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CALIBRATION AND VALIDATION OF CERES-SORGHUM CROP SIMULATION MODEL IN DSSATV 4.7

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Abstract– A study was conducted during *rabi*, 2016-17 and 2017-18 to calibrate and validate the CERES-Sorghum model in DSSATv 4.7. The NRMSE (Normal Root Mean Square Error) values for simulations for physiological maturity are 16.06 per cent, 19.7 per cent, 12.08 per cent and 14.3 per cent for Maldandi (V_1), Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively. The mean simulated grain yield was 37.4 (q/ha) against observed grain yield of 37.6 (q/ha) in case of V_1. The mean observed grain yields were 44.7 and 44.3, 37 and 35.6, 45.2 and 41.8 (q/ha) in case of V_2, V_3 and V_4, respectively. The NRMSE values for simulations were 19.6%, 19.6%, 15.71% and 17.2% for V_1, V_2, V_3 and V_4, respectively. The mean simulated straw yield was 77.51 (q/ha) against observed yield of 91.0 (q/ha) case of V_1. According to Loague and Green (1991) if NRMSE is between 10–20%, simulations are good and CERES- Sorghum model is good in predicting the growth and yield of Sorghum. As the model is predicting the phenology and yield well, CERES-Sorghum model can be used for climate change impact studies.

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is one of the main staple foods for the world's poorest and most food insecure people across the semi-arid tropics. It is an important food crop in India and fifth most important cereal crop followed by rice, wheat, maize and barley in the world. Sorghum plays very pivotal role in the food and nutritional security of poor nations as well as developing countries. In present times and in coming years, climate change and global warming are the concerning issues of the humanity. The rate of global warming is expected to continue increasing if no mitigation efforts taken place to reduce the carbon intensity of the world economy and the consequent emission of green-house gases (Raupach *et al.*, 2007). Agricultural production, and thus global food security, is directly affected by global warming (Ainsworth and Ort, 2010) which causes the uncertainity in food security of the millions of the people. Climate change is responsible for the increasing minimum temperatures in the Pune (Kharbade *et al.,* 2017). Increasing minimum temperatures are significantly reducing the yields (Subramanyam *et al.*, 2019)

Crop models are computer models that attempt to simulate the entire range of physical and biological effects that affect crop growth and development. Such models, which have been developed for a number of crops, allow variation in a number of parameters as well as the incorporation of variations in the interconnections between them (Whistler *et al.*, 1986). The CSM as implemented in the DSSAT has submodels that allow simulation of more than 25 crop species, including sorghum. CERES (Crop Environmental Resource Synthesis)-Sorghum model developed by Ritchie *et al.* (1988) is being used in the DSSATv4.6 (Decision Support System for Agro-Technology Transfer) (Hoogenboom *et al.* 2012). It is used to simulate sorghum growth, development and yield which will help in decision making. DSSAT is the widely used model around the world and useful in decision making. With the combination of effective management decisions with crop model will result in the increased crop yield. Not only management, crop models can also be used to assess the climate change impacts on different crops with minimum experimentation which reduces the costs of raising controlled experiments. But before using the models we should validate them for different simulation parameters. Calibrated and validated CERES-Sorghum model can be used to study the impact of climate change on sorghum yields for *kharif* and *rabi* seasons in India (Sandeep *et al.*, 2018). Locality specific studies should be conducted to understand the impacts of the climate change in finer scale. This study was aimed at fulfilling the gap of localized studies.

MATERIALS AND METHODS

Location of the Experimental Site

The field experiment was conducted for two consecutive years at the Department of Agricultural Meteorology Farm, College of Agriculture, Pune during *rabi* 2016 and 2017. The geographical location of the site (Pune) was 18°32'N, latitude; 73°5'E, longitude and 559 m above mean sea level (MSL). The soil is medium black calcareous having depth of about 1m. The average annual rainfall of Pune is 675 mm. Average *Rabi* rainfall is 113.8 mm.

