__Original Research Article__

SIMULATION OF MAIZE PHENOLOGY AND GRAIN YIELD USING DSSAT MODEL

ABSTRACT

The field experiment was conducted at the Farm of College of Agricultural Engineering and Technology, Godhra, Gujarat during the year 2018-19 and 2019-20 to simulate the phenology and yield of rabi maize (Zea Mays L.) in sandy loam soil of the central Gujarat. The field experiment design was split split plot with 36 treatment combinations with 3 replications including three irrigation regimes (1.0IW/CPE, 0.8IW/CPE and 0.6IW/CPE), four mulch conditions (control, paddy straw, black plastic, and reflective silver plastic mulch), and three stages (tasselling, silking and dough stage). The experimental data of the year 2018-19 and 2019-20 was used for the calibration and validation of the model respectively. The result revealed a significant difference in grain yield due to irrigation regime, mulching and growth stages. The DSSAT model could good simulate grain yield (R^2 = 0.989) under the simulation of irrigation regimes, mulching, and growth stages.

Key words: DSSAT, irrigation regimes, mulching, yield

INTRODUCTION

DSSAT (Decision Support System for Agrotechnology Transfer) is a computer- based crop modelling system that integrates various components to assist in the analysis and the management of agricultural systems. It helps bridge the gap between research and practical application, empowering farmers with information and tools to make informed decisions for improved agricultural productivity, sustainability, and profitability (Bannayan and Crout, 1999). It can also serve as helpful tools in taking critical decisions pertaining to the sustainable use of inputs, such as water, soil and nutrients. Modern agriculture involves numerous variables, including weather patterns, soil conditions, crop varieties and management practices (Jones *et al*., 2003). A decision support system helps navigate this complexity by integrating and analysing multiple data sources and providing insights on the best practices for improved agriculture outcomes.

The agricultural sector is constantly evolving with new technologies and innovations. The use of DSSAT facilitates the transfer of these advancements from research institutions to farmers by providing a platform to evaluate, adopt, and implement them at the local level. It empowers farmers with knowledge and tools to make informed decisions about adopting new agrotechnology. Crop simulation models have to be calibrated using local condition data and need to be validated for their effectiveness to adequately simulate the effects of the main factors limiting yields in a region. Thus, the objective was to calibrate and validate the DSSAT version 4.7 model for maize phenology and grain yield.

2. MATERIALS AND METHODS

2.1 Experimental Field

The experimental field in the year 2018-19 and 2019-20 where data were collected, is located at the College of Agricultural Engineering and Technology (CAET), Godhra, Gujarat. CAET is situated in north-eastern Gujarat state, west-central India. Figure 1 shows the image of the experimental field. The study area was geographically situated at 22° 46' 51.1" North latitude and 73° 39' 22.9" East longitude and an altitude of 132 m above mean sea level.

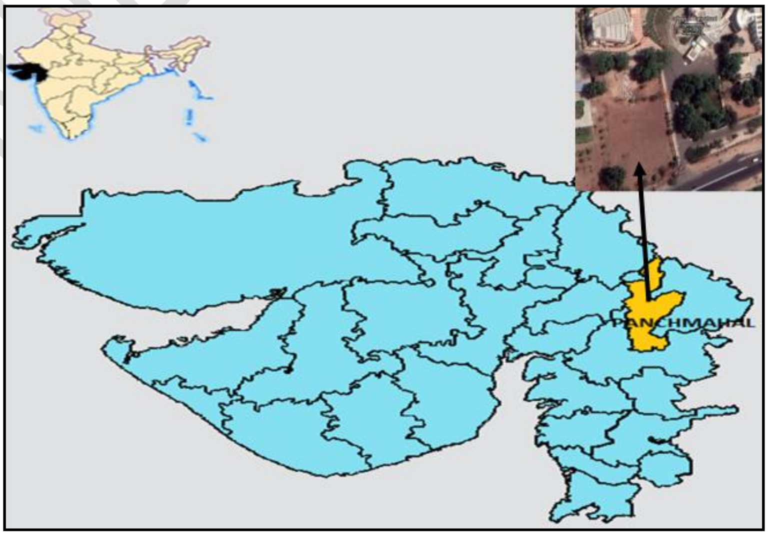

Figure 1. Image of the experimental field

2.2 Weather Data

It would be seen from the recorded data that the average maximum and minimum temperatures for the crop-growing season of the year of 2018-20 were 28.34°C and 11.96°C respectively. The highest maximum temperature was 34.5°C and the lowest minimum temperature was 7.5°C. The mean maximum temperature 28.34°C varied between 24 and 34.5°C. While the mean minimum temperature 11.96°C varied between 7.5°C and 16.5°C. The temperature was positive for the growth and the development of maize. Mean relative humidity for the crop-growing season was 64.38 % and its range was 77 to 45 %. Mean wind speed was 2.21m s^{-1} and it is varied between 3.61 to 0.83 m s^{-1}. The average sunshine hour for rabi maize's growing season was 8.68 h. The daily data pertaining to the various meteorological parameters recorded during the crop-growing period (from 1 November 2018 to 3 March 2019 and 7 November 2019 to 6 March 2020) are graphically provided in figure.2.

