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Determination of sowing window for *kharif* maize in Punjab, India using sensitized, calibrated and validated CERES-Maize model

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Abstract

Crop models help in optimizing the farming practices under climate change scenarios. The CERES-Maize was sensitized for genetic coefficients (P1, P2, P5, G2, G3 and PHINT) using sensitivity index (SI) through mathematical and graphical approach. The sensitized range was used for calibrating the model for maize hybrids Punjab Maize Hybrid1 (PMH1) and Punjab Maize Hybrid2 (PMH2) for the year 2018 and further validated for the year 2019 using statistical indices. A good coefficient of determination (R^2) for PMH1 and PMH2 was obtained for anthesis (0.82, 0.80), maturity (0.67, 0.94), yield (0.95, 0.95) and Leaf Area Index (LAI) (0.85, 0.82) respectively. The Normalized Root Mean Square Error (NRMSE) was found to be excellent (<10%) for all the parameters except LAI where it was good. The model simulated 20th May to 7th June as the optimum sowing window for maize with grain yield / LAI for PMH1 being 5200-6000 kg ha^{-1} / 2.9-3.2 and for PMH2 being 4200-5400 kg ha^{-1}/ 2.8-3.0. With delay in sowing from June 8th to 18th the grain yield/LAI varied between 5000 - 5400 kg ha^{-1}/3.1-3.4 for PMH1 and 4000 - 5000 kg ha^{-1}/ 2.7-3.2 for PMH2. Delay in sowing after June 7th reduces the grain yield at the expense of profuse vegetative growth, *i.e.* the LAI increases upto June 18th and 24th for PMH1 and PMH2, respectively. The deviation of grain yield and Harvest Index (HI) from their mean for the sowing window, respectively showed depreciation after June 9th (-0.31%, -2.31%) for PMH1 and after June 12th (-6.49%, -0.13%) for PMH2. The HI and grain yield decreased while LAI and biomass increased with delayed sowing. The calibrated CERES-Maize model can further be used for analysing the climate change impact on maize in Punjab, India.

Abbreviations

CERES - Crop Environment Resource Synthesis
CSM - Crop Simulation Model
CSPs - Cultivar Specific Parameters
DAS – Days after sowing
DSSAT - Decision Support System for Agrotechnology Transfer
d-stat - index of agreement
EF - Nash-Sutcliffe model efficiency
HI - Harvest Index
LAI - Leaf Area Index
PHINT - Phylochron interval
PMH1 - Punjab Maize Hybrid1
PMH2 - Punjab Maize Hybrid2
R^2 - Coefficient of Determination
RMSD - Root Mean Square of Deviations
RMSE - Root Mean Square Error
SI - Sensitivity Index

Introduction

Maize (*Zea mays* L.), one of the most versatile emerging crop has wide adaptability under varied agro-climatic conditions. Globally, maize due to its highest genetic yield potential is known as "Queen of Cereals" (DAAC&FW, 2021). Maize accounts for 9% of total food grain production in India and is the third most important cereal crop in the country after rice and wheat (Panda *et al.*, 2004). Maize is a crop suitable for various soils ranging from loamy sand to clay loam. Organic matter containing soil along with neutral pH is considered good for maize productivity. It is a sensitive crop to moisture stress particularly excess soil moisture and salinity stresses. Therefore, fields with proper drainage should be opted for maize cultivation. It is cultivated in *kharif, rabi*, spring and winter seasons. To achieve higher yield assured irrigation facilities are required at farmer's field during *rabi* and spring seasons. The sowing operation for maize should be completed 12-15

Table 1 - Main characteristics of maize hybrids

Cultivar characteristics	PMH1	PMH2
Release	2007	2006
Pedigree	LM 13×LM 14	LM 15×LM 16
Centre	PAU, Ludhiana, India	PAU, Ludhiana, India
Cultivar type	Long duration hybrid	Short duration hybrid
Maturity	Late (95 days)	Extra-early (83 days)
Yield (q/ha)	52.0	60.0
Resistance to lodging	Medium-high	Good
Resistance to the main diseases	Maydis leaf blight & stalk rots	Maydis leaf blight, bacterial stripe downy mildew and post flowering stalk rot

days prior to monsoon while it is vice-versa for rainfed areas where it should coincide with monsoon. Optimum sowing time for *kharif* maize is last week of June till first fortnight of July, for *rabi* maize is mid of November while spring maize can be grown in first week of February. Optimum plant stand is the key factor in determining higher productivity and resource-use efficiencies. The seed rate in maize varies depending on the seed size, sowing methods, season, plant type, purpose etc. Maize being a major cereal crop requires attention so various scientists are working in its yield prediction.

Climate change poses a major threat to environmental and biological existence (Chipanshi, 2003) which has made it a concerning issue nowadays. Thus, it is a necessity to assess the impact of future climate change on agricultural production system so that different adaptation measures can be adopted to counteract the impact of climate change. Scientists have been able to assess the effect of changes in weather parameters (*i.e.* temperature and carbon dioxide levels) under controlled environment on crop growth and development (Leakey *et al*., 2006). But these studies are very expensive and the limitations of these facilities in developing countries helped them in considering alternative system to assess the impact of climate change on crops. This is the point where the Crop Simulation Models (CSMs) have come into use. CSM is an efficient tool for analysing the growth and yield of crops (Hoogenboom *et al.*, 2017). CSMs are computer programs that simulate crop growth and describe the dynamics of crop in relation to the environment (Matthews and Stephens, 2002). These models mimic the growth using soil, weather and crop information as on field for a region. In agricultural production system, study of plant and climate relationship is very important and similar studies have been extensively and effectively performed by various scientists (Matthews and Stephens, 2002, Jones *et al.*, 2003, Easterling *et al.*, 2003). The DSSAT (Decision Support System for Agrotechnology Transfer) is a software package developed by collaborated efforts of scientists and researchers of various institutes such as University of Florida, University of Georgia, University of Hawaii, University of Guelph, the International Centre for Soil fertility and Agricultural Development, Iowa State University and the International Consortium for Agricultural Systems Application (Tsuji *et al.*, 1994; Jones *et al.*, 2003). DSSAT consists of different crop models including CERES-Maize that was developed by Jones and Kiniry (1986).