Experimental details

The experiment was raised in a split plot design with three replications & sixteen treatment combinations with four varieties and four sowing windows. Four varieties used were Maldandi, Phule Vasudha, Phule Maulee and Phule Chitra. Four sowings were taken up on 35th, 37th , 39th & 41st meteorological weeks respectively. Inter row spacing was 45 cm & intra row spacing was 15 cm. Gross plot size was 4.5 × 3.6 square meters and net plot size was 3.6 × 2.7 square meters (Table 2). The seeds were treated with *Azospirillum* + PSB culture @250gm/10kg seed for better nitrogen fixation in the soil. The seed rate used was 10 kg/ha.

Soil

The soil was analyzed for physical and chemical properties and presented in Table 1. The soil of experimental site was sandy clay loam in texture. The chemical composition indicated that the soil was low in available nitrogen (152.19 kg/ha), medium in available phosphorous (19.62 kg/ha) and very high in potassium (310.82 kg/ha). The soil was moderately alkaline in reaction (pH 8.4) and electrical conductivity was 0.25 dSm^{-1}. The field capacity and permanent wilting point was 31.76 and 17.10 per cent, respectively with bulk density of 1.38 g CC^{-1}.

Table 1. Physical properties of soil

S.No.	Particulars	Results
1.	Coarse sand (%)	12.25
2.	Fine sand (%)	33.33
3.	Silt (%)	23.54
4.	Clay (%)	28.43
5.	Bulk density (gcc^{-1})	1.38
6	Organic carbon (%)	0.45
7	Available N (ka ha-1)	152.19
8	Available P_2O_5(kg ha$^{-1)}$	19.62
9	Available K_2O (kg ha^{-1})	310.82
10	Soil pH(1:2.5soil water suspension)	8.5
11	Electrical conductivity (dSm^{-1})	0.25
12	Field capacity (%)	31.76
13	Permanent wilting point (%)	15.10

Table 2. Treatments details with symbols

S. No.	Treatment details	Symbol used
A.	**Main plot treatments : Varieties (V)**	
1	Maldandi (M-35-1)	V_1
2	Phule Vasudha	V_2
3	Phule Maulee	V_3
4	Phule Chitra	V_4
B.	**Sub plot treatments : Sowing window**	
1	1st Sowing window: 35th MW (27 Aug-02 Sep)	S_1
2	2nd Sowing window: 37th MW (10 Sep-16 Sep)	S_2
3	3rd Sowing window : 39th MW (24 Sep- 30 Sep)	S_3
4	4th Sowing window: 41st MW (08 Oct-14 Oct)	S_4

Calibration and Validation of CERES

The genetic co-effiecients used in the experiment are presented in Table 3. Validation is the comparison of the results of model simulations with observations that were not used for the calibration. The experimental data collected will be used for independent model validation. Statistical index generally used for model validation is

$$\text{RMSE (Root Mean Square Error)} = \sqrt{\frac{\sum_{t=1}^{n}(\text{Pi-Oi})^2}{n}}$$

Where Pi and Oi refer to the predicted and observed values for the studied variables (e.g. grain yield and total biomass), respectively and n is the mean of the observed variables.

The normalized root mean square error (NRMSE) that is expressed in per cent, calculated as explained by Loague and Green (1991) with the help of following Equation:

$$\text{NRMSE (Normalized Root Mean Square Error)} = \sqrt{\frac{\sum_{i=1}^{n}(Pi-Oi)^2}{n}} \times \frac{100}{M}$$

Where, n is the number of observations, Pi and Oi are predicted and observed values respectively and M is the observed mean value. The simulation is considered excellent with RMSE<10%, good if 10–20%, fair if 20–30%, and poor >30% for yield and other growth parameters.

Statistical Analysis

The data recorded from the field experiment was analyzed statistically using Analysis of variance technique. Split plot design was used in the analysis of weather and crop data (Gomez, 1972).

