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Calibration and validation of CERES-sorghum module of DSSAT model for *rabi* sorghum under rainfed condition

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Abstract

Crop simulation models were often used to characterize the growth and development of a crop and access the field crop production practices. The aim of this study is to calibrate and evaluate the *rabi* sorghum genotype under rainfed condition in the Viruthunagar and Thoothukudi districts of Tamil Nadu using the DSSAT crop simulation model. DSSAT requires weather and soil file of the study area, details of crop management practices and genetic coefficient of the specified crop to simulate the yield. In this study, the data from the six field trials with three different planting dates at the study area was used to calibrate the model for *rabi* season of 2019 -2020. Observed data on crop yield and Leaf Area Index (LAI) from the farmer's field at different sites was used to validate the model simulated results. This exercise of calibration of specific parameters of *rabi* sorghum using DSSAT-CERES Sorghum performed well and the model could be used as decision support tool for various applications.

Keywords: crop simulation model, DSSAT, CERES-sorghum, calibration and validation

Introduction

Sorghum (*Sorghum bicolor*) or Jowar is an important crop among cereals after maize, rice, wheat and barley on a global scale. As a C4 plant with higher photosynthetic capacity and greater productivity of nitrogen and water use, it is genetically adapted to arid and semi arid ecosystem where other crops are difficult to produce^[1]. Sorghum is truly a dual-purpose plant that can be used for both grain and stover in all agroecology. In India, area under sorghum cultivation was 7.38Mha on 2010-2011 that have been changed to 4.10Mha in 2018-2019 (FAOSTAT.2020). This is mainly due to the improvement in the other crop varieties and hybrids thereby the areas were shifted to the other crops. Unlike other countries, in India Sorghum was grown in two seasons *viz.*, kharif season (June/July -October/November) as a rainfed crop and *rabi* season (October – December /January) under limited irrigation or with residual moisture^[4]. In India on 2018-2019 an area, production and productivity of sorghum was 4.10 Mha, 3.48 MT and 849.1kg/ha respectively^[9]. The area (ha) and production (tonnes) of sorghum in India over last 10 years were given in Fig.1.

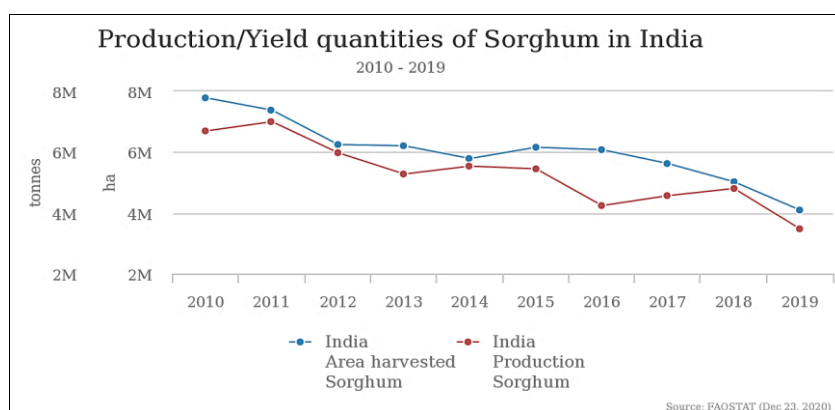


Fig 1: Area and production of sorghum in India for 2010 – 2019.

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Crop simulation models are principal tools to bring agronomic science into information science. The relationship between crop and environment can be well explained using crop simulation models. The crop growth models are used to assess the climatic impacts on the stability of crop production and productivity under different management practices [5]. It is well much helpful in reducing the cost of conducting the field experimentation to predict yield. Decision Support Systems for Agro-technology Transfer (DSSAT) is a process oriented dynamic crop simulation model. Model requires four main types of input data: weather, soil, crop and management. The daily weather data includes maximum and minimum temperature, rainfall and solar radiation. Soil data includes texture, color, slope, nitrogen and organic matter content across layers. Crop data includes cultivar specific genetic coefficients with information on development (phenology) biomass accumulation, grain yield and yield attributes, and management data includes soil preparation, planting dates, spacing, plant density, fertilization amounts and timing or other agricultural practices [2]. DSSAT was used to simulate the yield of various crops like maize [12], groundnut [6], etc. Before going for the crop simulation, the model has to be calibrated for specific genotype. After simulation of the growth and production, the simulated result has to be validated with the observed data. Therefore, this study was carried out i) to generate the genetic coefficient of the *rabi* sorghum genotype in rainfed condition and ii) to calibrate the and validate DSSAT crop model for simulation of growth and yield of sorghum.

Materials and Methods

Study area

The data for modeling was collected from the Viruthunagar and Thoothukudi districts of Tamil Nadu. Both districts were coming under the southern zone of Tamil Nadu.

