Original Research Article

Estimating genetic parameters for DSSAT CROPGRO-Cotton model calibration and validation

Abstract

DSSAT CROPGRO-Cotton Model (version 4.7.5) was widely evaluated as a tool to forecast the effect of climate change on productivity. The objective of this study was to calibrate and validate this model in Tamil Nadu, India for simulation of development, growth and seed cotton yield of Suraj cotton cultivars under varied planting dates *viz*., July 28, August 11, August 18, August 25, September 8 and September 15. The model was calibrated with data (phenology, biomass and yield components) collected during 2019. Calibration of CROPGRO-Cotton model with genetic coefficients of cultivar Suraj for seed cotton yield (kg ha^{-1}). Simulation of days to flowering, days from planting to first pod and physiological maturity, LAI and seed cotton yield with normalized RMSE (NRMSE) values of less than 10% across all the various planting dates densities were considered excellent. Finally, we discovered that planting at the right time can mitigate many of the negative effects of fluctuating weather on cotton productivity. As a result, we conclude that the DSSAT model will be used to make strategic cotton planting decision in changing climates.

Key words: *Gossypium hirsutum*, DSSAT CROPGRO-Cotton, Cotton cultivars, crop growth and yield simulation.

1. Introduction

In India Cotton is the ~~an~~ most important cash/fiber crops commonly ~~refered~~ referred to as"King of Natural Fiber and White Gold". *Gossypium* spp. plays an important part in the agricultural and textile industrial economies around the world. Cotton supplies 65 percent of the textile industry's demand in India and >70 countries widely growing cotton in tropical/subtropical climates. There are approximately 1500 mills, four million handlooms, 1.7 million power looms and thousands of garments, hosiery and processing units, providing employment directly or indirectly to about 45 million people. (Anonymous, 2020). Cotton was grown in areas with rainfall ranging from 600 to 2500 mm. To grow ~~produce a~~ cotton crop at least 500 mm (20 inch) of water (rainfall/irrigation) is necessary in a frequent and timely pattern throughout crop growing season (Doorenbos and Pruitt, 1984).

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India is the only country in the world to grow all the four cultivated species of cotton in addition to hybrids and has the distinction of having the largest area under cotton cultivation which is about 42% of the world area under cotton cultivation between 12.5 million hectares to 13.5 million hectares. Cotton may be grown in three different agro - ecological zones *viz*., northern, central and southern zone. Nearly 70 % of the crop is cultivated under rainfed conditions in the central and southern regions of the country. In India during 2019-2020 (provisional), production of Cotton was 354.91 lakh bales cultivated under an area of 133.7 lakh hectares (Directorate of Economics & Statistics, 2020-21).

Crop simulation models are one of the most important instruments for integrating agronomic and information sciences. Through the mathematical and conceptual relationship that governs a living plant's growth in the Soil - Water - Plant - Atmosphere continuum, these crop models made it possible to replicate a living plant. Crop simulation models explain a lot of what happens when the environment and the crops interact. Agricultural growth models are useful for assessing the influence of climate change on crop production stability under various management strategies (Hoogenboom *et al*., 1995). Crop growth simulation models allows researchers to measure the impact of climate change on soil, crop growth, productivity and the long-term viability of agriculture. Cotton is extremely sensitive to adverse environmental conditions and field management (Sowmiya *et al*., 2021). Hence these technologies can be used to examine yield gaps in a variety of crops and can decrease the need for costly and time-consuming field testing. Crop simulation model is very beneficial because it connects crop process analysis and performance evaluation.

The Decision Support System for Agricultural Technology Transfer (DSSAT) is a crucial tool for agricultural technology transfer and the prospect for DSSAT is really valuable. Using long-term weather and soil data information, it is possible to scale out short-duration field experimental results (Jones *et al*., 2003). DSSAT model can simulate cotton development, growth, and yield under a wide range of soil, diverse meteorological parameters and agronomic management conditions (Amin *et al*., 2018). Th~~e~~is study's purpose ~~was~~ is to determine how well perform DSSAT CROPGRO-Cotton model in simulating growth and yield of Suraj cotton.

