was calibrated and validated using seven years field experiments in semi-arid region of Haryana. Results showed that model satisfactorily simulated days to anthesis, physiological maturity and grain yields of pigeonpea crop. The simulated days to anthesis, days to maturity and yields were within ±10% range in close agreement with the observed values. The d-index for the crop phenology and yield indicated good performance of the model. Therefore, we found that validated CROPGRO-Pigeonpea model can be used to evaluate and improve the present management practices of pigeonpea crop to achieve enhanced yield and devise adaptation strategies to reduce the potential threat of global warming during end of 21$^{st}$ century.

**Key words:** Pigeon pea, CROPGRO, genetic coefficients, simulation

## Introduction

Climate change is the major challenging issue in supplying sufficient food for the exponentially increasing population and sustaining global food security under the already stressed environment (Mall *et al.,* 2017). Several researchers reported significant changes in long term weather due to climate change in different parts of India (Sah *et al*., 2021; Singh *et al.,* 2021a,b). Studies on impacts and adaptation strategies for the changing climate are increasingly becoming foremost areas of scientific research and crop simulation models are playing the role of important tool for climate change studies and risk analysis (Chenu *et al*., 2017). Impacts of climate change has been assessed by number of researchers on crops such as maize (Bedeke *et al.,* 2019; Chakrabarti *et al*., 2020), soybean (Singh *et al.,* 2021c), chickpea (Singh *et al.,* 2017; Bhatia *et al.,* 2021), wheat (Sandhu *et al*., 2019), sugarcane (Singh *et al.,* 2010), jute (Barman *et al*., 2020) and rice (Chun *et al.,* 2016; Mall and Aggarwal, 2002). In recent years, more attention has been paid to the risks associated with climate change and variability which will increase uncertainty with respect to food production. Crop models are major tools for such kind of research and analysis.

Pigeon pea (*Cajanus cajan* L. Mill sp.), is a well-established and one of the most important tropical pulse crop grown in Asia, Latin America, Africa, and the Caribbean (ICRISAT, 2019). India has highest area and production under pigeon pea in the world. It is cultivated worldwide on 4.92 million hectares (Mha) with an annual production of 3.65 Mt and productivity of 898 kg ha$^{-1}$. Out of this, India alone contributes 79% of the world area and 67% of world pigeon pea production. It is the second most important pulse crop of India and contributes to 21% of total pulse production of India (ICRISAT, 2019). Climate change have a major impact on rainfed crops especially pulses, which are particularly sensitive to heat or temperature stress at the blooming stage. High

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temperature (30-35ºC) can cause heavy yield losses (Siddique *et al*., 1999). Pigeon pea being a rainfed pulse crop is highly sensitive to the rise in maximum temperature (Mishra *et al.,* 2017). A 1°C rise in the maximum temperature in *kharif* season will reduce the yield of pigeon pea by 11-12% (Birthal *et al*., 2014). It is projected that by the year 2100 with a significant climate change, pulse production will be affected more than of any other crop and yield of pigeon pea will be lowered by around 25% vis-a-vis without climate change (Birthal *et al*., 2014).

Considering its global and national importance, pigeon pea was introduced recently in the Decision Support System in Agrotechnology Transfer (DSSAT) crop model as CROPGRO-Pigeonpea, which is a detailed process-based model simulating the growth and development of the crop. The climate change impact assessment studies on pigeon pea are gaining importance. The CROPGRO model was used by researchers for various studies related to climate change on chickpea (Sah *et al*., 2020), pigeon pea (Patil *et al*., 2018) and soybean (Walikar *et al.,* 2018). To use the model for such studies, development of genetic coefficients for different varieties at different locations is required by the model. Keeping this in view, present study was conducted to calibrate and validate the CROPGRO-Pigeonpea model in Hisar, Haryana.

