The Journal of Phytopharmacology 2021; 10(3):211-214
Online at: www.phytopharmajournal.com

The Journal of Phytopharmacology
(Pharmacognosy and phytomedicine Research)

Research Article

ISSN 2320-480X
JPHYTO 2021; 10(3): 211-214
May- June
Received: 04-04-2021
Accepted: 15-05-2021

doi: 10.31254/phyto.2021.10312

HN Kanjiya
Agrometeorology Cell, Department of Agronomy, JAU, Junagadh-362001, Gujarat, India

MC Chopada
Assistant Professor, Agrometeorology Cell, Department of Agronomy, JAU, Junagadh-362001, Gujarat, India

Correspondence:
HN Kanjiya
Agrometeorology Cell, Department of Agronomy, JAU, Junagadh-362001, Gujarat, India
Email: hardikkanjiya144[at]gmail.com

Calibrate and validate CERES-MILLET model under variant environmental condition for different cultivars of summer pearl millet in south Saurashtra region

HN Kanjiya*, MC Chopada

ABSTRACT

The field experiment was conducted during summer season of year 2019 at Instructional Farm, Department of Agronomy, JAU, Junagadh (Gujarat). The experiment was laid out in split plot design, consisting 36 treatment combinations comprised of four sowing dates were 25th January (D_1), 5th February (D_2), 15th February (D_3) and 25th February (D_4) and three varieties were GHB-538 (V_1), GHB-558 (V_2) and GHB-732 (V_3) with three replications. The result showed that the percent error was below 10 % in most of variables except biomass and harvest index. Thus, model simulated well for anthesis, physiological maturity, grain yield, stover yield and test weight, while, biomass and harvest index simulated fairly well. The mean bias error in all variables were positive, which showed that result were over simulated, except biomass and stover yield. The PE values in most of the cases was less than 10 %, which indicate that results were well matched with model, except biomass and harvest index.

Keywords: CERES-millet, calibration, DSSAT, simulation model, validation.

INTRODUCTION

India is the largest producer of pearl millet in the world. In India major producing states are Rajasthan (46 %), Maharashtra (19 %), Gujarat (11 %), Uttar Pradesh (8 %) and Haryana (6 %), which share about 90 per cent of total pearl millet production. Pearl millet occupies an area of 7.12 million hectares with a production of 8.06 million tonnes and productivity of 1132 kg/ha in the country. While in Gujarat, Total grown area 4.31 lakh hectares with a total production of 9.31 lakh tonnes and productivity of 2158 kg/ha [1].

IBSNAT (International Benchmark Sites Network for Agrotechnological Transfer) has integrated the process oriented dynamic crop simulation models into a single computer software package known as DSSAT (Decision Support System for Agrotechnology Transfer). The DSSAT has been in use for the last 15 years by researchers worldwide. At present DSSAT consists of 42 different crop simulation models. The DSSAT also comprises tools to facilitate effective use of the models. The tools include database management programs for soil, weather, crop management and experimental data, utilities and application programs. The crop simulation models simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics.

Model applications range from real-time decision support for crop management to assessing the potential impact of climate change on global food security. This also includes on-farm and precision management, regional assessments of the impact of climate variability, gene-based modelling and breeding selection, water use, greenhouse gas emissions, and long-term sustainability through the soil organic carbon and nitrogen balances. The ability of crop model to simulate how different weather years or soil conditions affect crop performance make models especially useful in research involving climatic uncertainty or geospatial variation. DSSAT has been in used by more than 14,000 researchers, educators, consultants, extension agents, growers, and policy and decision makers in over 150 countries worldwide [2, 3].

MATERIALS AND METHODS

The field experiment was conducted during summer season of year 2019 at Instructional Farm, Department of Agronomy, JAU, Junagadh (Gujarat). Geographically the experimental site was situated at 21.51° N latitude and 70.55° E longitude at an altitude of 83 m above mean sea level. The experiment was laid out in split plot design, consisting 36 treatment combinations comprised of four sowing dates were 25th January (D_1), 5th February (D_2), 15th February (D_3) and 25th February (D_4) and three varieties were GHB-538 (V_1), GHB-558 (V_2) and GHB-732 (V_3) with three replications.

CERES - millet model

CERES - millet model as adapted in this study showed a common input and output data format. It is a shell that allows the users to organize and manipulate crop, soil and weather data and to run the crop models in various ways and to give their output.

Input / Output Files

The input system for selected crop genotypic, weather, soil, and crop management data. The files were organized into input, output and experiment performance data files. The model was run on PC.