Viruthunagar district has a total area of 4243 sq.kms. The geographic coordinates of the district is 79°29'51.23" E longitude and 11°56'21.84" N latitude with the altitude range of 67m to 103m [11]. The predominant soil type of this district is deep black soil and the average annual rainfall over the district varies from 724mm to 913mm. The area under rainfed crops were high over the area under the irrigated crop. The major field crops grown in this region area paddy, maize, pulses, sorghum, cotton and groundnut [7].

Thoothukudi district has a total area of 4707 sq.kms. The geographic coordinates of the district are 78°08'42.5" E longitude and 8°48'09.29" N latitude with the altitude range of 2m to 100m [10]. The predominant soil type of this district is deep black soil and the average annual rainfall over the district varies from 570mm to 740mm. the area under rainfed crops were high over the area under the irrigated crop. The major field crops grown in this region area paddy, pulses, pearl millet and sorghum [8].

Data source

The calibration and validation were done for the predominant grain sorghum genotype in the selected study area viz., K12 (Fig.2) for *rabi* season (September - February) of 2019 - 2020 with three planting dates of sowing viz., September 15, September 25 and October 5 at six field trials. K12 was a dual-purpose sorghum variety released from Agricultural Research Station, Kovilpatti. It has a creamy white grain and tolerate to drought condition and moderately resistant to shoot fly and stem borer [3]. Recommended dose of fertilizer (90:45:45 kg N, P₂O₅, K₂O ha⁻¹) was applied to each field. 50% N and full dose of P and K were applied at basal during

sowing and remaining 50% of N was applied as top dressing at 30 days after planting. Continuous monitoring of the monitoring sites was done at regular intervals for observing the plant phenology.



Fig 2: K12 Sorghum variety

The daily weather data such as maximum temperature (°C), minimum temperature (°C) and solar radiation (MJm⁻²day⁻¹) and precipitation (mm) were collected for study area. Soil information for the study area was collected from Department of Remote Sensing and GIS, TNAU. The ground truth information on Leaf Area Index (LAI), crop management practices and yield data were collected from farmer's field at different sites for generating input files for DSSAT crop simulation model.

Statistical Approach of Model Evaluation

The root mean square error (RMSE) values indicate how much the model over or under estimate compared to observed measurements. Lower the RMSE values higher the performance of model. RMSE tests the accuracy of the model and set of RMSE values were calculated using the below formulae

$$RMSE = \left[\frac{1}{n} + \sum_{i=1}^n (Pi - Oi)^2 \right]$$

where Pi = Predicted yield,

n = number of samples, Oi= Observed yield

A smaller RMSE means less deviation of the simulated values from the observed values, thus indicates better performance.

Result and Discussion

Model calibration and validation

Calibration is a process of adjusting and/or optimizing model parameters, especially cultivar specific genetic coefficients, so that model simulated outputs match well with observed data from the experimentation for a given cultivar before the model is used for other application using those cultivars. Whereas, validation is the testing of crop models across the situation. The genetic coefficients of two sorghum cultivars mentioned above were calibrated with data (that included phenology, biomass and yield components) collected from the farmer's field using DSSAT-CERES Sorghum model. The genetic coefficients for the varieties used in the present simulation studies were optimized using Gencalc, a semi-automated program embedded within DSSAT to optimize genetic coefficients, followed by manual method. The optimized coefficients after calibration process are presented in Table.1 and the description of each coefficient is presented in Table.2.

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

Parameters	Sorghum variety K12
P1	400.0
P2	90.0
P2O	11.70
P2R	88.0
PANTH	590.5
P3	130.0
P4	80.5
P5	480.0
PHINT	60.00
G1	5.700
G2	6.400

Table.2: Description of genetic coefficients

Coefficient code	Description
P1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above base temperature during which the plant is not responsive to changes in photoperiod).
P2	Thermal time from the end of the juvenile stage to tassel initiation under short days (degree days above base temperature).
P2O	Critical photoperiod or the longest day length (in hours) at development occurs at a maximum rate. At values higher than P2O, the rate of development is reduced.
P2R	Extent to which phasic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P2O.
PANTH	Thermal time from the end of tassel initiation to anthesis (degree days above base temperature).
P3	Thermal time from to end of flag leaf expansion to anthesis (degree days above base temperature).
P4	Thermal time from anthesis to beginning grain filling (degree days above base temperature).
P5	Thermal time from beginning of grain filling to physiological maturity (degree days above base temperature).
PHINT	Phylochron interval; the interval in thermal time between successive leaf tip appearances (degree days).
G1	Scaler for relative leaf size
G2	Scaler for partitioning of assimilates to the head.

Fig. 3 and Fig.4 shows alignment of both simulated and observed data for Leaf Area Index. Leaf area Index of sorghum matched well after calibration which showed that model could simulate LAI with high accuracy as it showed minimum R² and RMSE of 0.754 and 0.581664 for calibration and 0.783 and 0.321455 for the validation respectively.