## Material and Methods

The study was carried out for the Hisar district of Haryana, India located at 29°10′ N latitude, 75°46′ E longitude and at an altitude of 215.2 m above MSL. The area comes in sub-tropical region with semi-arid climate. Field experiments were conducted with different treatments under the All India Coordinated Research Project (AICRP). Each treatment was different location wise, sowing date, variety and in nitrogen management. The soil of the experimental site is classified as Typic Ustochrept. Three most popular short duration varieties of pigeon pea UPAS 120, Pusa 992 and AL-201 were selected for the study. All the three early maturing varieties of the crop were sown in the first fortnight of June. Recommended agronomic practices were followed for field preparation and seeds were sown @ 25 kg/ha maintaining row to row spacing of 45 cm and plant to plant spacing of 15 cm. All the fertilizers were drilled in furrows at a depth of 5 cm and at the side of 5 cm from seed. Recommended dose of fertilizers i.e. 25 kg N, 45 kg $P_2O_5$ and 30 kg $K_2O$ per ha were applied at a depth of 5 cm as a basal dose at the time of sowing.

The CROPGRO-Pigeonpea model of the DSSAT-CSM version 4.7 used for the present study is a detailed, process-based model of crop growth and development that simulates basic biological processes, such as photosynthesis and nitrogen fixation (Alderman *et al.,* 2015). The model requires information of daily weather, soil, crop management datasets and cultivar details as an input in order to run the model.

### *Calibration and validation*

The CROPGRO-Pigeonpea model was calibrated with two years of datasets 2004-2005 and 2007-2008 in order to derive the genetic coefficients for the cultivars. The coefficients were estimated by Generalized Likelihood Uncertainty Estimation (GLUE) coefficient estimator using 8000 iterations and sensitivity analysis until a close match between the observed and simulated phenology and yield were obtained. The model was validated with 2008-09, 2009-10, 2013-14, 2014-15 and 2015-16 year datasets which were not used in calibration by comparing the observed versus simulated values of days to anthesis, physiological maturity date and grain yield. The genetic coefficients, obtained as part of calibration procedure, are shown in Table 1.

### *Model evaluation statistics*

Model accuracy and reliability evaluation during the calibration and validation was done using deviation statistics viz. index of agreement (d), and normalized root mean square error (n-RMSE) and one test statistic (coefficient of determination, $R^2$) for evaluating the model. Root mean square error (RMSE) was used to decide the statistical differences between observed and simulated variables and was computed by using Eq. (1) to determine the degree of predictability.

$$\mathrm{RMSE} = \sqrt{\left[\frac{\sum_{i=1}^{n}(X_S - X_O)^2}{n}\right]} \quad \ldots(1)$$

**Table 1.** Genetic coefficients of the pigeon pea cultivars

| Parameter | Cultivar coefficients description | Cultivars | | |
|---|---|---|---|---|
| | | UPAS-120 | Pusa- 992 | AL-201 |
| CSDL | Critical Short Day Length below which reproductive development progresses with no day length effect (for short day plants) (hour) | 12.73 | 12.53 | 12.45 |
| PPSEN | Slope of the relative response of development to photoperiod with time (positive for short day plants) (1/hour) | 0.39 | 0.39 | 0.40 |
| EM-FL | Time between plant emergence and flower appearance (R1) | 38.5 | 39.5 | 39.5 |
| FL-SH | Time between first flower and first pod (R3) | 16.4 | 16.4 | 15.8 |
| FL-SD | Time between first flower and first seed (R5) | 17.6 | 17.6 | 19.5 |
| SD-PM | Time between first seed (R5) and physiological maturity (R7) (photo thermal days) | 27 | 27 | 26 |
| FL-LF | Time between first flower (R1) and end of leaf expansion | 10.1 | 10.7 | 11.0 |
| LFMAX | Maximum leaf photosynthesis rate at 30° C, 350 vpm $CO_2$, and high light (mg $CO_2$/$m^2$-s) | 0.70 | 0.74 | 0.71 |
| SLAVR | Specific leaf area of cultivar under standard growth conditions ($cm^2$/g) | 312 | 316 | 318 |
| SIZLF | Maximum size of full leaf (three leaflets) ($cm^2$) | 151.4 | 152.4 | 150.4 |
| XFRT | Maximum fraction of daily growth that is partitioned to seed + shell | 0.70 | 0.70 | 0.79 |
| WTPSD | Maximum weight per seed (g) | 0.11 | 0.11 | 0.12 |
| SFDUR | Seed filling duration for pod cohort at standard growth conditions (photothermal days) | 16.5 | 16.1 | 14.5 |
| SDPDV | Average seed per pod under standard growing conditions | 2.99 | 2.99 | 2.99 |
| PODUR | Time required for cultivar to reach final pod load under optimal conditions (photothermal days) | 10.3 | 10.3 | 10.2 |
| THRSH | Threshing percentage. The maximum ratio of (seed/(seed+shell)) at maturity. Causes seeds to stop growing as their dry weight increases until shells are filled in a cohort. | 76.4 | 76.4 | 76.4 |
| SDPRO | Fraction protein in seeds (g(protein)/g(seed)) | 0.225 | 0.225 | 0.225 |
| SDLIP | Fraction oil in seeds (g(oil)/g(seed)) | 0.015 | 0.015 | 0.015 |