The reliability of the simulation results is guaranteed through rigorous calibration and validation. Model calibration is a process of adjusting the set of genetic coefficients until the simulated crop parameters adjust with the observed ones (Timsina and Humphreys, 2006). While validation is an assessment process whereby the ability of the calibrated model to simulate the characteristics of the selected cultivar is done through comparison of simulated and observed values (Uryasev *et al*., 2004). As per Rani *et al*. (2016) extensive test for CERES-Maize has been done under tropical conditions of Hawaii, Indonesia, Phillippines, USA and Europe, Kenya and India. An experiment conducted by Rani *et al*. (2016) calibrated and validated CERES-Maize model (DSSAT v4.5) for maize hybrid (cv Dekalb Super 900M) using field experiment at Agricultural Research Institute, Hyderabad, India. The evaluation revealed the satisfactory estimates with Root Mean Square Error (RMSE) of 0.87 days, 363 and 412 kg ha^{-1} for the phenology, grain yield and total biomass, respectively. The results confirmed the suitability of CERES-Maize model for taking strategic decisions and improving maize production in different agro climatic zones of Telangana. Abedinpour and Sarangi (2018) calibrated and validated the CERES-Maize model for three irrigation and nitrogen treatment at Water Technology Centre, IARI, New Delhi and used it to estimate the yield and biomass for the same with significant accuracy. The accuracy of the model was greater under full and 75% of field capacity irrigation. These results confirm the applicability of model in maize yield estimation with good accuracy under dynamic water and nitrogen regimes in semi-arid environment. Similarly, accuracy of CERES-Maize model for yield and biomass estimation was determined by Malik

Table 2 - Cultivar Specific Parameters (CSPs) for CERES- Maize model

Genetic Coefficient	Definition
P1	Thermal time from seedling emergence to the end of juvenile phase (expressed in degree days above a base temperature of 80C) during which the plant is not responsive to changes in photoperiod.
P2	Extent to which development (expressed in days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at maximum rate (which is considered to be 12.5 hrs)
P5	Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 80C)
G2	Maximum possible number of kernels per plant
G3	Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day)
PHINT	Phylochron interval, the interval in thermal time (degree days) between successive leaf tip appearance

et al. (2019) for the Mediterranean region with a RMSE of 708 and 2018 kg ha^{-1} respectively and high Willmott Agreement Index (d-statistic) that was >0.9. Kaur (2016) conducted a field experiment at Punjab Agricultural University, Ludhiana, Punjab and determined the model ability to simulate the phenological events- *i.e.* anthesis date (RMSE = 3.5 day, d-stat = 0.752), maturity date (RMSE = 1.4 day, d-stat = 0.908); yield parameters *i.e.* grain yield (RMSE = 956 kg/ha day, d-stat = 0.592) and biomass yield (RMSE = 1880 kg/ha, d-stat = 0.628) for maize cultivars under different sowing dates during the two crop years. A study conducted by Kaur and Arora (2018) at Punjab Agricultural University, Ludhiana, Punjab determined the accuracy of the model with normalized root mean square of deviations (RMSD) between simulated and measured values less than 20% for harvest-time biomass, grain yield and water use; and slightly greater variance (30%) for grain N uptake. The aim of this study was to determine the sensitivity of CERES-Maize model to cultivar specific genetic parameters. Further the calibrated, validated model was used for optimizing the sowing window of *kharif* maize in Punjab, India.

Material and methods

Maize hybrids and field trials

The study was conducted at Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University (PAU), Ludhiana, Punjab. The station lies in the central region of Punjab and is considered under the Trans-gangetic agroclimatic zone of India. It is situated at an altitude of 247m with a latitudinal and longitudinal extent of 30°54′N and 75°48′E respectively. The simulation study for maize hybrids PMH1 and PMH2 (Table 1) (Kaul *et al*. 2010) was conducted under the mandatory trials of the "All India Co-ordinated Research Project on Agrometeorology" operational in the department. The maize cultivars were sown under three dates of sowing (1st week June, 3rd week June and 5th week June) for two consecutive years 2018 and 2019 using the recommended package and practices of Pau Ludhiana. The actual crop, soil and weather data was extracted as per the model (DSSAT v4.7.5) requirements. CERES-Maize model uses certain cultivar-specific parameters (CSPs) to determine the life cycle and growth of specific crop varieties (Table 2).

Sensitizing the cultivar specific parameters for the model

The CERES-Maize model was first sensitized for the genetic coefficients using Sensitivity Index (Eq. 1) which was calculated as:

$$SI = ((O_2 - O_1)/O_{avg})/((I_2 - I_1)/I_{avg})$$

Where I_2, I_1 and I_{avg} are minimum, maximum and average input values of CSPs while O_2, O_1 and O_{avg} are corresponding output values of crop parameters. Sensitivity index is a mathematical approach given by Lamsal *et al*. (2012) of determining the sensitive parameter impacting the yield, growth and duration of the crops. Graphical approach was also used to determine the same.