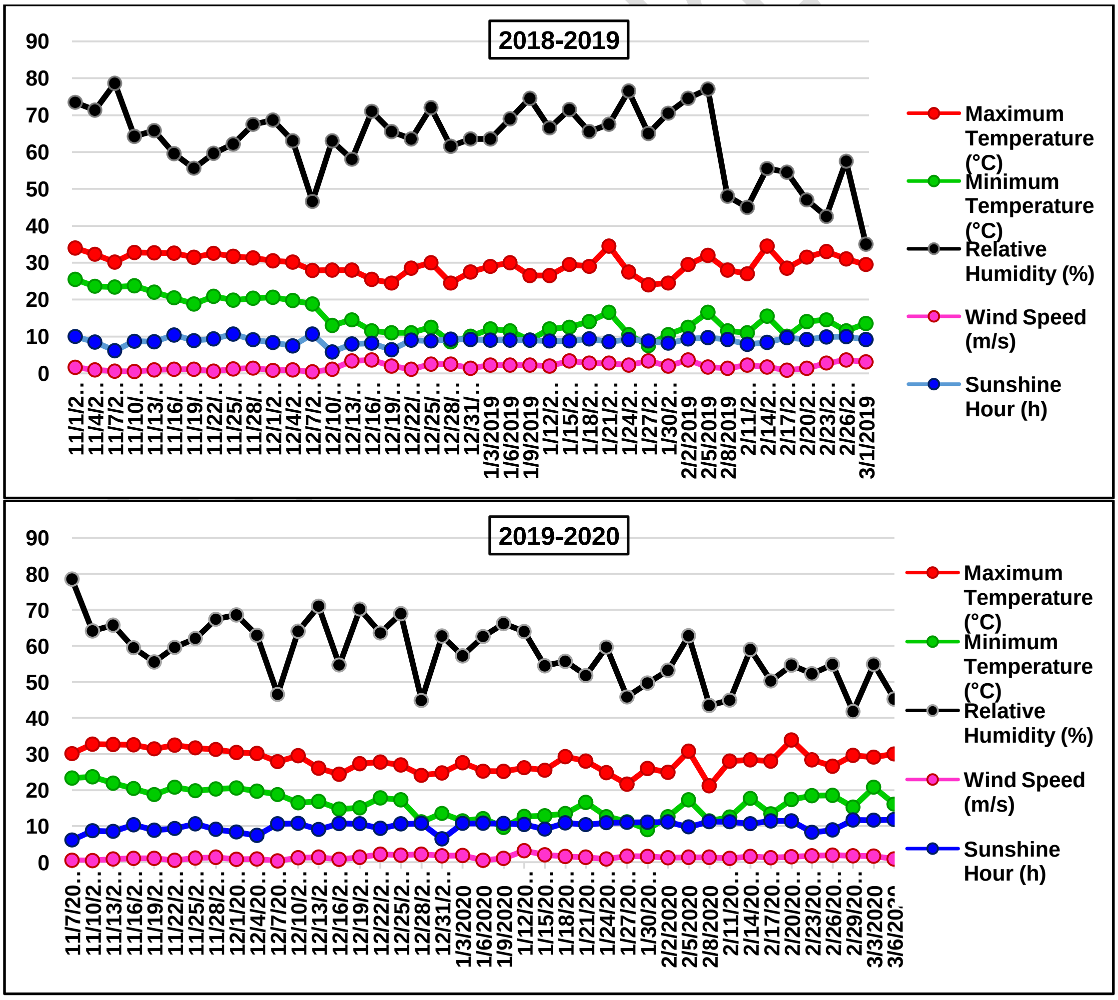

Figure: 2. Daily weather data recorded during the experimental period of Rabi Maize (2018-19 & 2019-20)

2.3 Field Preparation

The experimental field had a gentle slope and moderate drainage. The groundwater table is more than 10 meters deep. Hence, there is no problem with a high water-table in that region. The experimental field was ploughed to completely mix the soil profile and remove any compacted layers, then chiseled with 30 cm, harrowed, and pulverized the soil.

2.4 Soil Analysis

The composite soil samples were drawn at randomly from the three depths of 0-15 cm, 15-30 cm, and 30-45 cm soil depth from the research fields, and were found their physical and chemical properties through the application of the standard procedure provided in Table 1.

Table 1. Physico-chemical properties of the experimental soil

Particulars	Godhra	Method of analysis
Sand (%)	66	International Pipette Method (Piper, 1950)
Silt (%)	13	International Pipette Method (Piper, 1950)
Clay (%)	20.9	International Pipette Method (Piper, 1950)
Texture	Sandy Loam	
Bulk Density (g cm^{-3})	1.41	Core Sampler method
Soil pH (1:2.5) (Soil: Water)	7.84	pH meter (Jackson, 1973)
Electrical Conductivity dS m^{-1}	0.18	EC meter (Jackson, 1973)
Organic Carbon (%)	0.27	Walkley, 1947
Available Nitrogen (kg ha^{-1})	160.2	Subbaiah and Asija, 1956
Available Phosphorous (kg ha^{-1})	18.85	Olsen *et. al*., 1954
Available Potassium (kg ha^{-1})	128	Jackson, 1973

2.5 Experimental Design

The two-year experimental set up were in split-split plot design under 3 replications. There were 3 level of irrigation with 4 mulching conditions and 3 specific growth stages (Table 2). The total treatment combination was 108. The plot area under treatment was covered with paddy straw mulch uniformly spread at the rate of 6t/ha (i.e. 600 g/m^2) just after the sowing, black plastic mulch and reflective silver plastic mulch before sowing. Plastic mulches used for mulching had 120 cm width, 25µ LDPE thickness. The border of plastic mulch was incorporated in the soil for trapping of heat and to avoid disturbance from wind. Round holes were made at the spacing of 60 × 20 cm with the help of galvanized iron pipe of 2-inch diameter. Paddy straw mulch with the thickness of 3cm was applied on the respective plots. Gujarat Anand Yellow Maize Hybrid 1 variety of rabi maize was sown by manually at a spacing of 60 cm for row to row and 20 cm for plant to plant, net plot size was 3m ×1m with 30 plants. Seeds were placed at 4-5 cm depth. The recommended basal dose (120:60:40; N:P:K) of nitrogen @ 60 kg ha^{-1} in the form of the urea, phosphorus @ 60 kg ha^{-1} in the form of single super phosphate and potash @ 40 kg ha^{-1} from Murata of potash were given at the time of sowing. The remaining half 60 kg nitrogen ha^{-1} was given 30 days after sowing as fertigation.

