# Evaluation of DSSAT-CROPGRO module for spatialyield estimation of Chickpea in Vidisha(Madhya Pradesh) and Nagaur(Rajasthan)


## ABSTRACT

Crop simulation models are often used to characterize, develop and assess field crop production practices. The present study was carried out for chickpea spatial yield estimation at Vidisha of Madhya Pradesh and Nagaur district of Rajasthan employing the DSSAT model. In this study, the DSSAT-CROPGRO module was used to estimate chickpea yield during rabi 2022. To simulate the yield, DSSAT required datasets of crop growth and management, daily weather data, and soil data were provided. The simulated yield was validated using the observed yield through CCEs from farmers' fields. When the observed and simulated yields were compared, their deviation was found to be less than 20 percent for all varieties at experimental locations of the Vidisha and Nagaur districts. The observed yield of Chickpea matched well after calibration which showed that model could simulate the yield with high accuracy as it showed $R^2$, d, and MAPE of 0.873, 0.92, and 7.3 for calibration and 0.886, 0.90, and 7.6 for the validation, respectively. The model has been successfully calibrated and validated for the chickpea at spatial level and it can be taken for further applications in natural resources management and climate change impact studies.



*~~Key words~~Keywords: Chickpea, DSSAT, CROPGRO, Spatial yield, Vidisha, Nagaur*


## 1. INTRODUCTION

Chickpea (Cicer arietinum L.) is grown over a wide range of agroclimatic environments. It is traditionally grown in the northern hemisphere mostly between 20°N and 40°N latitude. Most of the desi (with yellow to brown seed testa) chickpea is grown between 20°N and 30°N, while kabuli (with ~~cream-coloured~~cream-colored, seed testa) types are grown above 30°N. In addition, there is a small area between 10°N and 20°N at relatively high elevations in India and Ethiopia where it is grown[1].

Crop simulation models involve the mathematical function of various crop physiological factors such as photosynthesis, respiration, and relative growth rate to describe the crop growth changes under various climatic and environmental conditions. The model at times becomes complicated as it needs several detailed inputs for simulation and makes the calibration process tedious to perform [2]. Crop simulation models are key components to test the advances in agricultural technology and to predict crop responses to present and future climate forcing. These models are being used widely to estimate the crop production potential, transfer ~~of~~ Agro-technologies, assist strategic decisions, and forecast real-time yield [3]. DSSAT model is one of the crop simulation models used to simulate the growth and development of a crop by integrating soil, crop phenotype, weather, and management options[4]. DSSAT has modules that allow users to build model input files for spatial simulations across predefined management zones, and calibrate the model to simulate historic spatial yield variability and crop response to environmental and management variations[5]. The capability of the DSSAT model in simulating crop responses and the sensitivity of the model output to input parameters with spatial attention to the determinants of the model response to the practice of conservation agriculture were analyzed. The results showed that the phenological cultivar parameters were the most influential model parameters. The correlation between the input parameters and output variables was stable over a wide range of seasonal rainfall conditions[6].

CERES-Maize module was employed to estimate maize yield spatially during kharif, 2017 at Ariyalur and Perambalur districts which indicates that the module can be used to estimate the maize yield spatially at different weather, and soil conditions [7]. Similar to CERES-Maize, the CROPGRO-Chickpea module is a dynamic simulation module, which replicates the growth and yield of a variety of leguminous crops, including chickpea, soybean, peanut, and groundnut. In India, Singh and Virmani et al.,1996 created the CHIKPGRO (CROPGRO-Chickpea) model, which can be used to predict potential and water-limited yields of chickpeas [8].Using the

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DSSAT-CROPGRO model in the CDR, the future climate change impact of black gram yield has been evaluated,the results show that the simulation of black gram yield change for RCP 4.5 might be around 34%, 52%, and 25% during the near-century, mid-century, and end-century, respectively [9].Calibration and validation were done for DSSAT (v.4.6) CROPGRO – chickpea model was used to study the impact of climate change by its at Anand. Thus, the higher temperature regimes resulted in a gradual decrease in grain yield whereas lower temperature showed an increase in grain yield [10].