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2. MATERIALS AND METHODS

DSSAT CROPGRO-Cotton model calibration was carried in the selected monitoring site of farmer's field during July, 2019 to January, 2020. The selected monitoring site is located in the Cuddalore district of Tamil Nadu at 11° 32' N latitude, 79° 8' E longitude and at an altitude of 68 m above mean sea level.

2.1. Selection of Cotton variety

This experiment involved six dates of sowing with Suraj cotton variety which ~~are~~ is the most commonly grown cotton variety in the study area ~~are~~ is selected for simulation of growth and yield.

2.2. Data collection

The data collection was guided by technical reports from the DSSAT software. Sample analysis, observations and the usage of existing data were used to create data sets. From the planting date to harvest date, daily maximum and minimum air temperature (°C), precipitation (mm), Relative Humidity (%) and solar radiation (MJ m^{-2} day^{-1}) were needed to create weather file. Soil information such as soil class, texture, bulk density, Organic Carbon percent, Sand percent, Silt percent, Clay percent, pH, and Cation Exchange Capacity in the surface layer and subsurface layer were needed to create Soil file in SBuild -DSSAT. Crop management data (XBuild) such as planting method, planting date, plant density, row spacing, fertilizer application, irrigation data, harvesting date, harvesting method, grain yield/m2, and leaf area index were gathered. The Weather data prevailed during crop growing season in the study area was presented in the figure 1.

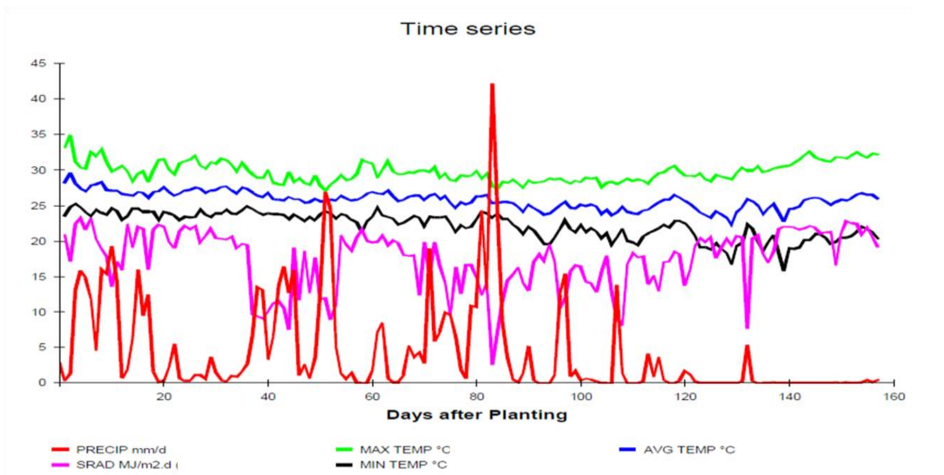

Fig.1. Weather data prevailed during crop growing season in the study area

2.3. Crop management

Cotton (*Gossypium hirsutum* L.) was sown in the *kharif* season ~~on~~ in the study area. The Suraj cotton variety was sown evenly at 100 cm apart, by bed-furrow method. Thinning was done after crop emergence to have a uniform p × p distance of 60 cm. When the field capacity dropped to 50%, a given quantity of water was applied to maintain the moisture level suitable for crop growing. The crop was fertilized with entire fertilizer dose as recommendation of TNAU crop production guide.