The scheduling of irrigation which is based on the regimes was done using Open-Class A pan method at three days intervals (three days cumulative evaporation amount) (Allen *et al*., 1998). Irrigation regimes (IW/CPE=irrigation depth/ cumulative pan evaporation; i.e. 0.6 IW/CPE, 0.8 IW/CPE, and 1.0 IW/CPE) were applied at the particular growth stages under different mulch conditions. Every cob from every net-harvested plot was dried in the sun for fifteen days before being shelled. The grain yield was represented as kg ha^{-1} and adjusted to a moisture level of 15%.

Table 2: Description of experimental treatments for rabi maize at central Gujarat

Treatments	Irrigation Regimes, (IW/CPE) (I)	Mulch Type, (M)	Crop Stages (S)	Treatments Combinations (IMS)		
T_1	(I_1) 0.6	No Mulch (M_0)	S_1, S_2, S_3	$I_1M_0S_1$	$I_1M_0S_2$	$I_1M_0S_3$
T_1	(I_1) 0.6	Paddy Straw Mulch (M_1)	S_1, S_2, S_3	$I_1M_1S_1$	$I_1M_1S_2$	$I_1M_1S_3$
T_1	(I_1) 0.6	Black Plastic Mulch (M_2)	S_1, S_2, S_3	$I_1M_2S_1$	$I_1M_2S_2$	$I_1M_2S_3$
T_1	(I_1) 0.6	Reflective Silver Plastic Mulch (M_3)	S_1, S_2, S_3	$I_1M_3S_1$	$I_1M_3S_2$	$I_1M_3S_3$
T_2	(I_2) 0.8	No Mulch (M_0)	S_1, S_2, S_3	$I_2M_0S_1$	$I_2M_0S_2$	$I_2M_0S_3$
T_2	(I_2) 0.8	Paddy Straw Mulch (M_1)	S_1, S_2, S_3	$I_2M_1S_1$	$I_2M_1S_2$	$I_2M_1S_3$
T_2	(I_2) 0.8	Black Plastic Mulch (M_2)	S_1, S_2, S_3	$I_2M_2S_1$	$I_2M_2S_2$	$I_2M_2S_3$

2.6 CERES Model for crop growth and yield simulation

Crop model is a mathematical equation or the set of equations, which represents the behaviour of system The CERES (Crop Environment Resource Synthesis) Maize model consists of various subroutines viz. Water balance subroutine, Phenology subroutine, Nitrogen subroutine, and Growth and

Development subroutine. The objective of the present study is to validate the growth and yield subroutine of CERES - Maize model.

CERES-Maize is a user oriented daily incrementing simulation model. It estimates Maize growth, development and yields and simulates the effects of weather, soil properties and genotype. The CERES-Maize model is divided into a mam programme and subroutine. The standard version consists of the mam programme, two initialisation subroutines (PROGRI and SOILRI); four process subroutines that simulate the soil water balance (WATBAL), phasic development (PHENOL and PHASEI) and growth (GROSUB), and four output subroutines (OUTWA, OUTGR, WRITE and CALDAT).

2.6.1 CERES Maize model inputs

The CERES model is designed to run with minimum data set and this data set reported in Table no 3. More data are needed to evaluate the accuracy of the various components of the model. These data are given in Table 4. The morphological (growth development) parameters and yield in relation to water response examined in the statistical evaluation.

2.6.2 Data Acquisition

The data required for the validation can be divided into crop data (management, genetic and biometric), soil data and climatic data.

Table 3. Minimum data set needed to run the CERES-Maize model

Types of Data	Data
Management	Cultivar name, planting date, Plant population, Irrigation date and amount
Climate	Longitude and latitude, Daily solar radiation Daily maximum temperature Daily minimum temperature Daily precipitation
Soil (by layers)	Initial soil water content Drained upper limit of soil Water availability and lower limit of plant extractable soil water; or 0.33 or 15 bar water content Soil texture and pH.
Crop Sowing	Planting date (DOY)

	Sowing depth (cm) Plant population (plant m^{-2})
Genetic parameters of genotype	Thermal time from seedling emergence to the end of juvenile phase (expressed in degree days above a base temperature 8°C) during which the plant is not responsive to change in photoperiod (P1). Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours) (P2). Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8°C) (P5) Maximum possible number of kernels per plant (G2) Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day) (G3).