The present study utilizes the CROPGRO-chickpea module for estimating the yield of ~~chickpea~~ chickpeasat spatial levels at different locations, weather, soil, and management conditions.

## 2. METHODOLOGY

### 2.1 Study area

Geographically, the experiment was carried out for the Rabi season (2022) in the Vidisha district of Madhya Pradesh and Nagaur of Rajasthan (Figures 1 & 2). Vidisha is situated at 23° 31' N latitude, 77° 49' E Longitude, and at an altitude of 429 meters above mean sea level (MSL) in the eastern part of the fertile Malwa Region. Similarly, Nagaur is situated at 27° 12' N latitude, 73° 44' E Longitude, and at an altitude of 302 meters above mean sea level (MSL) in the northwestern Marwar region of Rajasthan. Vidisha district enjoys a subtropical climate and receives an average annual rainfall of about 1299 mm. On ~~an~~ average, about 85 percent of the total rainfall is received during the South-West monsoon period i.e., from June to September. However, occasionally 5 to 10 percent showers occur during the winter season, whereas Nagaur district enjoys the desert climate and receives an average annual rainfall of about 307 mm. The experimental study was carried out in different locations in the Vidisha and Nagaur districts. In each of the districts, around 70 ground truth points and Crop Cutting Experiments (CCE) data were collected at random locations from which 20 monitoring sites for Vidisha and 17 monitoring sites for Nagaur were selected for the experimental study. The package of practices for the cultivation of ~~chickpea~~ chickpeaswas followed as per the recommendation. The crop parameters such as yield and yield attributes, LAI, harvest index, and phenology were used for calibration of the DSSAT v.4.8 model. Three varieties were chosen for Vidisha (JG 16, RVG 202, JAKI 9218) and three varieties were chosen for Nagaur (RSG 44, RSG 896, RSG 807).

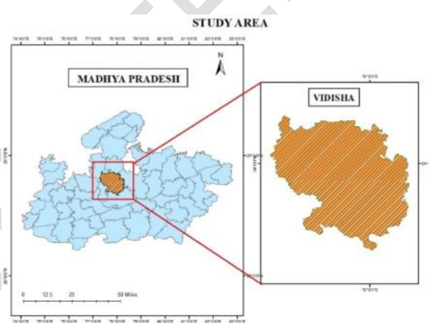


**Figure 1. Study area location of Vidisha (Madhya Pradesh)**

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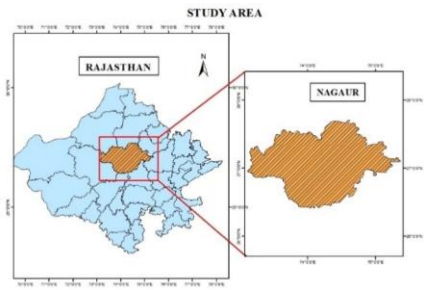


**Figure 2. Study area location of Nagaur (Rajasthan)**

## 2.2 CROPGRO module input

The pertinent daily weather, soil, and crop management data for all the sowing dates and irrigation levels were used as input and experiment performance data files. The daily weather data on minimum and maximum temperature ($^{o}$C), solar radiation (MJm$^{-2}$day$^{-1}$), and rainfall (mm) were collected for the study area. The weather input files for crop simulation were generated using the weatherman tool in DSSAT for monitoring sites and the soil files are gathered from International Soil Reference and Information Centre (ISRIC). These files were the inputs to the model for the monitoring fields for the study area to be simulated.

## 2.3 Calibration and Validation of the CROPGRO chickpea model

For calibration, the yield data from the three different monitoring sites for three different varieties (JG 16, RVG 202, JAKI 9218) in Vidisha and three different monitoring sites for three different varieties (RSG 44, RSG 896, RSG 807) in Nagaur were used for rabi season 2022 -23. The remaining 17 monitoring sites for three varieties in Vidisha and 14 monitoring sites for three varieties in Nagaur were used to validate the model using the yield data collected from farmers' fields through CCEs (observed yield data) in the study area.

