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Application of DSSAT Model to Identify the Optimum Sowing Dates in Improving Pearl Millet Yield

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ABSTRACT: Pearl millet has the potential to cope with the effects of climate change to some extent. Choosing an appropriate variety and planting date could help farmers increase their low yield. The Crop-Environmental Resource Synthesis Model for Pearl Millet (CERES-Millet) was used to stimulate crop yields during the *kharif* season 2018. This field experiment was laid out in a split-plot design comprised of three main plot treatments based on sowing dates namely D1 (5th July), D2 (15th July) and D3 (31st July) with sub plot treatments comprising three different cultivars *viz*., V1 (GHB 558), V2 (HHB 67 Improved) and V3 (HHB 272) with four replications. After simulation, the total predicted yield was 3000.89 Kg ha^{-1}, compared to the total measured yield of 2989.56 Kg ha^{-1}. The model overestimated the days to anthesis and physiological maturity in all the treatments while underestimating the maximum LAI. The model's simulation performance was found to be satisfactory and there was reasonable agreement (± 10). The simulated results were within the acceptable limit when compared to field experimental data. The performance of the model was tested with the help of MAE (Mean Absolute Error), MBE (Mean Bias Error), RMSE (Root mean square error), and PE (Percent error). The model has proved to be suitable tool for predicting phenology, maximum LAI and grain yield of pearl millet crop which could be a satisfactory support system for effective crop management decisions.

Keywords: CERES-Millet model, Pearl millet, yield attributes, simulation.

INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the most significant cereal crop of semi-arid and arid region. It is hardy, resilient crop that have a low carbon and water footprint, can withstand high temperatures, grow on poor soils with little or no external inputs and is also known as 'crops of the future'. In India, it is grown over an area of 7.65 million hectares with total production of 10.86 million tonnes whereas in Haryana total area under pearl millet is 0.57 million hectares with total production of 1.35 million tonnes (Anonymous, 2023). Pearl millet is a climate change-ready crop with massive potential to enhance the income and food security of small farming communities as they are the hardiest, most resilient and climate adaptable crops in harsh, hot (up to 50ºC) and drought environments. Due to its adaptability to low rainfall (200-600 mm), low soil fertility, high temperatures and drought escaping mechanism this crop can be grown in areas where other cereal crops would not do well. The temperature range for germination lies within 23 to 30 °C. Seedling stage and flowering stage are generally sensitive to low temperature. For grain maturity high day time temperature is required. It is also nutritionally superior and rich in micronutrients such as iron and zinc and can mitigate malnutrition and hidden hunger. It has greater ceiling temperatures for grain yield and is an underutilized crop with huge nutritional potential, which needs to be utilized fully (Krishnan and Meera 2018). Moreover, it is capable of eliminating micronutrient deficiency in developing countries because it provides 30-40% of inorganic nutrients and provides abundant iron and zinc (Anuradha *et al*., 2017; Rao *et al*., 2006). According to the research, it contains approximately 3.3 g fat, 10.6 g protein, 2.3 g mineral matter, 6 g dietary fibre content, 75 g carbohydrates, iron 16.9 mg calcium 38 mg and gives 351 kcal per 100 g with high amount of vitamins A, Vitamin B and also contain riboflavin. It can stand out as a climate-resilient and nutritionally rich crop of the future.

Decision Support System for Agrotechnology transfer (DSSAT) is the most commonly used model for simulating biomass and yield production. User oriented simulation models greatly facilitate the task of optimizing crop growth and deriving recommendations concerning crop management (Boote, 2004). The first version of DSSAT, Version 2.1, was released in 1989. The recent version of DSSAT Model (version 4.7) comprises approximately 42 crops as well as its derived tools which helped to facilitate effective use of the models. It is a software package integrating the effects of soil, crop phenotype, weather and management strategies to predict yield. The Crop-environment resource synthesis model for pearl millet (CERES-