Table 4 Minimum data set needed to evaluate CERES Maize Model

Types of data	**Data**
Crop	Dates of emergence, tasselling, silking and physiological maturity Leaf area index several times during the season Shoot weight several times during the season. Yield components.
Soil	
A) For each layer	Layer depth (cm) Lower limit of plant extractable soil water (cm) Drained upper limit of soil water availability (cm) Initial moisture content.
B) For the whole profile	Soil surface albedo First stage evapotranspiration (cm d^{-1}) Soil run off curve number Whole profile drainage rate constant (inch d^{-1})

C) Crop residue information	An estimate of the amount of crop residue presents its depth of incorporation and its C:N ratio or state of decay
D) Fertilizer	Fertilizer application date, rate and depth of all applications and the type of fertilizer.

3. Result and Discussion

Crop simulation models need some calibration before it would be used in an area other than where they originally made, especially when the model is to be use to predict the phenological development and yield of the crop. Calibration is the process of modifying certain model parameters to more closely reflect the local weather and soil conditions. The CERES-Maize model was calibrated for maize crop varieties GAYMH-1 under three irrigation regimes, at three growth stages, with four mulching conditions. CERES-maize requires a set of six genetic coefficients (P1, P2, P5, G2, G3 and PHINT) for simulation of phenology and grain yield of maize. The above genetic coefficients for the maize variety was estimated iteratively by running the model initially with the most appropriate matched values from the genetic coefficient file. The model output values were compared with actual data (rabi 2019-20) by altering the genetic coefficients until the predicted and measured values matched. The calibrated values of the genetic coefficients for maize varieties have been given in Table 5.

Table 5. Genetic coefficients of maize varieties used for CERES-Maize model

Maize varieties	Genetic coefficients					
	P1	**P2**	**P5**	**G2**	**G3**	**PHINT**
GAYMH1	223.3	0.38	704.3	644	6.8	47.7

3.1 Validation of CERES-Maize model

After calibration of model using 2018-19 data, CERES-Maize model was validated using 2019-20 experiment data. The validation describes the comparison of simulated parameters with corresponding data obtained from the field such as growth, and yield.

3.1.1 Crop phenology

Accurate simulation of phenological events in a crop model under different growth conditions is important for a perfect prediction of crop growth and yield.

3.1.1.1 Days to anthesis

Observed and simulated data of days to anthesis of maize under different irrigation regimes and mulch conditions is presented in table 6 and fig.3 and 4. Duration of days to anthesis varied due to mulching condition of maize for the both years under both observed and simulated values. The range of days to anthesis was 69 to 76 and 72 to 77 for observed and simulated data.

The model predicted anthesis dates with a corresponding deviation (%) in the range of 0 to 3. The coefficient of determination (R^2) between the simulated and observed days from sowing to anthesis for maize was 0.81 and 0.93, root mean square error (RMSE) was 1.45.

Table 6 Calibration and validation results of days to anthesis of maize varieties under different irrigation regimes with mulch conditions

Treatment	2018-19				2019-20			
	Simulated (days)	Simulated (days)	Simulated (days)	Simulated (days)	Simulated (days)	Observed (days)	Deviation (days)	% Deviation
I1M0S1	72	69	69	69	69	75	2	2.6
I1M0S2	72	70	70	70	70	75	1	1.3
I1M0S3	74	73	73	73	73	76	0	0.0
I1M1S1	74	73	73	73	73	76	1	1.3
I1M1S2	75	73	73	73	73	76	1	1.3
I1M1S3	73	70	70	70	70	73	2	2.7
I1M2S1	73	71	71	71	71	73	3	3.9
I1M2S2	75	73	73	73	73	75	2	2.6
I1M2S3	75	73	73	73	73	75	2	2.6
I1M3S1	76	74	74	74	74	75	3	3.8
I1M3S2	69	65	65	65	65	72	-2	-2.9
I1M3S3	75	70	70	70	70	72	2	2.7
I2M0S1	73	71	71	71	71	74	1	1.3
I2M0S2	75	73	73	73	73	74	1	1.3
I2M0S3	73	70	70	70	70	76	1	1.3
I2M1S1	74	72	72	72	72	72	2	2.7
I2M1S2	75	72	72	72	72	74	2	2.6
I2M1S3	75	73	73	73	73	75	1	1.3

I2M2S1	73	70	70	70	70	76	1	1.3
I2M2S2	74	72	72	72	72	76	1	1.3
I2M2S3	75	73	73	73	73	75	-1	-1.4
I2M3S1	74	74	74	74	74	75	-1	-1.4
I2M3S2	75	74	74	74	74	76	0	0.0
I2M3S3	73	70	70	70	70	76	1	1.3
I3M0S1	74	70	70	70	70	76	1	1.3
I3M0S2	74	72	72	72	72	73	1	1.4
I3M0S3	75	72	72	72	72	73	2	2.7
I3M1S1	76	72	72	72	72	75	2	2.6
I3M1S2	72	69	69	69	69	75	2	2.6
I3M1S3	74	71	71	71	71	75	3	3.8
I3M2S1	75	72	72	72	72	72	-2	-2.9
I3M2S2	76	72	72	72	72	72	2	2.7
I3M2S3	75	74	74	74	74	74	1	1.3
I3M3S1	73	71	71	71	71	74	1	1.3
I3M3S2	75	75	75	75	75	76	-2	-2.7
I3M3S3	73	70	70	70	70	72	2	2.7
Mean	**74**	**71.6**	**71.6**	**71.6**	**71.6**	**75.5**	**1.1**	**2.9**