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2.4. DSSAT CROPGRO-Cotton Model Calibration

DSSAT crop models require genotype specific parameters (GSPs), which are specific for each cultivar. GSPs allow the model to simulate performance of diverse varieties under different soil, weather and management conditions (Hunt et al., 1993). There are three input files were created in DSSAT to run model namely,

a) Weather file: Weatherman program in DSSAT and collected weather data
b) Soil file: SBuild program in DSSAT and soil data
c) Experimental data file: XBuild program in DSSAT and crop management data

The model was calibrated using collected data from selected monitoring site of farmer's field during 2019-2020 through determination of genetic coefficient for Suraj variety in DSSAT 4.7.5. Then the model was then validated using the data from selected monitoring site of farmer's field during 2019-2020 by comparing the observed results and simulated results. The methodology of DSSAT CROPGRO-Cotton model was presented in the Figure 2.

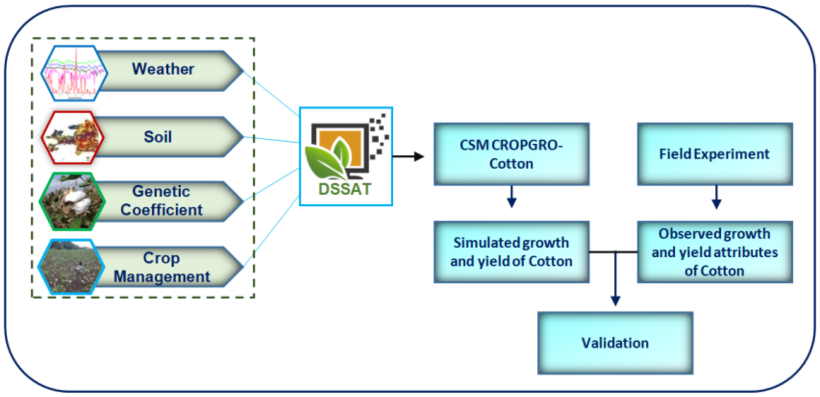

Fig.2. Methodology of DSSAT CROPGRO-Cotton

2.5. Crop model validation and test criteria

Validation is the comparison of the results of model simulations with observations from crops that were not used for the calibration. A model should be rigorously validated under widely differing environmental conditions to evaluate the performance of major processes in addition to its ability to predict the phenology and yield. Before any model can be used with confidence, it must undergo proper validation or an assessment of the severity of the mistakes that may happen as a consequence of its use. Model validation, in its simplest form is a comparison between simulated and observed values. Several criteria were used to quantify the differences between observed and simulated data.

2.5. 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 formulae given below (Wallach and Goffinet, 1989). A smaller RMSE means less deviation of the simulated values from the observed values and indicates better performance. 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% (Loague and Green, 1991) and Agreement percent (Jemison *et al*., 1994).

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

$$\text{NRMSE} = 100 \times \frac{RMSE}{Oi}$$

$$\text{Agreement (\%)} = 100 \times \frac{(Oi-RMSE)}{Oi}$$

where, P - Predicted data, O - Observed data and n - the number of observations

3. Results and Discussion

3.1 Calibration and validation results of DSSAT model

The calibration of the DSSAT CROPGRO-Cotton model was based on phenology and yield components were recorded at the time of harvesting. The genetic coefficients of the cotton cultivar will affect the phenological stages in the CROPGRO models were derived using the "trial-and-error" method of DSSAT v 4.7.5. Adjustment was performed to match the observed crop phenology and yield with the simulated values and to make the calibrated genetic coefficient lie within the predefined error limits for the cultivar. The genetic coefficients, as obtained through run of GLUE as part of Calibration exercise, are shown in (Table 1). The generated cultivar specific parameters were within the range of DSSAT cultivar database. So, we can use the generated genetic coefficient in model application for the study region.