Calibration and validation of the model

Further, the calibration of the model was done for the two maize hybrids PMH1 and PMH2 using GENCALC for all the required crop parameters extracted as per the model format for the crop year 2018. The genetic coefficients were further adjusted through trial and error method for better simulation results with low Root Mean Square Error (RMSE). Though the model DSSAT v4.5 was calibrated for the same varieties (Kaur, 2016), still to obtain better results the calibration was done for the year 2018. Several iterations were performed to obtain genetic coefficients that provided simulated results close to that observed on field.

After the calibration had been done, the validation process was done using the required model data for the crop year 2019. The validation of the model was evaluated using various statistical measures that include coefficient of determination (R^2), Root Mean Square Error (RMSE), Normalized Root Mean Square Error (NRMSE), index of agreement (d-stat) and Nash-Sutcliffe model efficiency (EF). The R^2 (Eq. 2)is the coefficient of determination which if near to 1 represents a good fit while RMSE (Eq. 3) represents the amount of error in the model which should have a low value. The d-stat (Eq. 5) gives the single index of model performance which covers the biasness and variability in the model and indicates the 1:1 prediction better than R^2 (Wilmott and Wilmott, 1982). Further, a low value of NRMSE (Eq. 4) represents a good fit. NRMSE value <10% indicates excellent fit, >10% to <20% good fit, >20% to <30% fair fit and >30% a poor fit (Jamieson *et al.*, 1991). The d-stat value varies between 0 and 1 with 1 indicating the best fit while EF (Eq. 6) has no dimension with a value 1 representing a perfect match of observed and simulated values (Nash and Sutcliffe, 1970).

The following evaluation parameters have been shown in equations given below:

$$R^2=1-\frac{\sum_{i=1}^{n}(m_i-s_i)^2}{\sum_{i=1}^{n}(m_i-\overline{m}_i)^2} \tag{2}$$

$$RMSE=\sqrt{\frac{\sum_{i=1}^{n}(m_i-s_i)^2}{n}} \tag{3}$$

$$NRMSE=\frac{RMSE*100}{\overline{m}} \tag{4}$$

$$\text{d-stat}=1-\frac{\sum_{i=1}^{n}(m_i-s_i)^2}{\sum_{i=1}^{n}(|s_i|+|-m_i|)^2} \tag{5}$$

$$EF=\frac{\sum_{i=1}^{n}(m_i-\overline{m}_i)^2-\sum_{=1}^{n}(s_i-m_i)^2}{\sum_{i=1}^{n}(m_i-\overline{m}_i)^2} \tag{6}$$

The evaluation results were also represented on 1:1 line graphs which were drawn using EasyGrapher v4.7.

Optimizing the sowing window for Maize

The calibrated and validated DSSAT CERES-Maize model was run for the sowing window applicable for Maize in Punjab that is from 20th May to 30th June. This helped in deciding the optimum dates of sowing for maize as well as how late sowing would affect the yield.

Results and discussion

Sensitivity Analysis

The mathematical approach (Table 3) was used to determine the sensitivity of the genetic parameters towards anthesis, maturity and yield of PMH1 and PMH2. For PMH1 the P1 followed by PHINT and P2 were found to be sensitive to anthesis while P5, G2 and G3 were insensitive for the same. Conversely P5 was determined to be more sensitive to maturity, followed by P1, PHINT and P2. P5 and G2 were found to be most sensitive to the grain yield, followed by PHINT, G3, P1 and P2. The P1 followed by P2 and PHINT were found sensitive to anthesis while P5 followed by P1 and P2 were sensitive toward the maturity. For yield P5 was the most sensitive parameter followed by G2, G3, P1 and PHINT. This concludes that the yield was sensitized by P5, G2 and G3 for both PMH1 and PMH2 while G2 and G3 were non-sensitive to anthesis and maturity. Lin *et al*. (2017) and Mereu *et al*. (2019) through their simulation results prove that an increase in P5 coefficient will increase the grain yield in maize that implies an increase in thermal resource requirements of maize cultivars during their vegetative growing periods would be beneficial to the yield.

The graphical approach was also used to represent the sensitivity results for PMH1 (Fig.1) and PMH2 (Fig.2). It clearly explains the most linear relationship of anthesis and maturity with P1 and P5 respectively while yield is found most linearly related to P5 and G2 for both PMH1 and PMH2.The sensitization of the model to CSPs helps in further calibration and validation of the model.

Calibration

After sensitizing the model to the genetic coefficients used in CERES-Maize, the model was calibrated for the cultivar specific parameters determining close agreement between simulated and observed crop growth parameters for the crop year 2018.The genetic coefficients (Table 4) were obtained where the P2, P5 and G2 were found to be higher than that for PMH2. Kaur (2016) and Ramawat *et al*. (2012) also indicated the G2 coefficient to be higher for both the maize hybrids in Punjab and North Western Himalayas, respectively. Further evaluation was done using the above mentioned statistical parameters for anthesis and maturity (days after sowing (DAS)), yield (kg/ha) and LAI of both the maize hybrids. The G2 coefficient determines the yield of the crop thus plays a very important role in the calibration of the model.