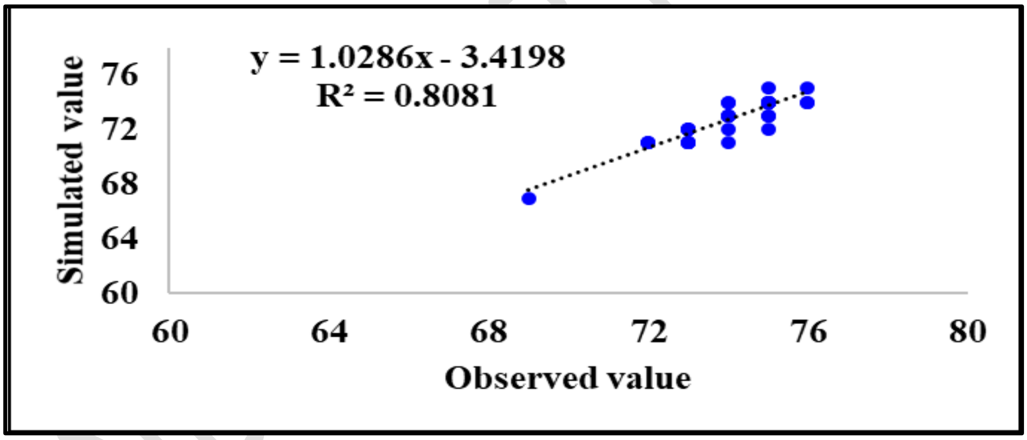

Figure 3 Comparison of observed and simulated values of days to anthesis of maize for 2018-19

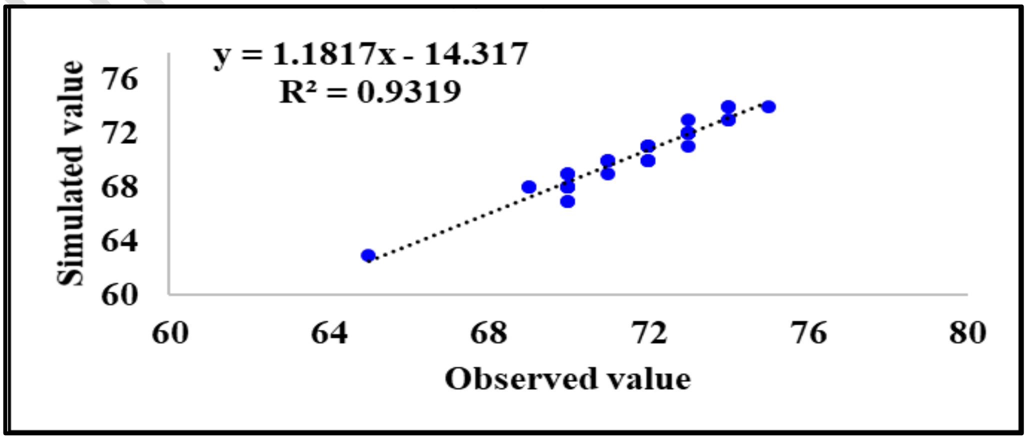

Figure 4 Comparison of observed and simulated values of days to anthesis of maize for 2018-19

4.13.3.2 Days to maturity

Observed and simulated data of days to maturity of maize under different irrigation regimes at three growth stage under different mulches presented in table 7 and fig. 5 & 6. Duration of days to maturity varied due to different irrigation regimes, stages and mulches under both observed and simulated values. The range of days to maturity was 129 to 135 and 128 to 134 for observed and simulated data, for 2018-19. The model predicted maturity dates with the deviation (%) in the range of 0 to 3.1.

The model accounted for 66 % variability in days to maturity for maize crop. Root mean square error (RMSE) was 1.7 days, however, normalized RMSE (nRMSE) values were 1.31 days.

Table 7 Calibration and results of days to maturity of maize varieties under different irrigation regimes with mulch conditions

Treatment	2018-19 (Calibration)				2019-20 (Validation)			
	Simulated (days)	Observed (days)	Deviation (days)	% Deviation	Simulated (days)	Observed (days)	Deviation (days)	% Deviation
I1M0S1	130	129	1	0.8	132	130	1	0.8
I1M0S2	130	129	1	0.8	135	135	1	0.8
I1M0S3	132	131	1	0.8	136	135	1	0.8
I1M1S1	133	132	1	0.8	137	136	1	0.8
I1M1S2	133	133	0	0.0	136	135	0	0.0
I1M1S3	131	130	1	0.8	136	135	1	0.8
I1M2S1	132	130	2	1.5	139	138	2	1.5
I1M2S2	134	130	4	3.1	143	142	4	3.1
I1M2S3	134	131	3	2.3	141	139	3	2.3
I1M3S1	135	134	1	0.7	142	141	1	0.7
I1M3S2	130	130	0	0.0	127	126	0	0.0
I1M3S3	130	129	1	0.8	128	127	1	0.8
I2M0S1	132	128	4	3.1	133	132	4	3.1
I2M0S2	132	130	2	1.5	132	130	2	1.5
I2M0S3	133	131	2	1.5	135	134	2	1.5
I2M1S1	129	128	1	0.8	131	130	1	0.8
I2M1S2	130	129	1	0.8	133	132	1	0.8
I2M1S3	131	130	1	0.8	134	132	1	0.8
I2M2S1	131	130	1	0.8	136	136	1	0.8