Where, n denotes the number of observations, $X_S$ are the simulated variables, while $X_o$ are the observed one used in the equation. The normalized root mean square error (n-RMSE) was computed using Eq. (2). X is the mean observed values which gives a percent measure of the relative difference between simulated and measured values.

$$n-RMSE = \frac{RMSE}{X} \times 100\% \qquad \ldots(2)$$

Willmott index of agreement (d) was used in this study using the following equation;

$$d = 1 - \left[ \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} \left( |P'i| - |O'i| \right)^2} \right] \qquad \ldots(3)$$

Where, n is the observations, $P_i$ is the predicted assessment for the $i^{th}$ quantity while $O_i$ is the observed one for the $i^{th}$ measurement. $P'_i$ was calculated as $P_i$ – O, and $O'_i$ was computed as $O_i$ –O, while O is the mean observation. Its value ranges from 0 to 1, closer the d index values to unity (1), the better the fit and better model simulation.

## Results and Discussion

### *Validation of CROPGRO-Pigeon pea model*

The genetic coefficients of the three cultivars determined through CROPGRO-pigeon pea model calibration used for subsequent validation are

**Table 2.** Simulated and observed days to anthesis for pigeon pea cultivars during validation

| Year | Cultivar | Days to Anthesis | | |
|---|---|---|---|---|
| | | UPAS 120 | Pusa 992 | AL-201 |
| 2008-09 | Observed | 92 | 82 | 83 |
| | Simulated | 95 | 85 | 85 |
| | % Error | 3.2 | 3.6 | 2.4 |
| 2009-10 | Observed | 85 | 93 | 92 |
| | Simulated | 88 | 91 | 90 |
| | % Error | 3.5 | 2.1 | 2.2 |
| 2013-14 | Observed | 87 | 91 | 84 |
| | Simulated | 84 | 88 | 82 |
| | % Error | 3.4 | 3.3 | 2.4 |
| 2014-15 | Observed | 88 | 91 | 82 |
| | Simulated | 91 | 92 | 81 |
| | % Error | 3.4 | 1.1 | 1.2 |
| 2015-16 | Observed | 88 | 92 | 84 |
| | Simulated | 89 | 90 | 83 |
| | % Error | 1.1 | 2.1 | 1.1 |

presented in Table 1. The independent data sets that were not used in calibration process are used for validation of the model.