RESULTS AND DISCUSSION

Genetic co-efficients were developed for different sorghum varieties for DSSAT model validation, presented in Table 4. Model was validated for phenology and yield.

Panicle initiation

The mean simulated number of days to panicle initiation was 38 days as against observed number of 35 days in case of Maldandi (V_1). The mean simulated number of days for panicle initiation and observed number of days were 35 and 32, 29 and 29, 31 and 29 in case of Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively. The RMSE values for simulations were 6.02, 6.71, 3.13 and 3.75 for Maldandi (V_1), Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively (Fig. 1). The NRMSE of simulations are 17.2 per cent, 20.0 per cent, 11.4 per cent and 12.1 per cent for Maldandi (V_1), Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively.

Table 3. Genetic Coefficients for the CERES-sorghum model

S.No.	Genetic co-efficient	Description
1	P_1	Thermal time from seedling emergence to the end of the juvenile phase
2	P_2	Thermal time from the end of the juvenile stage to tassel initiation
3	P_2O	Critical photoperiod or the longest day length
4	P_2R	Extent to which phasic development leading to panicle initiation
5	PANTH	Thermal time from the end of tassel initiation to anthesis
6	P_3	Thermal time from to end of flag leaf expansion to anthesis
7	P_4	Thermal time from anthesis to beginning grain filling
8	P_5	Thermal time from beginning of grain filling to physiological maturity
9	PHINT	Phyllochron interval; the interval in thermal time between successive leaf tip appearances
10	G_1	Scaler for relative leaf size
11	G_2	Scaler for partitioning of assimilates to the panicle

Table 4. Genetic co-efficients of different sorghum varieties for DSSAT model validation developed

S. No.	Genetic co-efficients	Maldandi	Phule Vasudha	Phule Maulee	Phule chitra
1.	P_1	315	410	310	375
2.	P_2	100	100	100	90
3.	P_2O	13	13	13.5	10
5.	P_2R	45	90	90	33.37
6.	PANTH	616	650	617	600
7.	P_3	45	45	50	130
8.	P_4	81.5	81.5	81.5	80
9.	P_5	546	550	552	500
10.	PHINT	49	49	49	45
11.	G_1	12	12	12	10
12.	G_2	4.5	4.5	4.5	4.5

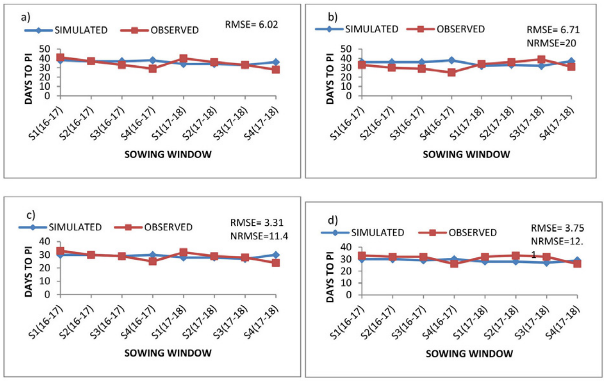

Fig. 1. Observaed and Simulated days to PI in a) Maldandi b) Phule vasudha c) Phule chitra d) Phule Maulee

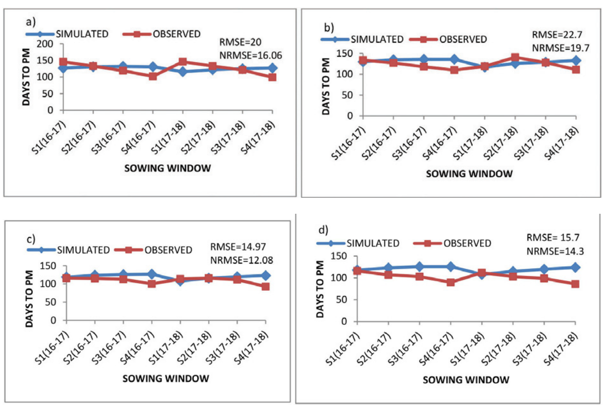

Fig. 2. Observaed and Simulated days to Physiological maturity in a) Maldandi b) Phule vasudha c) Phule chitra d) Phule Maulee