I2M2S2	133	131	2	1.5	138	137	2	1.5
I2M2S3	130	128	2	1.6	133	131	2	1.6
I2M3S1	130	129	1	0.8	136	137	1	0.8
I2M3S2	132	131	1	0.8	136	135	1	0.8
I2M3S3	133	132	1	0.8	137	136	1	0.8
I3M0S1	133	132	1	0.8	137	136	1	0.8
I3M0S2	131	131	0	0.0	135	134	0	0.0
I3M0S3	132	131	1	0.8	137	135	1	0.8
I3M1S1	134	132	2	1.5	140	138	2	1.5
I3M1S2	134	132	2	1.5	140	138	2	1.5
I3M1S3	135	132	3	2.3	141	137	3	2.3
I3M2S1	134	133	1	0.8	131	133	1	0.8
I3M2S2	133	130	3	2.3	128	125	3	2.3
I3M2S3	132	131	1	0.8	130	129	1	0.8
I3M3S1	132	131	1	0.8	132	131	1	0.8
I3M3S2	133	131	2	1.5	134	132	2	1.5
I3M3S3	135	134	1	0.7	131	130	1	0.7
Mean	**132.2**	**130.7**	**1.5**	**1.1**	**135.1**	**133.9**	**1.2**	**2.4**

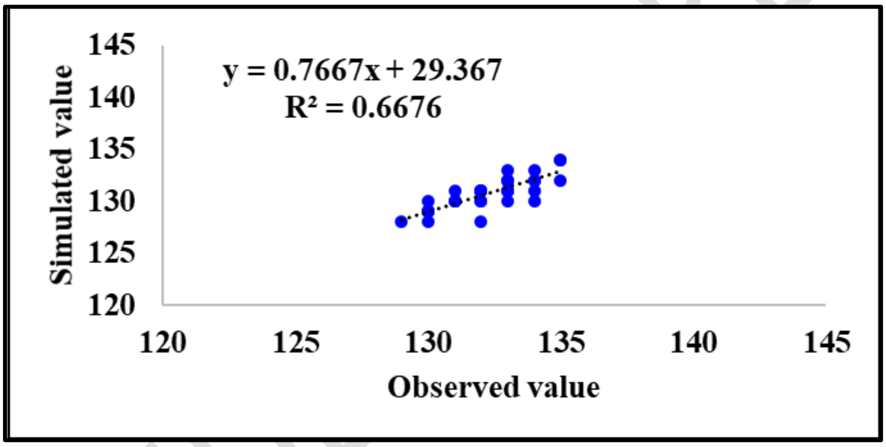

Figure 5 Comparison of observed and simulated values days to maturity of maize in 2018-19 (calibration)

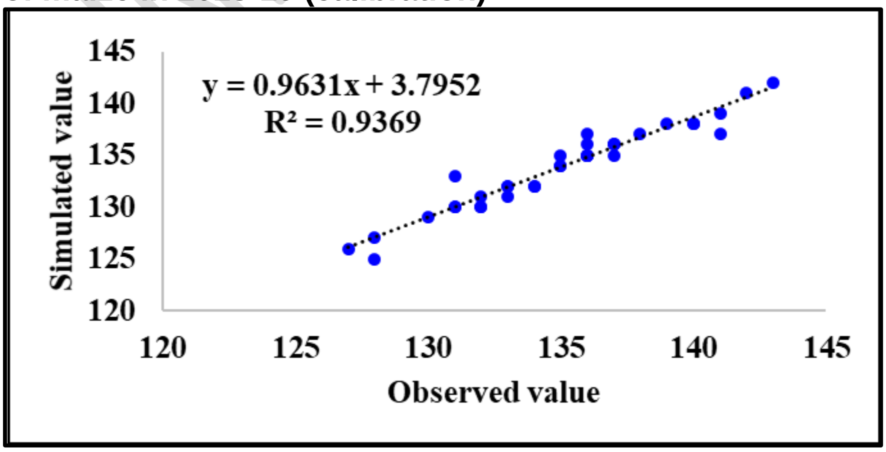

Figure 6 Comparison of observed and simulated values days to maturity of maize in 2019-20 (validation)

4.13.4 Grain yield

The observed and simulated grain yield of maize under different irrigation regimes based on growth stages and mulching conditions is presented in Table 8 and fig. 7 & 8 and the validation results revealed that maize grain yield could be predicted well through CERES-Maize model. The economic yield simulated by model corresponded well with that of actually observed in the fields.

For calibration observed and simulated grain yield of maize ranged between 4216- 12598 kg/ha and 4328-12645 kg/ha, respectively. Whereas, for the validation, range of maize grain yield 4454-12660 kg/ha and 4597-12547 kg/ha, respectively.

The deviation (%) for different treatments between observed and simulated grain yield ranged between -3.9 to 5.11. The coefficient of determination (R^2) among the observed and simulated grain yield of maize was 0.99, RMSE was 2.01, and nRMSE values was 2.55 q/ha. Maize crop sown under reflective silver plastic mulch with 1.0 IW/CPE at dough stage recorded more grain yield both under observed and simulated conditions. The simulated and observed results showed that the model is able to simulate the grain yield under different treatments. The similar findings were also reported by Mall *et al.* (2016) who observed RMSE and R^2 values 6.05 and 0.89 for grain yield of maize. The CERES-maize model provided rather reliable estimates for grain yield. Rezzoug *et al*. (2008) reported that the model tended to underestimate grain yield of maize.