## *Crop phenology*

### *Days to anthesis*

The validation results for the days to anthesis are given in Table 2 which shows that the observed values varied from 82 to 93 days whereas, the simulated values ranged from 81 to 95 days. These values were closely matched with an error percentage ranging from 1.1 to 3.6 among each varieties and year (Table 2). Fig. 1 represents comparison of

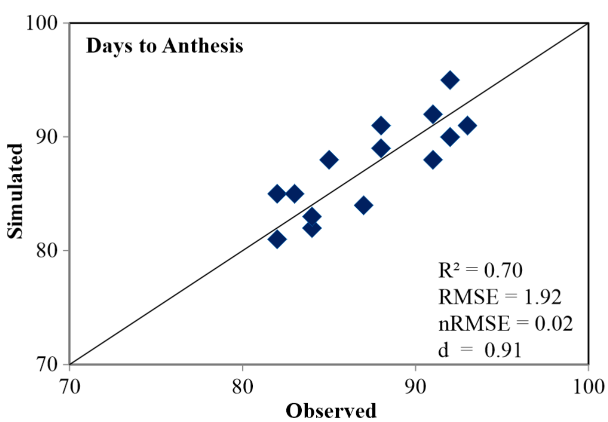


**Fig. 1.** Relationship between simulated and observed days to anthesis of pigeon pea cultivars

simulated results for anthesis days against the observed on 1:1 line, indicating that the model was performing well under the test environments. The performance statistics between simulated and observed days to anthesis are indicated by $R^2$, RMSE, n-RMSE and d-index. The coefficient of determination was 70% indicating a high degree of collinearity between observed and simulated values. The RMSE prediction was 1.92 with normalized RMSE value of 2.2% for the days to anthesis. The d-index was 0.91 indicating good performance of the model for different cultivars.

### *Days to maturity*

The validation results for the days to maturity are represented in Fig. 2 and Table 3. The observed days to maturity varied between 131 to 145 days whereas simulated days to maturity ranged from 130 to 144 for all the three cultivars. A close match was found between observed and simulated days to maturity with an error percentage ranging from 0.7 to 2.79. The model showed good performance between observed and simulated days to maturity on the 1:1 line. The coefficient of determination, $R^2$, between observed and simulated values was 74%. The model performed with reasonably good accuracy for all the cultivars with the RMSE, n-RMSE, $R^2$ and d-index values as 1.98, 0.01, 0.7 and 0.93,

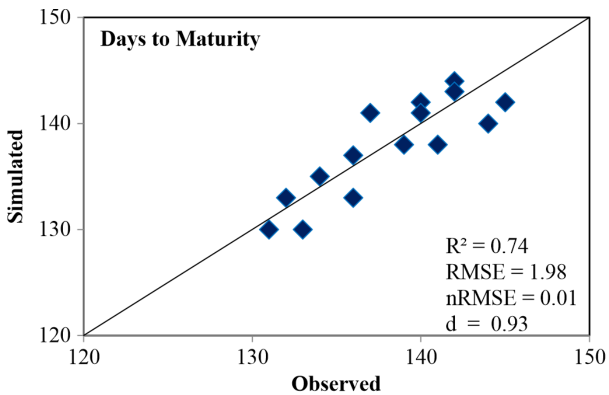


**Fig. 2.** Relationship between simulated and observed days to maturity of pigeon pea cultivars

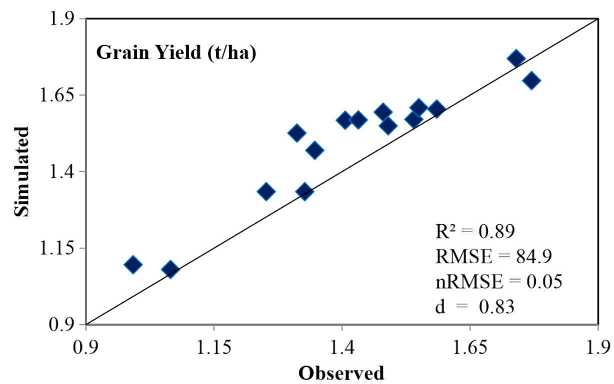


**Fig. 3.** Relationship between simulated and observed grain yield (t/ha) at the harvest of pigeon pea cultivars

respectively which indicate that this validated model can simulate the maturity days with accepted level of accuracy.