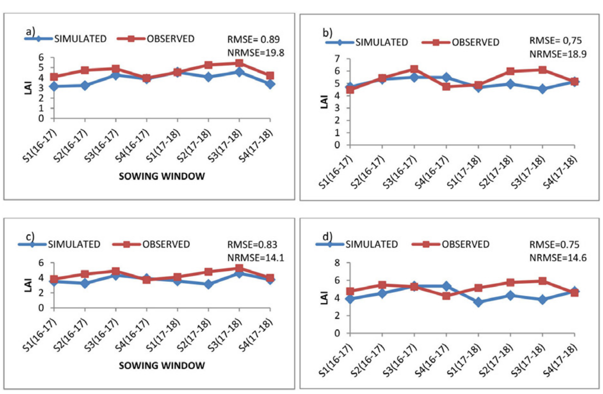

Fig. 3. Observaed and Simulated LAI in a) Maldandi b) Phule vasudha c) Phule chitra d) Phule Maulee

Physiological maturity

The mean simulated number of days to physiological maturity was 126 days as against observed number of 125 days in case of Maldandi (V_1). The mean simulated number of days to physiological maturity and observed number of days were 130 and 124, 120 and 102, 120 and 110 in case of Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively.

The RMSE for simulations were 20.0, 22.7, 14.97 and 15.7 for Maldandi (V_1), Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively. The NRMSE values for simulations are 16.06 per cent, 19.7 per cent, 12.08 per cent and 14.3 per cent for Maldandi (V_1), Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively (Fig. 2).

Leaf Area Index (LAI)

The mean simulated leaf area index was 3.31 against observed leaf area index of 4.65 in case of Maldandi (V_1). The mean leaf area index and observed leaf area index were 5.04 and 5.37, 3.38 and 4.38, 4.43 and 5.14 in case of Phule vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively. The RMSE values for simulations were 0.89, 0.75, 0.83 and 0.75 for Maldandi (V_1), Phule vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively. The NRMSE values for simulations were 19.18 per cent, 18.9 per cent, 14.1 per cent and 14.6 per cent for Maldandi (V_1), Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively (Fig. 3).

Grain Yield (q/ha)

The mean simulated grain yield was 37.4 (q/ha) against observed grain yield of 37.6 (q/ha) case of Maldandi (V_1). The mean grain yield and observed grain yield were 44.7 and 44.3, 37 and 35.6, 45.2 and 41.8 (q/ha) in case of Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively. The RMSE values for simulations were 737.24, 700.6, 695.6 and 722.5 for Maldandi (V_1), Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively (Table 4.34). The NRMSE values for simulations were 19.6 per cent, 19.6 per cent, 15.71 per cent and 17.2 per cent for Maldandi (V_1), Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively (Fig. 4).

Straw Yield (q/ha)

The mean simulated straw yield was 77.51 (q/ha) against observed grain yield of 91.0 (q/ha) case of Maldandi (V_1). The mean straw yield and observed straw yield were 80.46 and 108.55, 74.40 and 87.51, 95.31 and 10.17 (q/ha) in case of Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4),