Millet) is a crop module in a software package called DSSAT. This module was employed to compare the simulated values of pearl millet with the observed values under field conditions in a view to assess the performance of model. Standardization of the most appropriate planting date ensures better quality and quantity of grain yield. It can be more cost-effective and time-efficient to use these models in field experimentation as they can be used to extrapolate the results of research conducted in one season or location to other season and management practices (Arora *et al.*, 2013). Pearl millet crop failure at flowering stage is primarily due to rain. Sometime rain delays the sowing of crop. As a result, sowing time is critical in order to take maximum advantage of inputs. By adopting and quantifying the prevailing weather parameters and similarly by adopting a simulation model, there is considerable scope for improving the productivity of pearl millet. Thus, the specific objective of this paper is to illustrates the comparison of the predicted yield by CERES-millet model and the measured field values of three millet varieties and also the phonological parameters like anthesis, physiological maturity and maximum LAI.

MATERIALS AND METHODS

A. Site description

The present study was carried out during *kharif* season (2018) at Research farm of Department of Agricultural Meteorology, CCS HAU, Hisar (29°10′ N, 75°46′ E and altitude 215.2 m). The experiment was laid out in split-plot design comprised of three main plot treatments based on sowing dates namely D_1 (5th July), D_2 (15th July) and D_3 (31st July) with sub plot treatments comprising three different cultivars *viz.*, V_1 (GHB 558), V_2 (HHB 67 Improved) and V_3 (HHB 272) with four replications. This area has sub-tropical and semi-arid climate. Weather prevailed during the crop growing season is depicted in fig. The average maximum temperature, average minimum temperature and total rainfall during the crop season were 34.4 °C, 24.6 °C and 297.8 mm respectively.

B. Data description

In this study, the CERES-Millet model of DSSAT (version 4.7) was used. Various files are required to run the model in the form of input files. The weather file requires the information of daily solar radiation (MJ m^{-2} day^{-1}), precipitation (mm), maximum and minimum temperature (°C) to prepare and run the simulation. This weather data was collected from department of agricultural meteorology, CCS HAU, Hisar, and then it was imported to Weather Man in DSSAT. The experimental file consists of crop management data like latitude of location, planting date, row to row spacing, plant population, sowing depth, irrigation and fertilizer application information etc. which is required to simulate the results. It was obtained from field experiments conducted under three dates of sowing. The resulting 12 treatments were used to compare the field observed and simulated values. For the soil file, the data was taken from the department of soil science, CCSHAU, Hisar. This data was entered in the S Build tool of the DSSAT Model. The layer wise soil information used in the model is mentioned in Table 1.

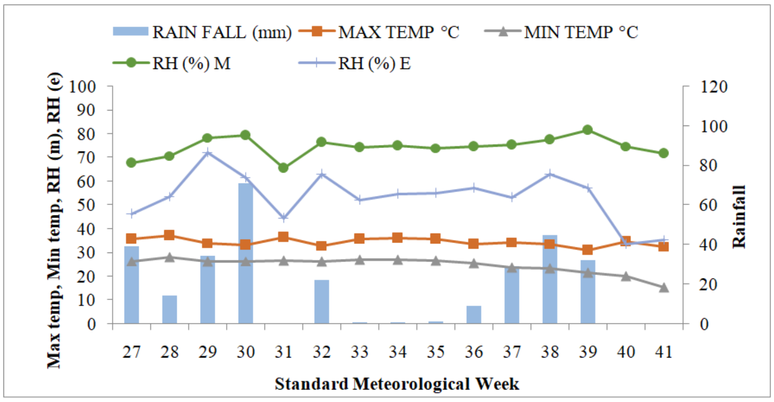

Fig. 1. Mean weekly values of important weather parameters during the crop season (*kharif* 2018).

Table 1: Layer-wise information for soil file of CERES-millet model.