## 2.4 Statistical Approach of Model Evaluation

The model's performances were evaluated by using the statistical indices including the coefficient of determination (R2), Mean Absolute Percentage Error (MAPE), Nash-Sutcliffe efficiency (NSE), and Index of Agreement (d) [11].

### 2.4.1 Pearson's correlation coefficient (r) and coefficient of determination (R2)

$$R^2 = 1 - \frac{RSS}{TSS}$$

R2 = Coefficient of determination

RSS = Sum of squares of residuals

TSS = Total sum of squares

### 2.4.2 Index of agreement (d)

$$d = 1 - \frac{\sum_{i=1}^{n}(n_i - s_i)^2}{\sum_{i=1}^{n}(|M_i - \bar{M}| + |S_i - \bar{M}|)^2}$$

where, Mi and Si are the observed and simulated values, respectively.

n = the number of observations

M = the mean of n measured values

#### 2.4.3 Mean Absolute Percentage Error (MAPE)

$$M = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right|$$

M = mean absolute percentage error

N = number of times the summation iteration happens

At = actual value

Ft = forecast value

## 3. RESULTS AND DISCUSSION

### 3.1 Chickpea genetic coefficients

The calibration of the CROPGRO - Chickpea module, data on plant growth and development, soil characteristics, weather, and crop management were collected as required for determining the cultivar coefficients of JG 16, RVG 202, JAKI 9218, RSG 44, RSG 896 & RSG 807 following the procedures described in International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). These coefficients allow the model to simulate the performance of diverse genotypes under different soil, weather, and management conditions [12].
To determine the genetic coefficients (Table 1) of ~~chickpea~~chickpeas, the calibrated values are obtained by changing their values to determine the variation in the magnitude of output manually. Then, those values of the genetic coefficients that ~~was~~ werefound most realistically simulated the growth and yield of ~~chickpea~~ chickpeaswere selected. The data set for genetic coefficients calculations ~~includes~~ includesdays to anthesis, days to the first pod, days to physiological maturity, days to harvest maturity, seed yield, by-product leaf area, and harvest index. The procedure for determining genetic coefficients involved in running the model using a range of values of each coefficient, until the desired level of agreement between simulated and observed values was reached.

**Table 1:Calibrated genotypic coefficients for rabi Chickpea cultivar**

| Coefficient code | Description | Genetic coefficient | | | | | |
|---|---|---|---|---|---|---|---|
| | | JG 16 | RSG 44 | RSG 896 | JAKI 9218 | RVG 202 | RSG 807 |
| CSDL | Critical Short-Day Length below which reproductive development progresses WITH daylength effect (for long day plants) (hour) | 11 | 11 | 10.9 | 10.9 | 10.9 | 11 |
| PPSEN | ~~Slope~~ The slopeof the relative response of development to photoperiod with time (negative for ~~long day~~long-day plants) (1/hour) | -0.143 | -0.143 | -0.32 | -0.32 | -0.143 | -0.43 |
| EM-FL | ~~Time~~ The timebetween plant emergence and flower appearance (R1) (photothermal days) | 31 | 42 | 35 | 40.8 | 32.8 | 36 |
| FL-SH | ~~Time~~ The timebetween the first flower and the first pod (R3) (photothermal days) | 5.5 | 10.5 | 7.7 | 8 | 5 | 6.5 |
| FL-SD | ~~Time~~ The timebetween the first flower and the first seed (R5) (photothermal days) | 13 | 13.5 | 14.5 | 13 | 9 | 11.1 |
| SD-PM | ~~Time~~ The timebetween the first seed (R5) and physiological maturity (R7) (photothermal days) | 30.5 | 50 | 45 | 41 | 35 | 39.7 |
| FL-LF | ~~Time~~ The timebetween the first flower (R1) and end of leaf expansion (photothermal days) | 34 | 60 | 53 | 49 | 45 | 45 |