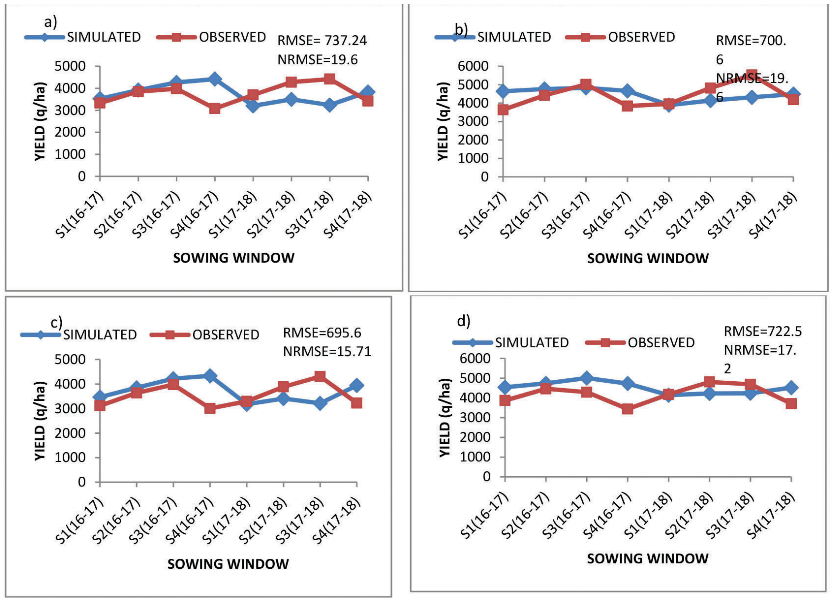

Fig. 4. Observaed and Simulated Yield in a) Maldandi b) Phule vasudha c) Phule chitra d) Phule Maulee

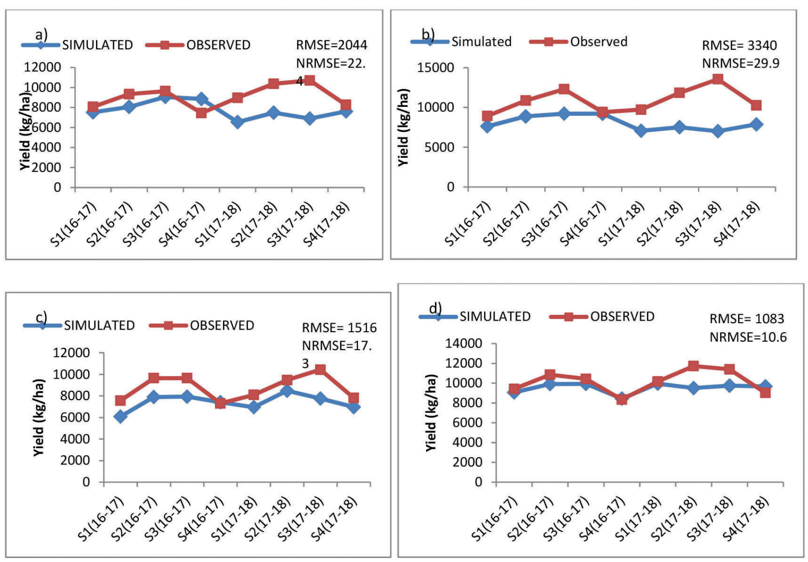

Fig. 5. Observaed and Simulated straw yield in a) Maldandi b) Phule vasudha c) Phule chitra d) Phule Maulee

respectively. The RMSE values for simulations were 2044, 3340, 1516 and 1083 for Maldandi (V_1), Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively. The NRMSE values for simulations were 22.4 per cent, 29.9 per cent, 17.32 per cent and 10.6 per cent for Maldandi (V_1), Phule Vasudha (V_2), Phule Maulee (V_3) and Phule Chitra (V_4), respectively (Fig. 5).

White *et al.* (2015) and Harb *et al.* (2016) also showed that DSSAT 4.6 simulates the phenology and yield with good accuracy (RMSE). These results are also in conformation with the results of Aundhkar (2001) and Madiwalar (2006). According to Loague and Green (1991), if NRMSE is between 10–20 per cent, simulations are fair to good. The model is predicting the phenology and grain yield well but Leaf area index and straw yield are concerns. The leaf area index module and straw yield needs to be improved in the model. As the model is predicting the phenology and yield well, CERES-Sorghum model can be used for climate change impact studies.

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