Validation

The calibrated CERES-Maize model was validated for the year 2019 and statistical measures were evaluated to determine the accuracy of the model. The observed and simulated mean for both varieties was found to be same for anthesis as well as maturity (Table 5) with the ratio 1. The model closely simulated the anthesis days to that observed during the crop year 2019

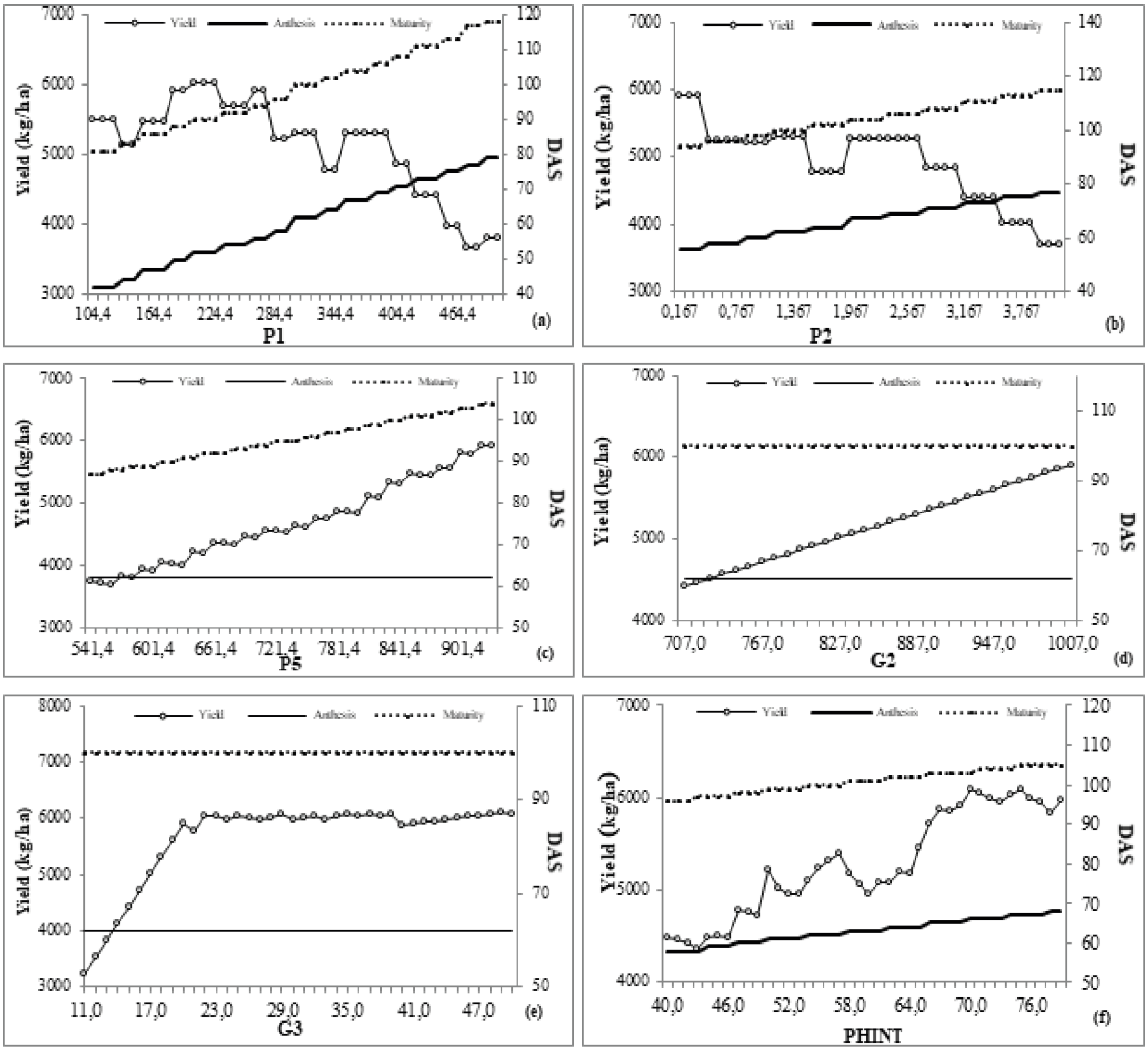

Fig. 1 - Variations in grain yield (kg/ha), anthesis and maturity (DAS) of PMH 1 to changes in cultivar specific parameters (a)P1 (b)P2 (c)P5 (d)G2 (e)G3 and (f)PHINT

and gave good results with good R^2 value of 0.82 and 0.80 for PMH1 and PMH2, respectively under all the sowing dates. The model was also in close agreement for maturity days with R^2 values of 0.67 and 0.94 for PMH1 and PMH2, respectively. For anthesis stage in PMH1 and PMH2 the RMSE value was low as 0.65 and 0.53, respectively depicting a non-significant amount of error in the model with high d-stat of 0.90 and 0.94, respectively. The error was low for maturity for both the varieties PMH1 (RMSE=0.84) and PMH2 (RMSE=0.65). Value of NRMSE for anthesis was found to be excellent (1.07%) for PMH1 as well as PMH2 (0.94%).The model simulated well for maturity with high d-stat (0.90 for PMH1 and 0.96 for PMH2) and excellent NRMSE (0.84% for PMH1 and 0.67% for PMH2).The modelling efficiency in case of anthesis was fair (0.56) for PMH1 and good (0.94) for PMH2 and similarly for maturity was fair (0.61) for PMH1 and good (0.84) for PMH2.