Soil Parameters	Depth (Bottom)			
	0-15 cm	15-30 cm	30-60 cm	60-90 cm
Master horizon	AP	A1	B2	B2
Clay (%)	10.7	13.4	14.3	15.8
Silt (%)	22.3	25.1	26.2	27.9
Stones (%)	-99	-99	-99	-99
Organic carbon (%)	0.41	0.26	0.23	0.22
Cation exchange capacity (C mol/Kg)	11.4	12.4	13.4	17.4
pH in water	8.1	8.4	8.3	8.3
Lower limit of drainage	0.09	0.10	0.10	0.11
Upper limit of drainage	0.18	0.19	0.20	0.21
Bulk density (g/cm^3)	1.49	1.54	1.50	1.49
Saturation	0.41	0.41	0.40	0.40
Saturated hydraulic conductivity (cm/hr)	2.59	2.59	2.59	2.59
Root growth factor (0.0-1.0)	1.00	0.64	0.42	0.21

C. Model calibration
In order to evaluate the applicability of CERES-Millet model in the region, calibration of model with the three different pearl millet cultivar GHB 558, HHB 67 Improved and HHB 272 was required. Seven genetic coefficients, including P1, P2O, P2R, P5, G1, G4, and PHINT, were necessary for this model. The calibrated value is mentioned in Table 2. Due to unavailability of true values of genetic constants for the desired location, the best approach was applied to conduct the sensitivity test by changing their values to determine the variations in the magnitude of the desired model output. The model was executed by varying the values of each genetic coefficient until the desired level of agreement between observed and stimulated values was achieved. The repetition of the process was stopped when the agreement reached ±10%. A variety of other crops have been studied by researchers using a similar method (Andarzian *et al.,* 2015; Saythong *et al.,* 2012).

D. Output file
After running the model, we get the output file which contains an overview of the input conditions like crop performance, characteristics of the soil, cultivar coefficient and information on the crop at various growth stages etc. From emergence through physiological maturity, the model forecasts the timing of major phenological stages, as well as Leaf Area Index, ultimate grain yield.

E. Model evaluation
The DSSAT model performance was evaluated using the field values, aboveground biomass crop yield, LAI, of the growing seasons. This study used four common statistical indicators for model evaluation; MAE (Mean Absolute Error), MBE (Mean Bias Error), RMSE (Root mean square error and PE (Percent error) Table 3. These statistical characteristics of simulated data was compared with observed data. By using the statistical component of DSSAT software and an excel worksheet, the simulated and observed mean yield was compared.

Table 2: Genetic coefficient of pearl millet varieties in different sowing environment used in DSSAT CERES-Millet model during *kharif* 2018.

Genetic coefficients	Description of genetic coefficients	Units	Calibrated value		
			GHB 558	HHB 67 Improved	HHB 272
P1	Thermal time from seedling emergence to the end of the juvenile phase during which the plant is not responsive to changes in photoperiod	°C day	160.0	152.2	152.2
P2O	Critical photoperiod or the longest day length at which development occurs at a maximum rate	Hour	14.2	12.8	13.3
P2R	Extent to which phasic development leading to panicle initiation is delayed for each hour increase in photoperiod above P2O	°C day	13.8	16.2	15.0
P5	Thermal time from beginning of grain filling (3–4 days after flowering) to physiological maturity	°C day	500.0	382.6	378.0
G1	Scaler for relative leaf size on main stem	-	1.00	1.00	1.00
G4	Scaler for partitioning of assimilates to the panicle (head).	-	1.00	1.25	1.00
PHINT	Phylochron interval; the interval in thermal time between successive leaf tip appearances	°C day	42.0	43.5	43.5

Table 3: Statistical indicators for evaluation of CERES-millet model.

Sr. No.	Statistical indicator	Formula
1.	MAE (Mean Absolute Error)	$\mathrm{MAE} = \sum_{i=1}^{n} [1P_i - O_i 1]/n$
2.	MBE (Mean Bias Error)	$\mathrm{MBE} = \sum_{i-1}^{n} [P_i - O_i]/n$
3.	RMSE (Root mean square error	$\mathrm{RMSE} = \left[\sum_{i=1}^{n} (P_i - O_i)^2/n\right]^{1/2}$
4.	PE (Percent error)	PE = (RMSE / Observed mean) *100
5.	Error %	Error % = {(P – O) / O} * 100

Where, Pi = i-th measurement of simulated value, Oi = i-th measurement of observed value, n = number of observations, P= simulated value, O = observed value

RESULTS AND DISCUSSION

Pearl millet has been simulated using DSSAT crop model. The CERES-millet model effectively performed in simulating the grain yield, maximum LAI and occurrences of phenological events *viz.,* days to anthesis, days to physiological maturity as indicated by low MAE, MBE, RMSE and PE during 2018.