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|---|---|---|---|---|---|---|---|
| **LFMAX** | Maximum leaf photosynthesis rate at 30 C, 350 vpm CO2, and high light (mg CO2/m2-s) | 0.95 | 1.3 | 1 | 0.95 | 1.2 | 1.2 |
| **SLAVR** | Specific leaf area of cultivar under standard growth conditions (cm2/g) | 200 | 200 | 200 | 200 | 220 | 200 |
| **SIZLF** | Maximum size of the full leaf (three leaflets) (cm2) | 10 | 10 | 10 | 10 | 10 | 10 |
| **XFRT** | Maximum fraction of daily growth that is partitioned to seed + shell | 0.96 | 1.05 | 1 | 0.95 | 0.95 | 0.95 |
| **WTPSD** | Maximum weight per seed (g) | 0.17 | 0.32 | 0.18 | 0.18 | 0.22 | 0.19 |
| **SFDUR** | Seed filling duration for pod cohort at standard growth conditions (photothermal days) | 22 | 28 | 22 | 20 | 20 | 20 |
| **SDPDV** | Average seed per pod under standard growing conditions (#/pod) | 1.2 | 1.6 | 1.3 | 1.3 | 1.5 | 1.2 |
| **PODUR** | Time required for cultivar to reach final pod load under optimal conditions (photothermal days) | 18 | 19 | 18 | 18 | 16 | 16 |
| **THRSH** | The maximum ratio of (seed/(seed+shell)) at maturity. | 82 | 85 | 85 | 85 | 85 | 85 |
| **SDPRO** | Fraction protein in seeds (g(protein)/g(seed)) | 0.216 | 0.216 | 0.216 | 0.216 | 0.216 | 0.216 |
| **SDLIP** | Fraction oil in seeds (g(oil)/g(seed)) | 0.48 | 0.048 | 0.048 | 0.048 | 0.048 | 0.048 |





### 3.2Yield Analysis

The observed yield and simulated yield are compared, and their deviation is calculated. It indicates that the deviation is less than 20 per cent for all varieties of chickpea in 20 experimental locations of Vidisha district (Table 2). In Nagaur district, the deviation is less than 18 per cent for all varieties of chickpea in 17 experimental locations (Table 3). For all varieties in Vidisha and Nagaur districts, simulated yield fitted well with the observed yield although the simulated yield was slightly higher than the observed values. Choudhury et.al (2018) [13] also stated that the simulated biomass yield was slightly higher than that of the observed biomass yield in wheat while using the DSSAT model

**Table. 2 Observed and simulated yield for Vidisha Monitoring Sites**

| | | Vidisha | | |
|---|---|---|---|---|
| **Latitude** | **Longitude** | **Observed Yield (kg/ha)** | **Simulated Yield (kg/ha)** | **Deviation (%)** |
| | | ***Variety I - JG 16*** | | |
| 23.51063 | 78.06736 | 1464 | 1536 | 4.9 |
| 23.71673 | 77.86417 | 1655 | 1996 | 19.6 |
| 23.72553 | 77.83993 | 1995 | 2011 | 0.8 |
| 23.68868 | 78.00718 | 1765 | 1904 | 7.9 |
| 23.70251 | 77.99177 | 1318 | 1366 | 3.6 |
| 24.06780 | 77.91728 | 1427 | 1537 | 7.7 |

| | | | | |
|---|---|---|---|---|
| 23.63285 | 77.84866 | 1185 | 1238 | 4.5 |
| | | *Variety II - JAKI 9218* | | |
| 23.71113 | 77.90449 | 1750 | 1809 | 3.4 |
| 23.48960 | 78.05553 | 1834 | 1916 | 4.5 |
| 23.47606 | 78.03633 | 1812 | 1922 | 6.1 |
| 23.70830 | 77.93528 | 1969 | 2041 | 3.7 |
| 24.02634 | 77.86156 | 1703 | 1863 | 9.4 |
| 23.39478 | 78.01640 | 1684 | 1790 | 6.3 |
| | | *Variety III - RVG 202* | | |
| 23.67509 | 77.97400 | 1492 | 1633 | 9.5 |
| 23.73018 | 77.86488 | 1585 | 1689 | 6.6 |
| 23.58353 | 77.98783 | 1612 | 1715 | 6.4 |
| 23.53913 | 78.02460 | 1505 | 1670 | 11.0 |
| 24.00687 | 78.14264 | 1320 | 1550 | 17.4 |
| 24.06878 | 77.74187 | 1386 | 1570 | 13.3 |
| 23.54101 | 77.98305 | 1198 | 1260 | 5.2 |