Table 8 Calibration results of maize yield under different irrigation regimes with mulch conditions

Treatment	2018-19 (Calibration)				2019-20 (Validation)			
	Simulated (q/ha)	Observed (q/ha)	Deviation (q/ha)	% Deviation	Simulated (q/ha)	Observed (q/ha)	Deviation (q/ha)	% Deviation
I1M0S1	43.28	42.16	1.12	2.66	45.97	44.54	1.43	3.21
I1M0S2	56.11	54.78	1.33	2.43	60.05	59.08	0.97	1.64
I1M0S3	54.44	54.24	0.20	0.37	70.12	69.6	0.52	0.75
I1M1S1	50.24	46.14	4.10	8.89	56.11	55.54	0.57	1.03
I1M1S2	60.21	58.40	1.81	3.10	61.62	60.64	0.98	1.62
I1M1S3	59.11	58.96	0.15	0.25	60.25	59.1	1.15	1.95

I1M2S1	60.01	61.54	-1.53	-2.49	68.25	67.98	0.27	0.40
I1M2S2	79.01	77.92	1.09	1.40	87.54	87.12	0.42	0.48
I1M2S3	75.22	74.86	0.36	0.48	86.95	86.54	0.41	0.47
I1M3S1	44.00	43.78	0.22	0.50	48.21	47.1	1.11	2.36
I1M3S2	55.10	54.92	0.18	0.33	61.82	60.86	0.96	1.58
I1M3S3	55.02	54.26	0.76	1.40	72.15	70.06	2.09	2.98
I2M0S1	56.15	55.78	0.37	0.66	60.85	58.2	2.65	4.55
I2M0S2	70.41	69.18	1.23	1.78	71.45	71.34	0.11	0.15
I2M0S3	66.25	66.60	-0.35	-0.53	74.25	73.26	0.99	1.35
I2M1S1	65.81	65.98	-0.17	-0.26	70.84	70.64	0.20	0.28
I2M1S2	88.20	87.18	1.02	1.17	86.00	91.72	-5.72	-6.24
I2M1S3	86.54	86.44	0.10	0.12	95.63	99.06	-3.43	-3.46
I2M2S1	51.24	50.28	0.96	1.91	56.76	56.26	0.50	0.89
I2M2S2	77.12	76.34	0.78	1.02	79.35	76.38	2.97	3.89
I2M2S3	93.55	92.98	0.57	0.61	86.15	89.18	-3.03	-3.40
I2M3S1	76.87	76.58	0.29	0.38	72.13	72.34	-0.21	-0.29
I2M3S2	92.16	91.74	0.42	0.46	91.72	89.76	1.96	2.18
I2M3S3	103.13	102.02	1.11	1.09	98.12	97.06	1.06	1.09
I3M0S1	79.54	79.60	-0.06	-0.08	84.15	80.06	4.09	5.11
I3M0S2	106.51	105.18	1.32	1.25	98.09	100.6	-2.51	-2.50
I3M0S3	106.52	102.62	3.88	3.78	111.05	110.04	1.01	0.92
I3M1S1	60.20	58.58	1.62	2.77	60.25	58.26	1.99	3.42
I3M1S2	80.61	89.64	-9.04	-10.08	89.72	93.42	-3.70	-3.96
I3M1S3	104.92	102.92	2.00	1.94	101.1	99.06	2.04	2.06
I3M2S1	77.89	80.58	-2.69	-3.34	80.12	76.96	3.16	4.11
I3M2S2	98.45	95.58	2.87	3.00	98.54	97.70	0.84	0.86
I3M2S3	103.52	102.92	0.60	0.58	101.25	100.06	1.19	1.19
I3M3S1	81.89	82.18	-0.29	-0.35	81.92	80.54	1.38	1.71
I3M3S2	105.38	106.38	-1.00	-0.94	105.58	104.40	1.18	1.13
I3M3S3	126.45	125.98	0.47	0.37	125.47	126.60	-1.13	-0.89
Mean	**76.42**	**75.98**	**0.44**	**0.74**	**79.43**	**78.92**	**0.51**	**0.91**

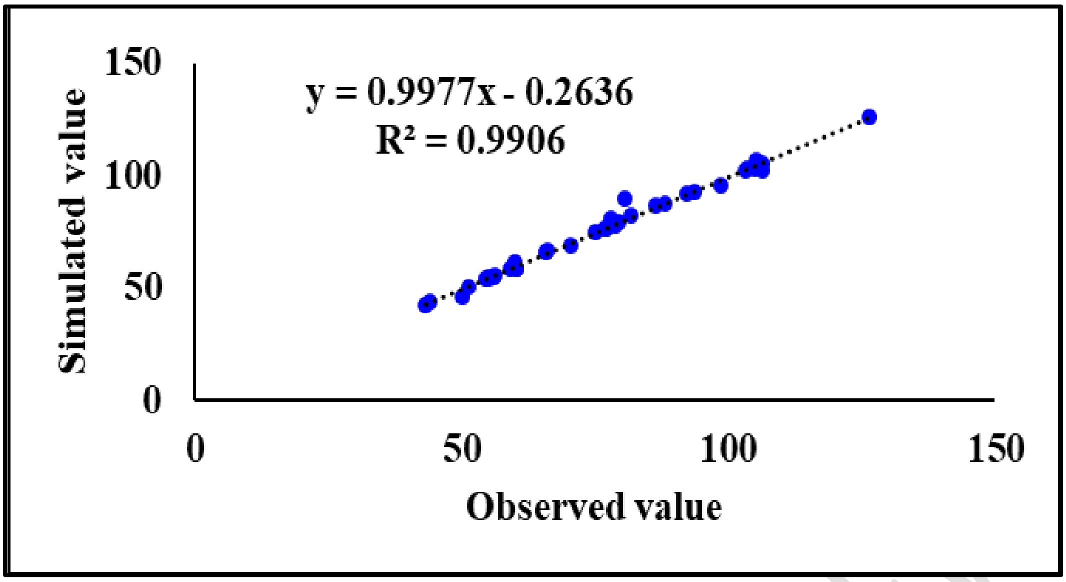

Figure 7 Comparison of observed and simulated maize grain yield in 2018-19 (calibration)