### *Yield at harvest*

Validation results for the yield at maturity are represented in Fig. 3 and Table 4. The observed yield ranged from 0.99 to 1.77 t/ha whereas, the simulated yield ranged from 1.09 to 1.76 t/ha. Fig. 3 represents the regression line which was more or less near to 1:1 line, indicating that the model was performing well under the test environments. Similarly, the coefficient of determination ($R^2$), n-RMSE as well as d-index between observed and simulated, indicates good performance of the model. The coefficient of determination was found 89% while model capability for grain yield at harvest simulations was in good agreement, with lower values of n-RMSE (5.6%) and higher values of d-index (0.83) for different cultivars. Overestimation of grain yield by simulation model shows its limitation due to the impact of the weeds, diseases and insect pests on crop growth, development and final yield formation assumed to be controlled, which is not in the case of field experiments.

**Table 3.** Simulated and observed days to maturity for pigeon pea cultivars during validation

| Year | Cultivar | Days to maturity | | |
|---|---|---|---|---|
| | | UPAS 120 | Pusa 992 | AL-201 |
| 2008-09 | Observed | 133 | 134 | 144 |
| | Simulated | 130 | 135 | 140 |
| | % Error | 2.3 | 0.8 | 2.7 |
| 2009-10 | Observed | 131 | 132 | 141 |
| | Simulated | 130 | 133 | 138 |
| | % Error | 0.8 | 0.8 | 2.1 |
| 2013-14 | Observed | 136 | 136 | 145 |
| | Simulated | 133 | 137 | 142 |
| | % Error | 2.2 | 0.7 | 1.4 |
| 2014-15 | Observed | 139 | 142 | 137 |
| | Simulated | 138 | 144 | 141 |
| | % Error | 0.7 | 1.4 | 2.9 |
| 2015-16 | Observed | 140 | 142 | 140 |
| | Simulated | 142 | 143 | 141 |
| | % Error | 1.4 | 0.7 | 0.7 |

**Table 4.** Simulated and observed grain yield at harvest for pigeon pea cultivars during validation

| Year | Cultivar | Grain Yield (t/ha) | | |
|---|---|---|---|---|
| | | UPAS 120 | Pusa 992 | AL-201 |
| 2008-09 | Observed | 1.54 | 1.48 | 1.31 |
| | Simulated | 1.57 | 1.59 | 1.53 |
| | % Error | 2.0 | 7.0 | 16.3 |
| 2009-10 | Observed | 1.49 | 1.55 | 1.41 |
| | Simulated | 1.55 | 1.61 | 1.57 |
| | % Error | 4.0 | 3.8 | 11.5 |
| 2013-14 | Observed | 1.74 | 1.35 | 1.60 |
| | Simulated | 1.76 | 1.47 | 1.60 |
| | % Error | 1.7 | 9.1 | 1.2 |
| 2014-15 | Observed | 0.99 | 1.33 | 1.77 |
| | Simulated | 1.09 | 1.33 | 1.68 |
| | % Error | 10.5 | 0.6 | 4.1 |
| 2015-16 | Observed | 1.43 | 1.06 | 1.25 |
| | Simulated | 1.57 | 1.08 | 1.69 |
| | % Error | 9.5 | 1.4 | 6.6 |

The deviation between simulated and observed values might be attributed partly to error introduced during deriving the genetic coefficient of different varieties of pigeon pea and also with the precision by which field measurement data used in the simulation study was collected, which usually lies between +10 to +15% (Mall and Aggarwal, 2002; Singh *et al*., 2010).

## Conclusion

The results show that the days to anthesis, physiological maturity and grain yields were very well simulated and were in close agreement with the corresponding observed values. It can be inferred from this study that the CROPGRO-Pigeon pea model of DSSAT version 4.7 can be successfully employed for simulating the growth and yield of pigeonpea cultivars grown under semi-arid climatic conditions. The validated model can be further used for various applications such as estimation of the crop production, enhancing resource use efficiency, yield forecasting and to evaluate the effects under different climate change scenarios, etc. The results imply that models can be used as an effective tool to evaluate and improve the management practices for the pigeon pea and can further be used in weather-based agro advisories.

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