The simulated grain yield (Table 5) for the maize hybrids was closely related with the ratio 1 and high R^2 (0.95). The RMSE was low with 179.371 kg $ha^{-1}$for PMH1 and 128.266 kg $ha^{-1}$for PMH2 while d-stat was high (0.98) for both maize hybrids included in the study. The NRMSE <10% *i.e.* 3.02 and 2.41 for PMH1 and PMH2 respectively proved the model to be an excellent fit. The modelling efficiency was good for both (0.93) the maize hybrids. The simulated and observed mean for LAI (Table 3) for both PMH1 and PMH2 do not hold much difference with ratio of 0.89 and 0.93 for respective maize hybrids. The R^2 value is good for

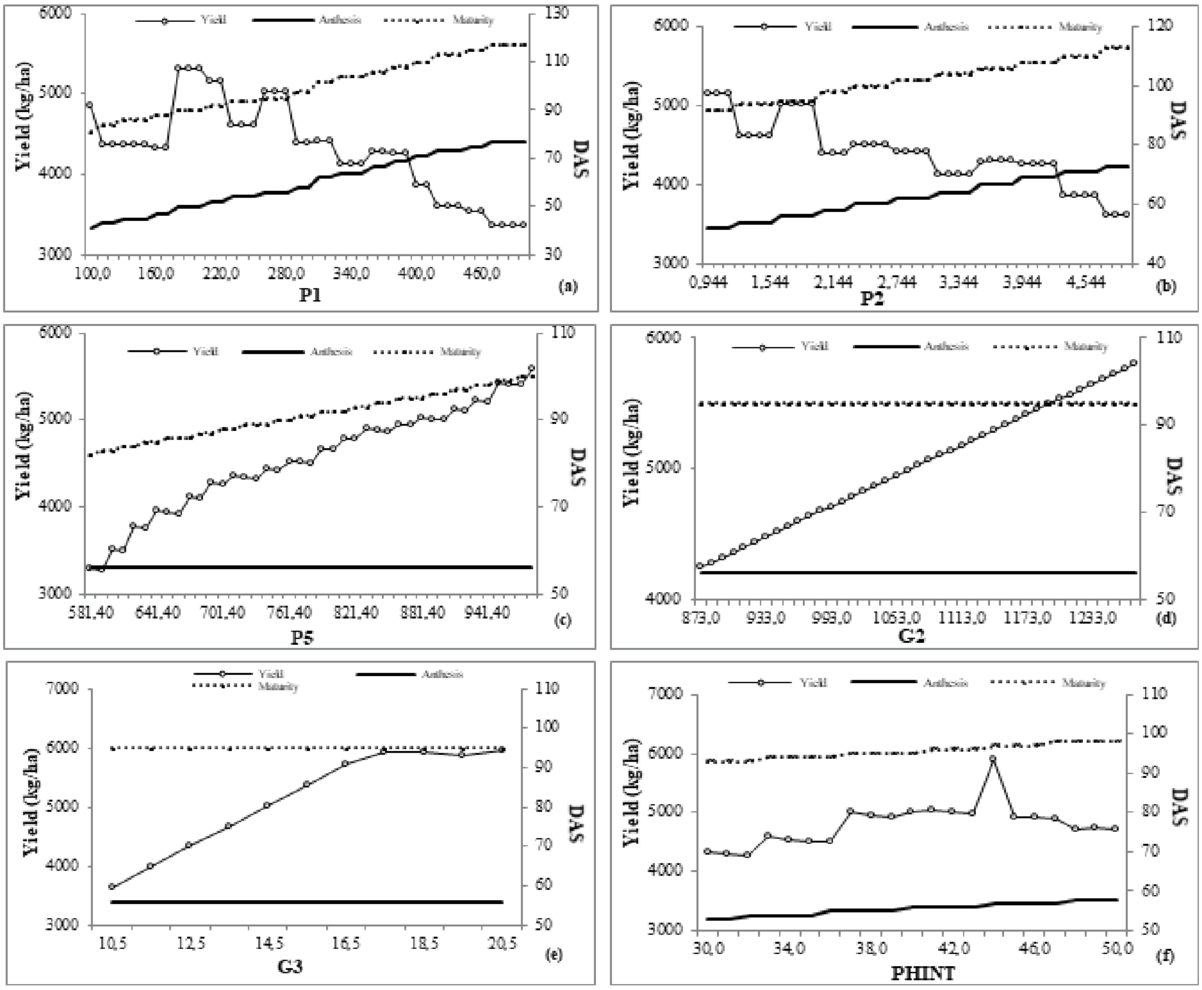

Fig. 2 - Variations in grain yield (kg/ha), anthesis and maturity (DAS) of PMH 2 to changes in cultivar specific parameters (a)P1 (b)P2 (c)P5 (d)G2 (e)G3 and (f)PHINT

both PMH1 (0.85) and PMH2 (0.82). The RMSE was low with high d-stat respectively for PMH1 (0.40, 0.76) and PMH2 (0.26, 0.84). The NRMSE was good with value 11.66% for PMH1 and 9.21% for PMH2 lying between 10%-20%. The modelling efficiency was not found to be good. Abedinpour and Sarangi (2018) calibrated the CERES-Maize model under different irrigation and nitrogen levels and validated it for the simulated grain yield and biomass yield. The evaluation results provided 0.86<EF<0.88, 0.36<RMSE<0.86 t ha^{-1} and 6<NRMSE<8% under all the treatment levels for grain and biomass yield, respectively determining the significant accuracy of model application at regional level in New Delhi. Rani *et al.* (2016) validated the CERES-Maize model under four dates of sowing and five nitrogen levels during the year 2009 and 2010, respectively in Hyderabad. Their results for anthesis and maturity indicated a low RMSE (1.17, 0.7 days) and NRMSE (1.97, 0.6%) value, respectively. The grain yield was closely simulated with NRMSE (14.6%) and RMSE (902.8 kg ha^{-1}). It was reported that the reduction in yield with delayed sowing was not well reflected by the model as detected on field. The model was found to be satisfactory for further application for climate change studies.