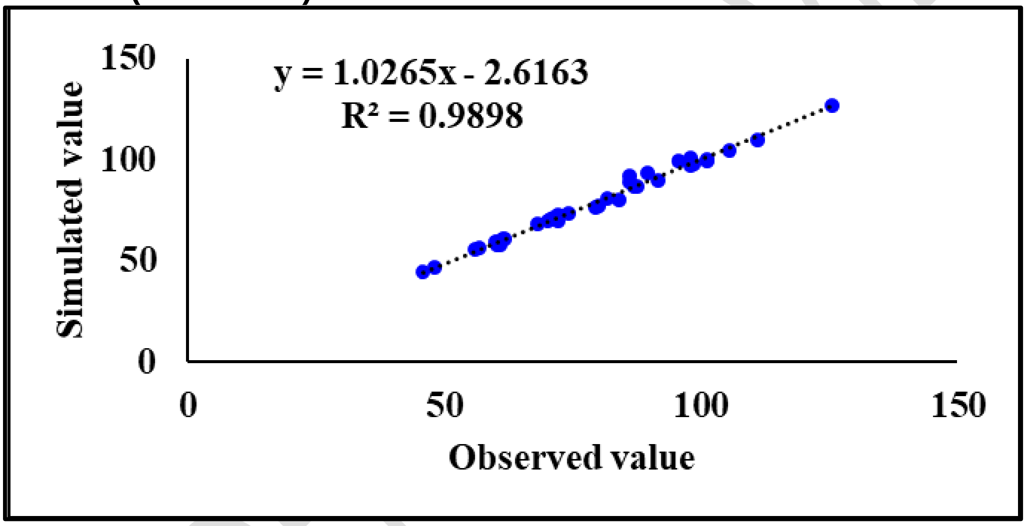

Figure 8 Comparison of observed and simulated grain yield of maize in 2019-2020 (validation)

4.14 Validation of CERES- Maize model

The performance of the CERES-Maize model was validated after calibration using the data which was not used for calibration. The variables tested include the key phenological dates *i.e.*, anthesis and physiological maturity and the final grain yield. In general, the model gave good predictions of crop development and then final yield of maize. The % deviation, correlation coefficient (r), root mean square error (RMSE), normalized root mean square error (NRMSE), standard deviation (observed and simulated), coefficient of variance, R^2, mean bias error (MBE) and mean absolute percentage error (MAPE) have been used for analysing the performance of

CERES-Maize model in this study. The results also showed that the model is able to simulate duration to anthesis and maturity reasonably well for most of the treatments. In general, there was a good agreement between the observed and simulated values of days to anthesis and maturity except some peak and low values.

Table 9 Mean, Standard deviation (SD) and Coefficient of Variance (CV) values of simulated and observed data of different parameters.

Parameters (Calibration)	**Simulated**			**Observed**		
	Mean	**SD**	**CV %**	**Mean**	**SD**	**CV %**
Anthesis (DAS)	74.00	1.39	1.80	72.70	1.59	2.19
Maturity (DAS)	132.20	1.62	1.20	130.70	1.52	1.10
Grain yield (q/ha)	76.42	0.20	0.27	75.98	0.21	0.28
Parameters (Validation)	**Simulated**			**Observed**		
	Mean	**SD**	**CV %**	**Mean**	**SD**	**CV %**
Anthesis (DAS)	71.00	1.90	2.60	70.30	2.33	3.30
Maturity (DAS)	135.10	3.93	2.90	133.90	3.91	2.90
Grain yield (q/ha)	79.43	0.18	0.23	78.92	0.19	0.24

Table 10 Performance of DSSAT CERES- Maize model of simulated vs observed data by different indices

Parameters (Calibration)	**r**	**RMSE**	**NMRSE**	**MBE**	**MAPE**
Anthesis (DAS)	0.80	1.45	1.90	1.30	1.80
Maturity (DAS)	0.66	1.70	1.30	1.40	1.10
Grain yield (kg/ha)	0.99	2.07	2.72	0.44	0.74
Parameters (Validation)	**r**	**RMSE**	**NMRSE**	**MBE**	**MAPE**
Anthesis (DAS)	0.89	1.45	2.06	1.31	1.88
Maturity (DAS)	0.93	1.50	1.12	1.19	0.89
Grain yield (kg/ha)	0.98	2.01	2.55	0.51	0.90

5. Summary and Conclusion

Maize crop at different irrigation regimes and mulch conditions recorded a greater number of days for anthesis both under observed and simulated conditions. Maize crop is grown under irrigation regimes (0.6, 0.8 and 1.0 IW/CPE) at three growth stages (tasselling, silking, and dough stage) and mulching (no mulch, straw mulch, black plastic mulch and reflective silver plastic mulch) both under observed and simulated conditions.

The comparison of observed and predicted grain yields were both over and underestimated by the model; however, the trend noted for the field observed and model simulated grain yields matched well.

STUDY AREA/ SAMPLE COLLECTION: Farm of College of Agricultural Engineering and Technology, Anand Agriculture University, Godhra, Gujarat.

ETHICAL APPROVAL: This article does not contain any studies with human participants or animals performed by any of the authors.

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