Fig. 5 and Fig.6 shows alignment of simulated and observed data for grain yield (kg ha⁻¹). Grain yield of sorghum matched well after calibration which showed that model could simulate grain yield with high accuracy as it showed minimum R² and RMSE of 0.739 and 123.252 for calibration and 0.728 and 110.704 for the validation respectively.

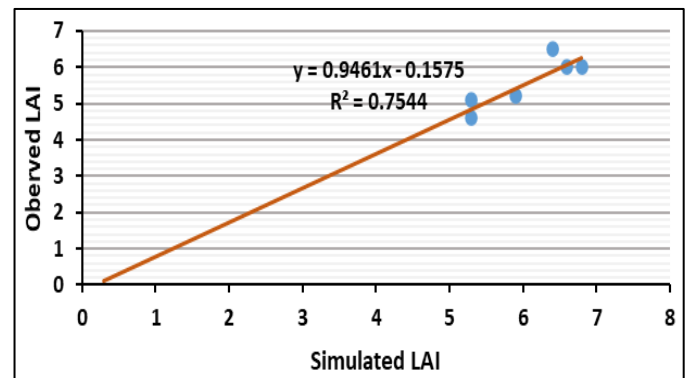


Fig 3: Simulated and observed LAI for calibration

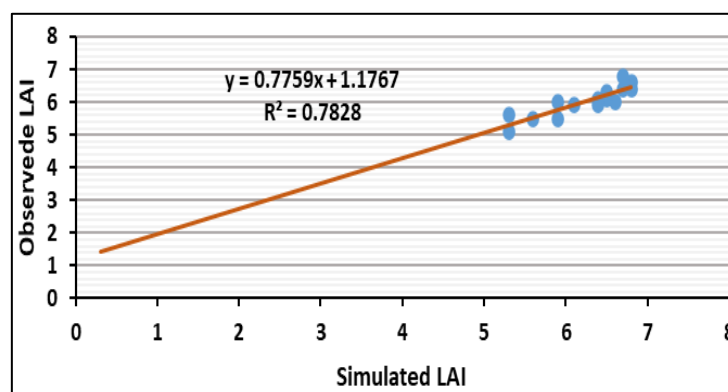


Fig 4: Simulated and observed LAI for validation

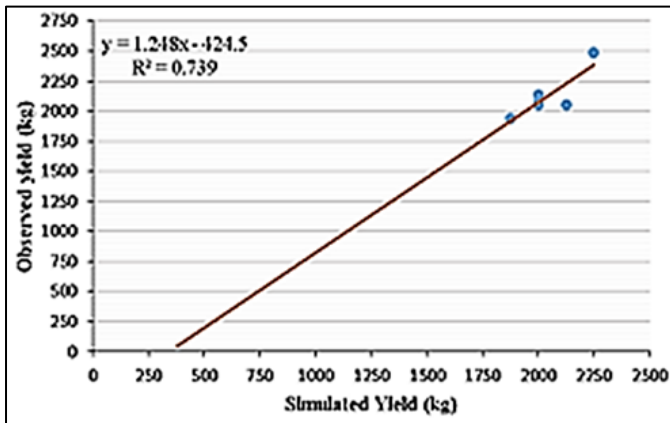


Fig 5: Simulated and observed grain yield for calibration

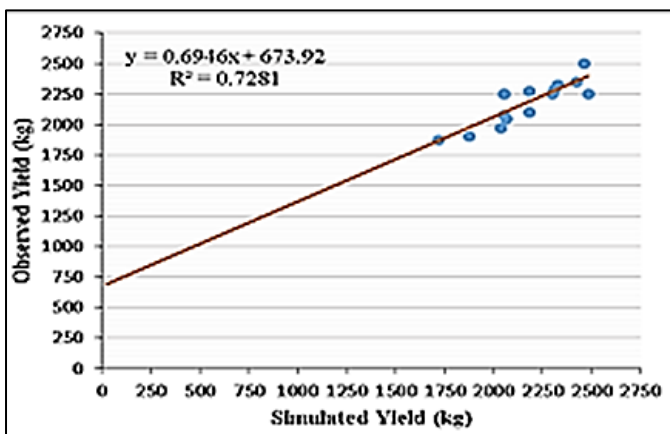


Fig 6: Simulated and observed grain yield for validation

Conclusion

This exercise of calibration of DSSAT CERES Sorghum model by optimizing crop specific parameters of sorghum genotype followed by evaluation of the model using data observed from the farmer's field showed that DSSAT CERES-Sorghum performed well to simulate phenology and yield *rabi* sorghum genotypes. This was carried out mainly for setting a genetic coefficient for *rabi* sorghum in rainfed condition. It could be concluded that the model works well for rainfed growing environment, and can thus be taken for application in natural resource management and climate change impact analysis studies.

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