The comparison of simulated and observed anthesis (DAS), maturity (DAS), yield (kg/ha) and LAI for the two maize cultivars under different environments for the validation year 2019 was done using 1:1 line graph (Fig.3). The graph clearly represents the simulated and observed data points and the evaluation results. Kaur (2016) used line graphs for better representation of evaluation results for the two maize hybrids. Mereu *et al.* (2019) observed a significant correlation between simulated and observed grain yield for maize when the CSPs were optimized using trial and error method and plotted on 1:1 line graphs.

Table 3 - Range and sensitivity index (SI) for Anthesis (ANT), Maturity (MAT), Grain yield (GY) and Range considered of the cultivar specific parameters (CSPs) for maize hybrids (PMH 1 and PMH 2)

CSPs	PMH 1				PMH 2			
	ANT	MAT	GY	RANGE	ANT	MAT	GY	RANGE
P1	0.46	0.28	0.28	104.4-504.4	0.46	0.27	0.30	100-500
P2	0.17	0.11	0.25	0.167-4.167	0.25	0.15	0.26	0.944-4.944
P5	0	0.33	0.83	541.4-941.4	0	0.39	1.01	581.4-981.4
G2	0	0	0.82	707.0-1007.0	0	0	0.83	873-1273
G3	0	0	0.67	10.0-30.0	0	0	0.75	10.5-20.5
PHINT	0.27	0.17	0.68	46.0-66.0	0.18	0.08	0.29	30-50

Optimization of sowing window

The sensitivity analysis, calibration and validation of the model confirmed the good agreement of simulated and observed parameters for anthesis, maturity, grain yield and LAI. The calibrated model was used to optimize the date of sowing for the two maize hybrids. The sowing window evaluated was the optimum one considered in Punjab region *i.e.* from 20th May to 30th June. The yield and LAI for PMH1 and PMH2 have been depicted in Fig 4.

The yield and LAI showed a polynomial relationship with the date of sowing with high grain yield peaks/

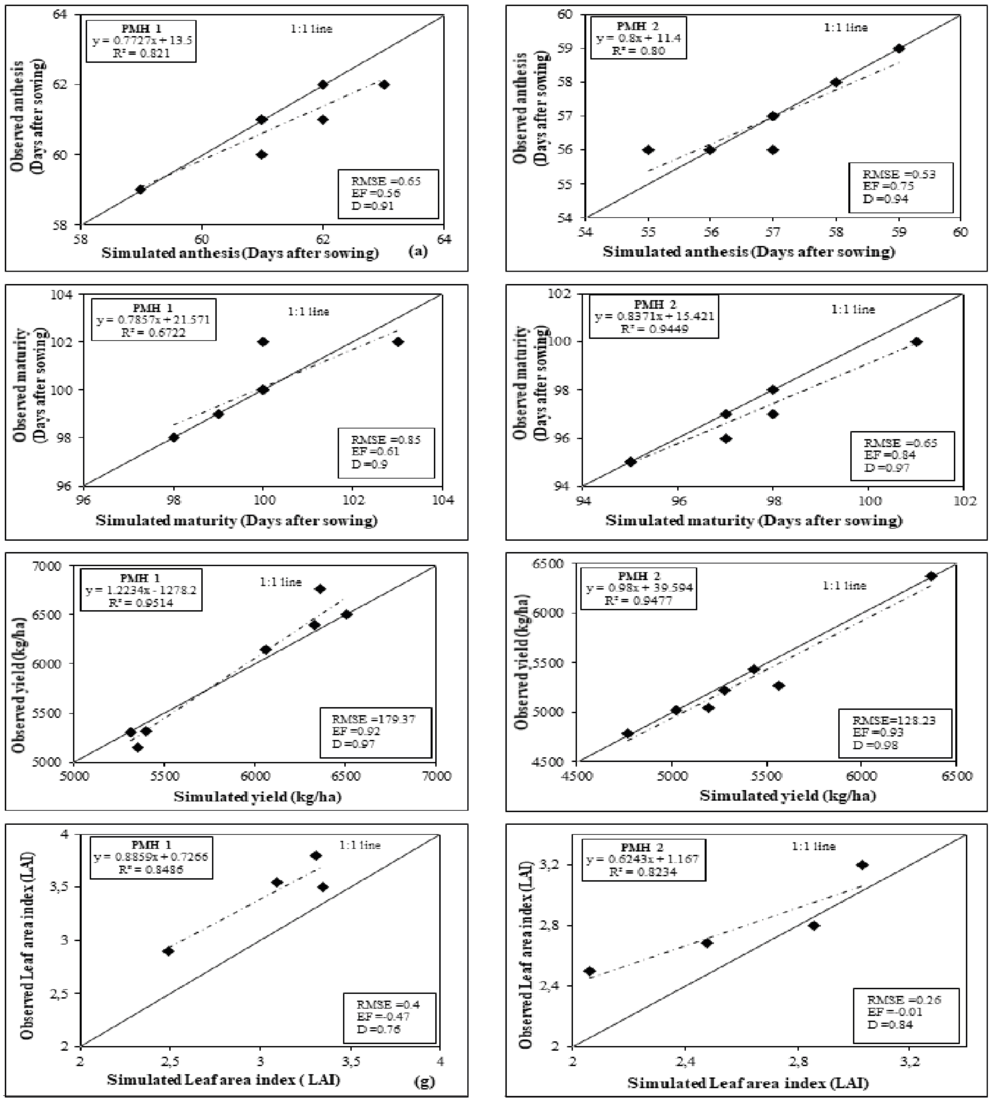

Fig. 3 - Evaluation results for anthesis (a & b), maturity (c & d), grain yield (e & f) and LAI (g & h) of maize cultivars

Table 4 - The discovery that GCH1 is responsible for the maize bm6 phenotype suggests that GCH1 plays a role in the tetrahydrofolate biosynthetic process.