Types of data required for crop simulation

The minimum data required to run crop models are different for different crop growth models (INFOCROP, DSSAT, EPIC, APSIM etc.). But, in general following datasets are required to run the crop models.

Weather data

This data base contains daily data of temperature (maximum and minimum), sunshine hours / solar radiation, rainfall. In addition to this, data on wind speed, relative humidity, soil moisture at different depths if available, it is added advantage.

Soil data

This data base is comprised principally soil physical, chemical and biological properties of the experimental site.

Crop management data

This data includes information on planting dates, when initial soil conditions were measured before planting/sowing, planting density, row spacing, variety, irrigation and fertilizer practices.

Observed / measured crop data

This data comprises time series (phenology-wise or at preferred intervals) data on dry matter production, plant height, number of seeds/pods per plant, leaf area index, by product yield and grain yield etc.

Calibration of the model

Calibration of the model means adjusting certain model parameters to make the model work for any desirable location. In many instances, even if a model is based on observed data, simulated values do not exactly comply with the observed data and minor adjustments have to be made for some parameters. In this experiment, D_1V_1, D_1V_2 and D_1V_3 treatments used for calibration of the model.

Validation of the Model

Model validation, in its simplest form is a comparison between simulated and observed values. The procedure involves of a comparison of simulated output data and observed data that have not been previously used in the calibration. In this experiment, D_2V_1, D_2V_2, D_2V_3, D_3V_1, D_3V_2, D_3V_3, D_4V_1, D_4V_2 and D_4V_3 treatments used for validation of the model. For evaluations, some statistical measures use the association between simulated and observed data. Among them, Mean absolute error (MAE), Mean bias error (MBE), Root mean square error (RMSE), Percent error (PE), R value (Multiple correlation coefficient) were used to evaluate the general applicability of the models. The MAE value always comes positive, because absolute value of difference use in formula. The negative MBE revealed that variable is under estimated, while, the positive MBE shows that simulation model was over simulated. Lower values of all the error, indicates better fit to the model. The PE below 10 % indicates well combination of simulated and observed data, whereas, PE above 10 % and below 25 % showed combination of simulated and observed data fairly. The PE above 25 % showed that simulation not comply with observed data. The mean deviation percentage between ± 15 %, indicate better fit to the model. The expression of the statistical relationship given below,

$$\textbf{(1)}\quad MAE = \sum_{i=1}^{n} | (S_i - O_i) | / n$$

$$\textbf{(2)}\quad MBE = \sum_{i=1}^{n} (S_i - O_i) / n$$

$$\textbf{(3)}\quad RMSE = \left[\sum_{i=1}^{n} (S_i - O_i)^2 / n\right]^{1/2}$$

$$\textbf{(4)}\quad PE = \frac{RMSE}{\text{Mean observed value}} \times 100$$

Where, S_i = simulated value at i^{th} observation
O_i = observed value at i^{th} observation
n = total number of observations

RESULTS AND DISCUSSION

Crop genetic data showed that cultivar characteristics with effect of environment. In crop model, if previously not determined, estimate the cultivar characteristics. The model needs seven cultivar specific genetic coefficients. The procedure for determining genetic coefficients involved running the model using a range of values of each coefficient, in the order indicated above, until the desired level of agreement between simulated and observed values was reached. Iteration for the coefficients were stopped when the agreement reached within the range of ± 10 %. The details of genetic coefficients and the calibration of genetic coefficient of GHB 538, GHB 558 and GHB 732 at Junagadh (Gujarat) condition mentioned in Table 1.

Table 1: Genetic coefficients of pearl millet cultivars GHB 538, GHB 558 and GHB 732 in agro-climatic condition at Junagadh, (Gujarat).

Sr. No.	Genetic coefficients	GHB 538	GHB 558	GHB 732
1	Emergence to end of juvenile stage (P1)	100.0	110.0	106.0
2	Optimal photoperiod (P2O)	12.0	10.0	10.0
3	Photoperiod sensitivity coefficient (P2R)	530.0	510.0	498.0
4	Grain filling to physiological maturity (P5)	300.0	295.0	290.0
5	Scaler for relative leaf size (G1)	0.6	0.5	0.6
6	Scaler for partitioning of assimilates to the panicle (G4)	11.3	13.5	13.8
7	Phylochron interval, the interval in thermal time (PHINT)	43.0	43.0	43.0

The validation of the CERES-millet model is presented in Table 2 and 3. The days of anthesis, days of physiological maturity, biomass and grain yield simulated by the CERES-millet model along with the observed presented in Table 2 and stover yield, harvest index and test weight simulated by the CERES-millet model along with the observed as influenced by different treatments are presented in Table 3.