**Table.3 Observed and simulated yield for Nagaur Monitoring Sites**

| | | Nagaur | | |
|---|---|---|---|---|
| **Latitude** | **Longitude** | **Observed Yield (kg/ha)** | **Simulated Yield (kg/ha)** | **Deviation (%)** |
| | | *Variety I - RSG 44* | | |
| 26.79998 | 74.23855 | 1788 | 1907 | 6.7 |
| 26.64958 | 74.27593 | 1518 | 1559 | 2.7 |
| 26.82605 | 74.65694 | 1645 | 1897 | 15.3 |
| 26.99160 | 74.77227 | 1377 | 1476 | 7.2 |
| | | *Variety II - RSG 807* | | |
| 26.62767 | 74.19618 | 1809 | 1840 | 1.7 |
| 26.64373 | 74.00105 | 1695 | 1994 | 17.6 |
| 26.86517 | 74.76031 | 1126 | 1290 | 14.6 |
| | | *Variety III - RSG 896* | | |
| 26.74230 | 74.40154 | 1492 | 1666 | 11.7 |
| 26.78795 | 74.22688 | 1259 | 1341 | 6.5 |
| 26.77226 | 74.43233 | 1380 | 1520 | 10.1 |
| 26.77273 | 47.43463 | 1210 | 1308 | 8.1 |
| 26.75381 | 74.43324 | 1380 | 1459 | 5.7 |
| 26.66367 | 74.31238 | 1579 | 1617 | 2.4 |
| 26.59892 | 74.17314 | 1412 | 1559 | 10.4 |
| 26.61882 | 74.16225 | 1477 | 1559 | 5.6 |
| 26.77100 | 74.46893 | 1421 | 1474 | 3.7 |
| 26.82490 | 74.65146 | 1462 | 1582 | 8.2 |

### 3.3Calibration and validation of model

The observed yield of Chickpea matched well after calibration which showed that model could simulate the yield with high accuracy, as it showed R2, d and MAPE of 0.873,0.92 and 7.3 for calibration and 0.886,0.90 and 7.6 for the validation respectively, which indicates a good prediction efficiency. The R2 values are good and significant, the 1:1 line graph was drawn showing observed yield in X-axis and simulated yield in Y-axis. The regression line of grain yield was near to the 1:1 line, indicating that the model was performing well under the test environment, thus model simulated the yield perfectly (Figures 3 & 4).

The index of agreement (d) ranges around 0.9, it indicates all varieties have high index of agreement (i.e., perfect match). Thus, The MAPE is very good for all varieties (< 10 %) thus, the mean absolute percentage errors between the predicted and actual values in the calibration and validation of the model were less and the model predicted the yield well and which indicates a very good score for the simulation. The MAPE was good for evaluating the yield and growth of wheat in Algeria[14].