Table.1. Calibrated genotypic coefficients of Suraj Cotton - DSSAT CROPGRO-Cotton model

No.	CODE	DESCRIPTION	Suraj variety
1	CSDL	Critical Short Day Length below which reproductive development progresses with no day length effect (for short day plants) (hour)	23.00
2	PPSEN	Slope of the relative response of development to photoperiod with time (positive for short day plants) (1/hour)	0.01
3	EM-FL	Time between plant emergence and flower appearance (R1) (photo thermal days)	50.0
4	FL-SH	Time between first flower and first pod (R3) (photo thermal days)	11.0
5	FL-SD	Time between first flower and first seed (R5) (photothermal days)	14.0
6	SD-PM	Time between first seed (R5) and physiological maturity (R7) (photo thermal days)	49.00
7	FL-LF	Time between first flower (R1) and end of leaf expansion (photo thermal days)	75.00
8	LFMAX	Maximum leaf photosynthesis rate at 30 C, 350 vpm CO2, and high light (mg CO^2/m^2-s)	1.16
9	SLAVR	Specific leaf area of cultivar under standard growth conditions (cm2/g)	174.0
10	SIZLF	Maximum size of full leaf (three leaflets) (cm^2)	293.0
11	XFRT	Maximum fraction of daily growth that is partitioned to seed + shell	0.70
12	WTPSD	Maximum weight per seed (g)	0.170

13	SFDUR	Seed filling duration for pod cohort at standard growth conditions (photo thermal days)	35.0
14	SDPDV	Average seed per pod under standard growing conditions	30.00
15	PODUR	Time required for cultivar to reach final pod load under optimal conditions (photo thermal days)	11.0
16	THRSH	Threshing percentage. The maximum ratio of (seed/(seed+shell)) at maturity. Causes seeds to stop growing as their dry weight increases until the shells are filled in a cohort.	68.0
17	SDPRO	Fraction protein in seeds (g(protein)/g(seed))	0.153
18	SDLIP	Fraction oil in seeds (g(oil)/g(seed))	0.120

For calibration, information for key phenological events (anthesis day, LAI, first pod day, days to physiological maturity and yield at harvest maturity) and yield-related data are needed. The model simulation was accordingly started with the default values available in the model for similar soils of other regions. Details of the experiment, data collection and model calibration are described by Banterng *et al*. (2003).

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Table.2. Observed and predicted Anthesis, first pod day, Physiological maturity day and yield at harvest maturity under different planting window.

Day After Planting	Obeserved Value	Simulated Value	RMSE	NRMSE	AGREEMENT (%)
28th July 28, 2019					
Anthesis	60	59	1	1.67	98.33
First pod day	74	73	1	1.35	98.65
Physiological maturity day	143	145	2	1.40	98.60
Yield at harvest maturity	2589	2782	193	7.45	92.55
11th August, 2019					
Anthesis	59	61	2	3.39	96.61
First pod day	74	75	1	1.35	98.65
Physiological maturity day	145	149	4	2.76	97.24
Yield at harvest maturity	2634	2735	101	3.83	96.17
18th August, 2019					
Anthesis	59	60	1	1.69	98.31
First pod day	75	74	1	1.33	98.67
Physiological maturity day	145	149	4	2.76	97.24
Yield at harvest maturity	2681	2842	161	6.01	93.99
25th August, 2019					
Anthesis	60	61	1	1.67	98.33
First pod day	74	75	1	1.35	98.65
Physiological maturity day	149	150	1	0.67	99.33
Yield at harvest maturity	2650	2804	154	5.81	94.19
8th September, 2019					