Phenophasic Development

The accurate simulation of phenophasic development of a crop is crucial for accurate simulation of crop growth, development and yield. Thus, evaluation of the phenophasic development is first and the most important step in any study, aimed at assessment of the performance of a simulation crop model.

Anthesis

The mean simulated 59 days and observed 56 days for anthesis. The mean deviation percentage of simulated and observed days for anthesis was 4.57 %, which was less than 15 % and hence can be said good. The highest (11.5 %) and lowest (-3.5 %) deviation percentage in D_3V_2 and D_3V_3 treatments respectively.

The MAE, MBE, RMSE and R were 2.25 days, 1.92 days, 3.16 days and 0.65 respectively. The positive MBE shows that the variable is over simulated. The PE between simulated and observed days for anthesis was 5.62 % only, which was below 10 %. So, simulation was well combination with observed value.

Physiological maturity

The mean simulated 102 days and observed 95 days for physiological maturity. Mean deviation percentage of simulated and observed days 7.62 %, which was less than 15 % and hence can be said good. The highest (12.9 %) and lowest (3.1 %) deviation percentage in D_4V_3 and D_2V_1 treatments respectively.

The MAE, MBE, RMSE and R were 5.38 days, 5.38 days, 6.73 days and 0.61 respectively. The positive MBE shows that the variable is over simulated. The PE between simulated and observed days for anthesis was 7.07 % only, which was below 10 %. So, simulation was well combination with observed value.

Growth

Biomass

The mean simulated 10136 kg/ha and observed 11510 kg/ha for biomass. Mean deviation percentage of simulated and observed biomass -11.66 %, which was less than 15 % and hence can be said good. The highest (-5 %) and lowest (-15 %) deviation percentage in D_4V_1 and D_3V_3 treatments respectively.

The MAE, MBE, RMSE and R were 1031.06 kg/ha, -1031.06 kg/ha, 1261.86 kg/ha and 0.97 respectively. The negative MBE revealed that variable is under estimated. PE between simulated and observed days for biomass was 10.96 %, which was more than 10 % but less than 25 %. Thus, simulation was fairly matched with observed data.

Yield and Yield Components

Grain yield

The mean simulated 4542 kg/ha and observed 4282 kg/ha for grain yield, while mean deviation percentage of simulated and observed grain yield 6.69 %, which was less than 15 % and hence can be said good. The highest (11.2 %) and lowest (-4.0 %) deviation percentage in D_2V_1 and D_3V_3 treatments respectively.

The MAE, MBE, RMSE and R were 231.72 kg/ha, 195.61 kg/ha, 277.32 kg/ha and 0.97 respectively. The positive MBE shows that the variable is over simulated. The PE of simulated and observed grain yield was 6.48 % only, which was below 10 % means that simulation was well matched with observed data.

Table 2: Simulated days of anthesis, days of physiological maturity, biomass and grain yield by CERES-millet model compared to observed for different treatments in pearl millet crop.

Yield and yield attributes / Treat.	Days of anthesis			Days of physiological maturity			Biomass			Grain yield		
	Obs.	Sim.	Dev. %	Obs.	Sim.	Dev. %	Obs.	Sim.	Dev. %	Obs.	Sim.	Dev. %
D_2V_1	60	65	8.3	97	100	3.1	9790	9148	-7	3185	3541	11.2
D_2V_2	59	59	0.0	100	103	3.5	10698	9541	-11	3809	4189	10.0
D_2V_3	57	61	7.0	102	108	5.9	12157	10500	-14	4857	5214	7.4
D_3V_1	55	55	0.0	93	101	9.2	11621	9987	-14	4399	4782	8.7
D_3V_2	57	63	11.5	95	104	9.5	11259	9854	-12	4058	4325	6.6
D_3V_3	57	55	-3.5	96	100	4.2	13435	11380	-15	5382	5165	-4.0
D_4V_1	52	56	7.7	90	98	9.5	10230	9698	-5	3596	3894	8.3
D_4V_2	54	56	3.7	92	102	10.9	11347	9854	-13	4059	4451	9.7
D_4V_3	55	58	6.4	93	105	12.9	13056	11258	-14	5189	5321	2.5
Mean	56	59	4.57	95	102	7.62	11510	10136	-11.66	4282	4542	6.69
MAE	2.25			5.38			1031.06			231.72		
MBE	1.92			5.38			-1031.06			195.61		
RMSE	3.16			6.73			1261.86			277.32		
PE	5.62			7.07			10.96			6.48		
R	0.65			0.61			0.97			0.97		

Treat. = Treatments, Obs. = Observed, Sim. = Simulated, Dev. % = Deviation %

Table 3: Simulated stover yield, harvest index and test weight by CERES-millet model compared to observed for different treatments in pearl millet crop.