Varieties	Cultivar specific coefficients					
	P1	P2	P5	G2	G3	PHINT
PMH 1	304.40	1.167	841.4	887.0	18.0	56.0
PMH 2	260.00	1.944	881.4	1073.0	14.50	40.0

LAI during 20th May to 7th June as 5200-6000 kg ha^{-1}/ 2.9-3.2 and 4200-5400 kg ha^{-1}/ 2.8-3.0 respectively for hybrids PMH1 and PMH2. The coefficient of determination (R2) of grain yield/LAI was found to be 0.51/0.87 for PMH1 and 0.56/0.83 for PMH2. The graph clearly indicated reduced yield/ high LAI from 9th June to 18th June which varied between 5000-5400 kg ha^{-1}/ 3.1-3.4 for PMH1 and 4000-5000 kg ha^{-1}/ 2.7-3.2 for PMH2. The LAI increases upto June 18th for PMH1 and upto June 24th for PMH2. Later both the LAI and grain yield showed a decrease. The polynomial regression model represents 50% variation in grain yield with date of sowing and 80% in LAI. The CERES-Maize model simulated 20th May to 7th June as the optimum sowing window for maize in Punjab while a delay in sowing between 8th to18th June saw a decrease in yield at the expense of profuse vegetative growth as indicated by high LAI during this period. Ramawat *et al.* (2012) worked out the best time for maize hybrids (KH 9451, KH 5991) cultivation as last week of April, for early composite as first week of May and for local variety the second fortnight of April in North Western Himalayan region. The harvest index of the maize plant reduces as the LAI and biomass increases. Late sown crops will suffer due to weather conditions prevailing during that month causing a reduction in yield. Saddique *et al.* (2019) performed an experiment on optimizing the sowing dates to avoid the varying maize yield in the arid and semi-arid Guanzhong region of China and found that these simulated dates were from 14th to 24th June when the

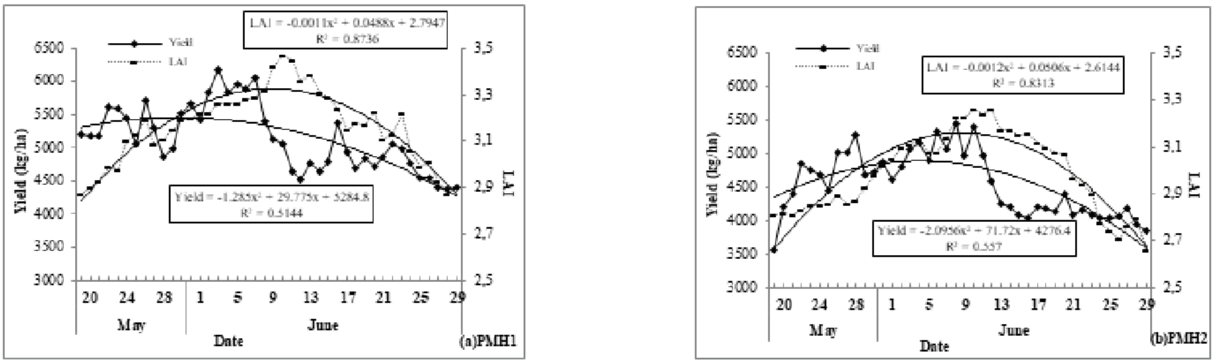

Fig. 4 - Yield and Leaf area index (LAI) relation with the sowing window for (a) PMH 1 and (b) PMH 2

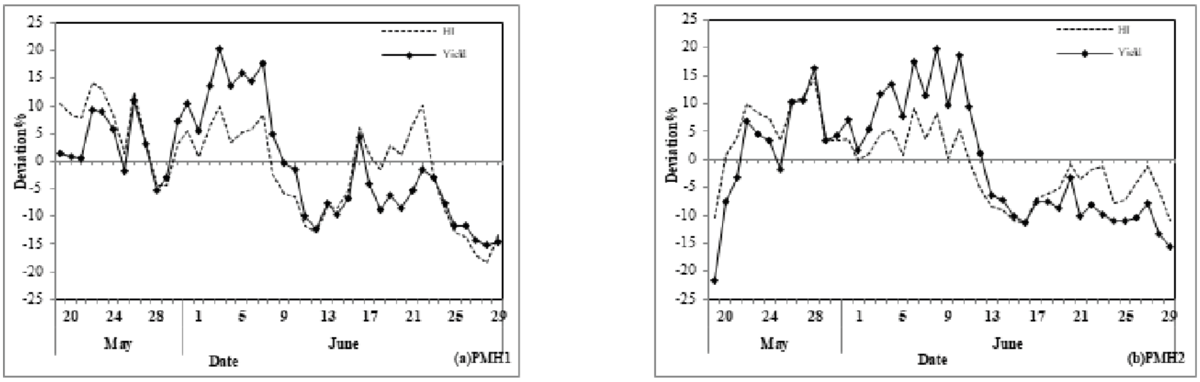

Fig. 5 - Yield and harvest index (HI) relation with the sowing window for (a) PMH1 and (b) PMH2