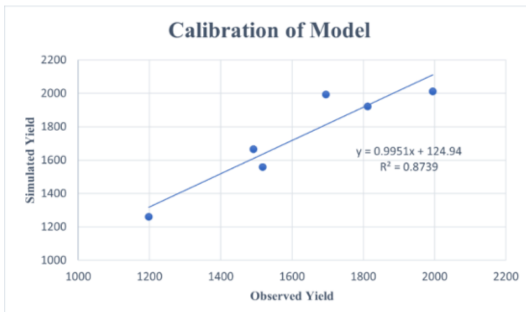




**Figure 3 Simulated and observed yield for calibration**

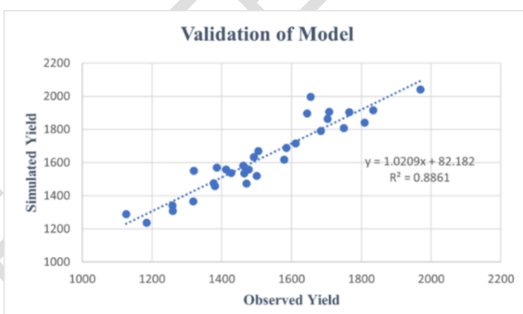




**Figure 4 Simulated and observed yield for Validation**

### 3.4 Correlation Matrix of weather variables with yield

The climatic conditions of the experimental area are taken and analyzed for predicting their correlation matrix. The Minimum dataset of weather parameters that is required for DSSAT (Maximum Temperature, Minimum Temperature, Solar Radiation and Rainfall) are chosen. The correlation matrix using R-Studio indicates that the yield when correlated with the TMax (Maximum Temperature) indicated a positive value and significant relationship. It is also noted that the yield when correlated with rain shows negative and non-significant correlation for Vidisha. For Nagaur, when the yield is correlated with all the parameters it shows a negative value and non-significant. The correlation with the Tmin (Minimum Temperature) showed a positive correlation (Figures 5&6).

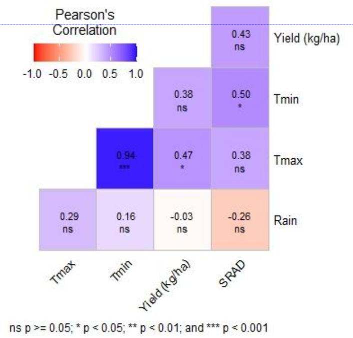


**Figure 5 Correlation Matrix for Vidisha**

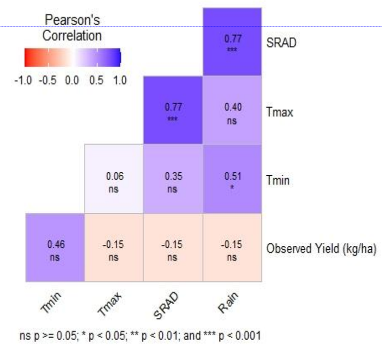


**Figure 6 Correlation Matrix for Nagaur**

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Studies on zoning and agricultural potential of tropical crops in Latin America have relevance and importance similar to the evaluation of DSSAT-CROPGRO for chickpea in India. However, there are key differences and possible areas of comparison. The geographical and climatic conditions in Latin America differ significantly from those in Vidisha and Nagaur [15, 16]. Comparing the performance of crop models like DSSAT-CROPGRO across diverse regions can provide insights into their generalizability and adaptability[17, 18].

Latin America hosts a wide range of tropical crops[19, 20, 21], each with unique responses to environmental conditions. Evaluating zoning studies for multiple crops can offer a comprehensive understanding of how well different crops are suited to specific regions compared to a focused evaluation of a single crop like chickpea[22, 23].Comparing the methodologies and data sources used in the Latin American studies with the evaluation in India can highlight the importance of accurate and consistent data for robust crop modeling and decision-making[24].The socio-economic context in Latin America may differ from that in India, influencing the implementation of agricultural policies and the adoption of technology[25, 26]. Understanding these differences can aid in tailoring interventions to specific regional needs[27, 29, 29].

In conclusion, the evaluation of the DSSAT-CROPGRO module for spatial yield estimation of chickpea in Vidisha and Nagaur is highly relevant and important for improving agricultural practices, climate change adaptation, and policy formulation. By comparing these findings with studies on tropical crop

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zoning in Latin America, we can gain valuable insights into the transferability of crop models across regions and the broader implications of precision agriculture and climate-resilient farming practices.

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## 4. CONCLUSION

The validated outcomes of the DSSAT-CROPGRO Chickpea module revealed that this model simulates the yield attributes more than that of observed crop data. The DSSAT model has proved to be a valuable tool for predicting chickpea yield. Therefore, the validated DSSAT can be further used for applications such as prediction of crop growth, phenology, potential and actual yield, performance of chickpea under climate change study, etc., The model may also be used to improve and evaluate the current practices of chickpea growth and its management as well as the CROPGRO module can be used to simulate the yield spatially for different conditions of soil, weather and management practices to enhance chickpea production. It could be concluded that the model works well for rainfed growingenvironments and further it can be taken for application in natural resource management and climate change impact analysis studies.

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