Treat. / Yield and yield attributes	Stover yield			Harvest index			Test weight		
	Obs.	Sim.	Dev. %	Obs.	Sim.	Dev. %	Obs.	Sim.	Dev. %
D_2V_1	6605	6589	-0.2	32.52	38.71	19.03	8.32	8.77	5.45
D_2V_2	6889	6622	-3.9	35.71	43.91	22.94	9.28	8.98	-3.27
D_2V_3	7300	6571	-10.0	39.80	49.66	24.77	9.77	10.30	5.46
D_3V_1	7221	6532	-9.5	37.88	47.88	26.39	9.71	11.20	15.35
D_3V_2	7201	6451	-10.4	36.09	43.89	21.62	9.80	10.84	10.61
D_3V_3	8053	7541	-6.4	40.04	45.39	13.37	9.92	11.30	13.87
D_4V_1	6633	6121	-7.7	35.21	40.15	14.05	9.22	10.29	11.65
D_4V_2	7288	6328	-13.2	35.78	45.17	26.25	9.63	10.77	11.80
D_4V_3	7867	6621	-15.8	39.93	47.26	18.38	9.75	10.44	7.08
Mean	7229	6597	-8.57	36.99	44.67	20.75	9.49	10.32	8.67
MAE	473.51			5.76			0.67		
MBE	-473.51			5.76			0.62		
RMSE	621.78			6.82			0.85		
PE	8.60			18.44			8.97		
R	0.68			0.85			0.83		

Treat. = Treatments, Obs. = Observed, Sim. = Simulated, Dev. % = Deviation %

Stover yield

The mean simulated 6597 kg/ha and observed 7229 kg/ha for stover yield, while, mean deviation percentage of simulated and observed stover yield was -8.57 %, which was less than 15 % and hence can be said good. The highest (-0.2 %) and lowest (-15.8 %) deviation percentage in D_2V_1 and D_4V_3 treatments respectively.

The MAE, MBE, RMSE and R were 473.51 kg/ha, -473.51 kg/ha, 621.78 kg/ha and 0.68 respectively. The negative MBE revealed that variable is under estimated. PE between simulated and observed stover yield was 8.60 % only, which was below 10 % means that simulation was well matched with observed data.

Harvest index

The mean simulated 44.67 % and observed 36.99 % for harvest index, while mean deviation percentage of simulated and observed grain yield was 20.75 %, which was more than 15 % and hence can be said not good. The highest (26.39 %) and lowest (13.37 %) deviation percentage in D_3V_1 and D_3V_3 treatments respectively.

The MAE, MBE, RMSE and R were 5.76 %, 5.76 %, 6.82 % and 0.85 respectively. The positive MBE shows that the variable is over simulated. The PE between simulated and observed harvest index was 18.44 %, which was more than 10 % and less than 25 %, means that simulation was fairly matched with observed data.

Test weight

The mean simulated 10.32 gm and observed 9.49 gm for test weight, while mean deviation percentage of simulated and observed test weight was 8.67 %, which was less than 15 % and hence can be said good. The highest (15.35 %) and lowest (-3.27 %) deviation percentage in D_3V_1 and D_2V_2 treatments respectively.

The MAE, MBE, RMSE and R were 0.67 gm, 0.62 gm, 0.85 gm and 0.83 respectively. The positive MBE shows that the variable is over simulated. The PE between simulated and observed test weight was 8.97 %, which was less than 10 % means that simulation was well matched with observed data.

CONCLUSION

The model satisfactorily simulated anthesis, physiological maturity, grain yield, stover yield and test weight. The over simulations of biomass and harvest index consequently effected increase in the simulation of grain yield and biological yield. The percentage error was below 10 % in most of variables except biomass (10.96 %) and harvest index (18.44 %). Thus, model simulated phenology very well, while, growth and yield components simulated fairly well.

Acknowledgement

The authors sincerely thankful to Department of Agricultural Meteorology, BACA, AAU, Anand for the analysis of latest version of CERES-millet (DSSAT 4.6) model for summer pearl millet.

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HOW TO CITE THIS ARTICLE
Kanjiya HN, Chopada MC. Calibrate and validate CERES-MILLET model under variant environmental condition for different cultivars of summer pearl millet in south Saurashtra region. J Phytopharmacol 2021; 10(3):211-214.