A. Phenology
The comparison of observed and simulated days to anthesis is presented in Table 4. The results reveal that the observed duration of anthesis varied between 41

(D_2V_2) to 55(D_2V_1) days and the simulated values varied from40 (D_1V_2) to 58(D_2V_1) days. Treatment wise deviation evaluated for days to anthesis was ranged between -3 to +6. The RMSE is 4.33 days which shows that the efficiency of model to predict the days to anthesis is in reasonable limits and the positive value of MBE shows the over estimation by the model. The simulated day for anthesis is in good agreement with the observed values *i.e*., MAE, MBE, RMSE and PE of 1.44, 1.44, 4.33 and 9.26 respectively. All the prediction was within ± 10 per cent of observed values. The prediction was well matched with the observed values hence, it can be concluded that observed days to anthesis was in good agreement with simulated values.

The observed duration of physiological maturity was in range of 62 (D_1V_2, D_1V_3 and D_3V_2) to 70 (D_3V_1) days while simulated duration was in range of 59 (D_3V_2) to 72 (D_1V_1 and D_2V_1) days as depicted in Table 4. The majority of treatment shows over estimation of the days to physiological maturity in all the treatments. Treatment wise deviation for days to physiological maturity was ranged between -3 to +4. The negative values of deviation show the under estimation of physiological maturity by model for crop sown on D_1 and D_3, whereas, the model prediction is towards over estimation for D_2 sown crop. The error values for the observed and simulated output computed through various statistical error estimator are MAE, MBE, RMSE and PE and number of values evaluated by an estimator are 0.89, 0.89, 2.66 and 4.10, respectively. It indicates the capability of model to reproduce both anthesis and physiological maturity stages of pearl millet for different environment. Similar type of finding was supported by Matthews and Pilbeam (2005); Nayak (2018); Biswas (2013).

Table 4: Observed and simulated value of phenology (anthesis phase and physiological maturity) in pearl millet varieties at different sowing environment during *kharif* 2018.

Treatments	Anthesis				Physiological maturity			
	Observed (O)	**Simulated (P)**	**Deviation (P-O)**	**Error %**	**Observed (O)**	**Simulated (P)**	**Deviation (P-O)**	**Error %**
D_1V_1	54	56	2	3.7	68	72	4.0	5.9
D_1V_2	43	40	-3	-7.0	62	65	3.0	4.8
D_1V_3	44	42	-2	-4.5	62	60	-2.0	-3.2
D_2V_1	55	58	3	5.5	69	72	3.0	4.3
D_2V_2	41	45	4	9.8	64	65	1.0	1.6
D_2V_3	44	46	2	4.5	63	64	1.0	1.6
D_3V_1	49	55	6	12.2	70	69	-1.0	-1.4
D_3V_2	46	47	1	2.2	62	59	-3.0	-4.8
D_3V_3	45	45	0	0.0	63	65	2.0	3.2
Observed Mean	**46.78**				**64.78**			
Simulated Mean	**48.22**				**65.67**			
MAE	**1.44**				**0.89**			
MBE	**1.44**				**0.89**			
RMSE	**4.33**				**2.66**			
PE	**9.26**				**4.10**			

MAE=Mean Absolute Error; MBE= Mean Bias Error; RMSE=Root Mean Square Error; PE=Percent Error

B. Maximum Leaf Area Index (LAI)

The observed maximum LAI of pearl millet which were varied from 2.9 (D_3V_1 and D_3V_2) to 4.2 (D_1V_1), while model simulated maximum LAI values ranged between 3.0 (D_3V_2) to 4.0 (D_1V_2). At different phenophases the overall model prediction of maximum LAI is towards under estimation. Treatment wise deviation for maximum LAI was in range of -0.5 to +0.5. Lowest error percentage was recorded under D_3 sown crop as compared to other. The model has shown the under estimation due to negative value of MBE (-0.10) as shown in Table 5. Simulation performance of different treatment combinations was reasonably good. Pal *et al*. (2012) reported that delayed sowing reduced leaf area.