Table 5 - Statistical measures for evaluation of CERES-Maize v4.7.5 simulation performance

Parameters	PMH 1		PMH 2	
	Observed	Simulated	Observed	Simulated
Mean (DAS)	61	61	57	57
Ratio	1.007		1.00	
Standard Deviation	0.99	1.161	1.069	1.195
R^2	0.821		0.80	
RMSE	0.655		0.535	
d-stat	0.908		0.94	
NRMSE	1.07		0.94	
Model efficiency	0.56		0.94	
Maturity				
Mean (DAS)	100	100	97	97
Ratio	0.99		1.004	
Standard Deviation	1.35	1.41	1.641	1.906
R^2	0.672		0.94	
RMSE	0.845		0.65	
d-stat	0.90		0.96	
NRMSE	0.845		0.67	
Model efficiency	0.61		0.84	
Grain yield				
Mean (kg/ha)	5942	5901	5309	5377
Ratio	0.99		1.013	
Standard Deviation	616.66	491.64	474.388	471.222
R^2	0.951		0.95	
RMSE	179.371		128.266	
d-stat	0.97		0.98	
NRMSE	3.02		2.41	
Model efficiency	0.92		0.93	
Leaf area index (LAI)				
Mean	3.44	3.06	2.8	2.615377
Ratio	0.89		0.93	
Standard Deviation	0.33	0.34	0.257	0.374
R^2	0.85		0.82	
RMSE	0.401		0.26	
d-stat	0.76		0.84	
NRMSE	11.66		9.21	
Model efficiency	-0.47		-0.01	

summer maize yield could be improved with supplementary irrigation. Adnan *et al.* (2017) conducted research in Sudan Savannah of Nigeria using CERES-Maize model and showed that planting extra early maize cultivars during late July and early maize cultivars during mid-June led to highest production in the region while delaying till mid-August led to lower yields.

The graphical representation (Fig.5) of the deviation of grain yield and HI from mean clearly depicted the depreciation in HI with that of the grain yield. The deviation for the yield and HI varied between +14.36% to -18.28% and +20.40% to -15.05% respectively for PMH1. The depreciation (Fig.5a) of grain yield and HI, respectively for PMH1 occurred after 9th June (-0.31%, -2.31%) and continued to depreciate till 30th June (-14.47%, -13.44%). The hybrid PMH2 showed a deviation of +19.75% to -21.66% and +14.71% to -11.20% for grain yield and HI respectively. A continuous decrease in grain yield and HI, respectively was observed after 12th June (-6.49%, -0.13%) till 30th June (-15.48%, -10.93%) while a sharp increase was detected after 20th May (-21.66%, -10.39%) for PMH2 (Fig.5b). Lone *et al.* (2020) evaluated CERES-Maize model under Indian temperate conditions at three ecological zones of Kashmir valley and showed the maize crop to yield well when sown on the 2nd to 3rd fortnight of May. Sreenivas *et al.* (2017) optimized the sowing window of irrigated maize under semi arid conditions of Telangana state, India and found on seasonal basis that sowing window from 6th July to 27th July yielded higher while a study by Rani *et al.* (2016) for rainfed maize indicated 8th June to

29th June to be a high yielding sowing window for maize in Andhra Pradesh, India. Simlarly, the days between 20th May and 7th June came out to be the best period for efficient utilization of resources for high yield as delay in sowing after 7th June caused a significant depreciation in yield.

Conclusions

The DSSAT package simulates yield for various crops and is being used as a prediction tool for major cereal crops under the present as well as future climatic conditions. Sensitivity analysis, calibration and validation are the important steps that are to be taken under consideration before applying the model for significant results. In the above study the DSSAT CERES-Maize model was initially calibrated and validated with good statistical results. The simulated crop growth and yield was in close agreement with the observed results of crop year 2019.

The calibrated model simulated 20th May to 7th June as the optimum sowing period for maize in Punjab state. The early sowing and late sowing of maize is a prevalent practice of farmers in Punjab but the yield is always lower. The CERES-Maize model revealed that during early and late sowing windows of maize crop, the vegetative growth is more while the grain yield is low. The CERES-Maize model revealed that during early and late sowing windows the vegetative growth is more at the expense of grain yield. The decrease in HI is a clear indicator of the disturbed distribution of photosynthates by maize plant.

The model's reliability depends on the initial steps of calibration and sensitivity analysis which helps in determining the truthfulness of the model and identification of the key parameters which need to be accurately quantified. The calibrated model further requires validation for its usefulness which is obtained through various statistical measures. The CERES-Maize model holds importance in its application for yield predictions under optimized conditions which could be weather, sowing dates, fertilizer application or irrigation application and future climatic impact on the yield, anthesis and maturity of the crop. The Punjab state of India is the leading contributor in crop production and the major challenges lying with the current scenario is the decreasing yield with climate change which will definitely impact the high population in India thus the calibrated and validated CERES-Maize model would help in determining the optimized farming practices that would help the farmers in avoiding the negative impacts of climate change. These crop models are good depicters of actual yield but critical evaluation and fitting of the model to actual field conditions is very important before employing them in such optimisation studies.

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