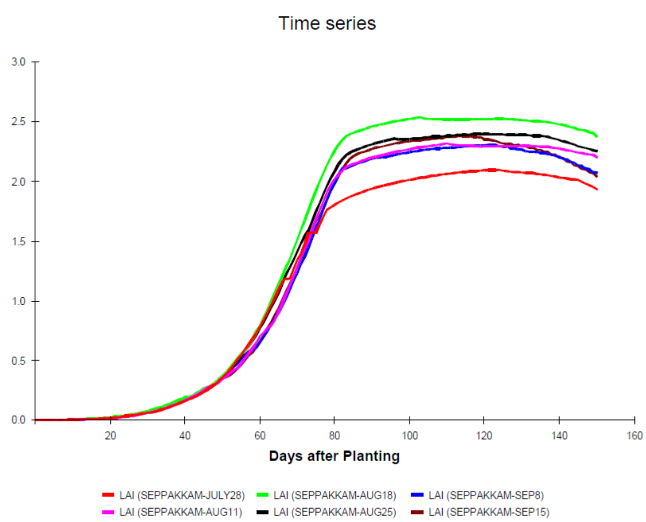
Anthesis	60	62	2	3.33	96.67
First pod day	74	75	1	1.35	98.65
Physiological maturity day	144	148	4	2.78	97.22
Yield at harvest maturity	2639	2745	106	4.02	95.98
15th September, 2019					
Anthesis	58	62	4	6.90	93.10
First pod day	73	76	3	4.11	95.89
Physiological maturity day	146	147	1	0.68	99.32
Yield at harvest maturity	2688	2759	71	2.64	97.36

3.2. Days to Anthesis

The CROPGRO-Cotton under DSSAT realistically simulated days taken to flowering under different dates of sowing. The RMSE for calibrated treatment for observed and simulated days to flowering of Suraj cotton cultivar under different sowing dates are represented in Table 2. The crop simulation model showed almost the same days of flowering as observed. Results from the crop simulation model evaluation showed that the crop reached flowering stage between 59 and 62 days after sowing for all the various planting dates (similar results also reported by Dakhore et al., 2021).

3.3. Leaf Area Index (LAI)

The observed LAI of the Suraj cultivar between 1.85 and 2.75 at harvest whereas DSSAT DSSAT CROPGRO-Cotton simulated LAI between 2.1 to 2.5 at harvest. LAI was given in Fig.3 at different dates of sowing.



Fig, 3. LAI of cotton under different dates of sowing

3.4. Days to First Pod and Physiological maturity day

The crop establishment to first pod under different planting dates are compared with observed and simulated values, this agreement was found to be 95.89 to 98.67 (table 2). The performance of model was better as compared in first pod day after planting. Crop physiological maturity was 143 to 149 days for observed and 147 to 150days for simulated days in the model and found to be more than 97 per cent agreement. Similar result was found in cotton reported by Arshad and Muhammad (2017).

3.5. Yield at harvest maturity

The cotton yield at harvest maturity was found to be 2688 to 2589 kg ha^{-1} (observed). The highest DSSAT simulate cotton yield at harvest maturity was found to be 2842 kg ha^{-1} when the crop was sown during 18th August, 2019 followed by 2804 and 2782 kg ha^{-1} with sowing dates of 25th August and 25th July, 2019, respectively. The RMSE was found to be 71 to 193 for Suraj cotton cultivar. Similar findings also reported in various crop like cotton, maize, groundnut, sorghum in DSSAT model by Kumar *et al*. (2017); Venkatesan and Pazhanivelan (2018); Deiveegan *et al*. (2019); Sabarinathan *et al*. (2021), respectively.

Conclusion

The experiment was carried out to calibrate and validate the DSSAT CROPGRO-Cotton model. The calibrated model was capable of simulating all the studied parameters of different dates of sowing. The implementation of calibrated DSSAT-CROPGRO-Cotton model by optimizing crop specific parameters of Suraj cotton genotypes followed by evaluation of the model using another independent set of data showed that DSSAT CROPGRO-Cotton model performed better in comparison with simulate phenology and yield. Hence it indicates that the DSSAT CROPGRO-Cotton model can be used as decision support tool for all these optimized Suraj cotton genotype with their respective coefficients for various applications *viz*.,optimizing dates of sowing, plant population, spacing and fertilizer inputs. It can be concluded from the our findings that the evaluation of DSSAT CROPGRO-Cotton model was found good enough research tools to predict the phenological occurrence, yield and harvest index of the cotton crop in advance and model will facilitate the farmers to make broad decision on the crop management operations. DSSAT simulation model is quite useful since it connects agriculture process analysis and good performance evaluation.

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