C. Grain Yield

The data pertaining to observed and simulated value of grain yield is presented in Table 5. The simulated grain yield was in good agreement with observed values as observed from the experimental field. The observed grain yield varied between 2359 kg ha^{-1} (D_3V_2) to 4182 kg ha^{-1} (D_1V_1). Similarly, the consequent values as simulated by the model ranged between 2248 kg ha^{-1} (D_3V_2) to 3952 kg ha^{-1} (D_1V_1). The treatment wise error percentage for grain yield ranged between -13.0 (D_1V_2) to +10.3 (D_3V_3). Lowest error percentage was observed under D_2 sown crop as compared to other. Simulation performance of the model for all treatment combination was found satisfactory with minor under estimation in early sowing and over estimation in timely sowing and in delayed sowing. The RMSE is 34 which showed that the efficiency of model to predict the grain yield is in reasonable limits and had positive values (11.33) of MBE which shows the over estimation by the model. The simulated grain yield values reveal the good agreement with the observed values. The values of various statistical measures were analysed and performance is 11.33, 11.33, 34 and 1.14 of MAE, MBE, RMSE and PE, respectively. This is in agreement with the findings of Silungwe *et al.* (2019), who calibrated and evaluated the models using the CERES-

Millet model. According to these authors, the model calibration performed admirably for all crop parameters. The model also accurately predicted anthesis and maturity day. The results were also supported by Saseendran *et al*. (2005); Murty *et al*. (2007); Mubeen *et al*. (2013); Soler *et al*. (2008); Rezaei *et al*. (2014); Abasaheb (2004); Ahmad *et al*. (2016). Grain yield was over estimated by Parmar (2006); Dilip (2005).

Table 5: Observed and simulated value of maximum Leaf Area Index (LAI) and grain yield of pearl millet varieties at different sowing environment during *kharif* 2018.

Treatments	LAI				Grain yield (Kg ha^{-1})			
	Observed (O)	**Simulated (P)**	**Deviation (P-O)**	**Error %**	**Observed (O)**	**Simulated (P)**	**Deviation (P-O)**	**Error %**
D_1V_1	4.2	3.9	-0.3	-7.9	4182	3952	-230	-5.5
D_1V_2	3.5	4.0	0.5	13.4	2994	2605	-389	-13.0
D_1V_3	3.8	3.3	-0.5	-12.9	2961	3025	64	2.2
D_2V_1	3.9	3.7	-0.2	-5.9	3419	3562	143	4.2
D_2V_2	3.5	3.2	-0.3	-9.0	2967	3200	233	7.9
D_2V_3	3.4	3.1	-0.3	-8.2	3194	3215	21	0.7
D_3V_1	2.9	3.1	0.2	7.9	2435	2560	125	5.1
D_3V_2	2.9	3.0	0.1	2.9	2359	2248	-111	-4.7
D_3V_3	3.4	3.4	-0.1	-1.6	2395	2641	246	10.3
Observed Mean	**3.51**				**2989.56**			
Simulated Mean	**3.41**				**3000.89**			
MAE	**0.10**				**11.33**			
MBE	**-0.10**				**11.33**			
RMSE	**0.303**				**34**			
PE	**9.04**				**1.14**			

CONCLUSIONS

This study evaluated the performance of DSSAT (CERES-millet) model and the results revealed that comparison of observed and simulated days to anthesis and physiological maturity, maximum LAI and grain yield were in good agreement with observed values of growth and yield attributes for Hisar conditions. The model over estimated days to anthesis, physiological maturity and grain yield in all the treatments while under estimated the maximum LAI. The RMSE shows that the efficiency of model to predict the days to anthesis and physiological maturity is in reasonable limits. On the basis of outcome, farmers are suggested that second fortnight of June sowing was more suitable for pearl millet sowing for Hisar conditions. Simulation performance of the model was found satisfactory with reasonable agreement (±10 %) under different sowing dates. The model has proven to be a useful tool for pearl millet crop management optimization, phenology prediction, and potential yield estimation.

FUTURE SCOPE

In this era of climate change DSSAT model can prove a beneficial tool in crop production analysis and yield prediction. Pearl millet being a drought tolerant crop can reduce the risk of food insecurity. Thus, there are many scopes of this study.

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Conflicts of Interest. None.

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