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EVALUATION OF CERES-BARLEY MODEL AND ITS VALIDATION UNDER VARYING GROWING ENVIRONMENTS

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ABSTRACT

The field study was conducted in *rabi* 2019-20 at University Research farm of Department of Agricultural Meteorology, CCS HAU, Hisar (Lat.: 29° 10′ N; Log.: 75° 46′ E; Alt.: 215.2 m). The study was comprised of four sowing dates as factor (A) namely (D_1) -15th November, (D_2) – 30th November, (D_3) – 15th December and (D_4) – 30th December, comprising four different cultivars factor (B) viz. (V_1)- BH 393, (V_2)-BH 902, (V_3)- BH 946 and (V_4)-BH 885. The experiment was laid out in factorial RBD design with three replications. CERES-Barley model of the DSSAT Version 4.7.5 was used to simulate growth parameters, development, yield attributes and yield. CERES-Barley model evaluation results concluded that model overestimated the days to anthesis and grain yield and underestimated the days to maturity and leaf area index. Lower RMSE in estimation of days to anthesis (1.12), physiological maturity (0.75) and leaf area index (0.04), validation results revealed that good agreement between actual and predicted. Higher RMSE of grain yield (265.25) showed low model performance and was not found to be in good agreement.

Keywords : CERES, DSSAT, Model, Predicted, Percent Error, RMSE

Introduction

Barley (*Hordeum vulgare* L.,) is one of the most important cereal grain crops after rice, wheat and maize. In older days, Barley was mainly used as livestock feed and currently it is one of the grains used in human consumption (barley malt). Barley also plays major role in industrial consumption. It is a short growing season crop. Generally, in scenario of barley is cultivated as a *rabi* seasons crop in India and sowing being under taken from Nov. to Dec. and harvesting will be started from April to May. Barley cultivation in India is very old and slightly progressively increases the cultivation acreage. India covers about 662.52 thousand hectares area with total production of 2617 thousand tones and productivity 2617 kg/ha (ICAR-IIWBR, 2019). The area and production of barley in Haryana during 2018-19 was 18.77 thousand hectares and 57.99 thousand tones with the productivity of 3204 kg ha^{-1} (ICAR-IIWBR, 2019).

Haryana ranks sixth in Barley production in country and contributes around 3.0% towards national production of Barley growing area in the country. This crop prevailing weather condition requires as air temperature of 12°C to 16°C at growing stage and about 30°C to 32°C at maturity. This crop is very sensitive to frost at any stage of its growth. This crop yield is highly impacted by incidence of frost at flowering stage. Barley has very good tolerance to drought condition. The crop simulation model DSSAT (Decision Support System for Agro Technology) was chosen because it has been successfully used worldwide in a broad range of conditions and for multipurpose: as an aid to crop management. Decision Support System (DSS) are interactive computer-based systems that help decision makers to effectively utilize the valuable data to solve unstructured problems and optimized the resource management (Sprague and Carlson 1982).

The models running under DSSAT include the CERES (Crop Environment Resource Synthesis) model for rice, wheat, maize, sorghum, pearl millet and barley (Ritchie 1998). The barley model is specifically named as CERES-Barley. DSSAT has the Capability to analyze multiple simulation treatments in simple economic terms (Godwin *et al.* 1990). The models can be used to address various management options like scheduling of irrigation (Boggess and Ritchie 1988; Bosch and Ross 1990), scheduling of N fertilization, time of sowing (Anapalli *et al.* 2005), and development of Agro techniques (Kumar and Sharma 2005), risk analysis in rainfed cropping, selection of suitable varieties under varying agro-climatic situations, etc. CERES-Barley models can be used to simulate the collective effects of meteorological conditions (Jones *et al.,* 2003). The CERES-Barley (Crop Estimation through Resource and Environment Synthesis, CERES) model is a well-known barley crop dynamic simulation model. It is now available as part of the DSSATv4.5 (Decision Support System for Agro technology Transfer) and its higher version, which incorporates models of >25 different crops on the common set of software, that facilitates the evaluation and application of the crop simulation models for different purposes. CERES-Barley model has found worldwide applications for many researchers related to inter seasonal weather variability, water, crop and nutrient managements in barley productions, e.g. for the simulation of the effect of different growing environments as sowing dates and cultivars on barley production. The CERES-Barley model simulates the input of the main environmental factors, such as weather, soil and soil characteristics along with the crop management of barley growth, development and its yield. . The plan of this work was to calibrate CERES-Barley model for barley varieties (distinctly different in their genetic makeup, growth and development habits) sown on different dates and to validate model performance.

Evaluation of this model under Hisar condition may give a prospect to rearrange barley production management practices accordingly to mitigate of seasonal variability and terminal heat stress under various growing environments.

Materials and Methods

In order to achieve the objectives of the study entitled "Evaluation of CERES-Barley model and its validation under varying growing environments" a field experiment, conducted in the University Research Farm, Department of Agricultural Meteorology, CCS HAU, Hisar during *rabi* season of 2019-2020 which is located at latitude 29°10'N, longitude 75°46'E and altitude of 215.2 m above mean sea level. The main characteristics of climate in Hisar are dryness, extreme of temperature and scanty rainfall with very hot summers and relatively cool winters. Soil was sandy loam in texture and contain some amount of calcium carbonate in its profile. Chemical analysis of soil sample indicate that the soil of experimental site was low in organic carbon having value(0.43%) and nitrogen(162kg ha^{-1}), medium in phosphorus (25kgha^{-1}) and rich in potassium(321kg ha^{-1}) and slightly alkaline in reaction having pH 8.1.The experiment was comprised of four sowing dates as factor (A) namely (D_1) -15th Nov., (D_2) – 30th Nov., (D_3) – 15th Dec. and (D_4) – 30th Dec., comprising four different cultivars factor (B) viz. (V_1)- BH 393, (V_2)-BH 902, (V_3)- BH 946 and (V_4)-BH 885 in factorial RBD design with three replications. The inter row spacing was 22.5 cm and gross plot of size 4.0 m × 3.6 m and net plot of size 3.0 m× 2.6 m.

DSSAT model

DSSAT-CERES-Barley Decision Support System for Agrotechnology Transfer (DSSAT) (Jones 1993; Uehara and Tsuji, 1993) is software, which includes models of about two dozen crops. The models running under DSSAT include the CERES (Crop Environment Resource Synthesis) model for rice, wheat, maize, sorghum, pearl millet and barley (Ritchie 1998; Ritchie and Otter, 1985). The barley model is specifically named as CERES-Barley. The crop growth model CERES-Barley (Otter- Nacke *et al.,* 1991) was used in this study. This model was run within the DSSAT v 4.7.

Table 1: List of input required by CERES-Barley model

List of default parameters		
Input Variables	**Acronym**	**Units**
Site data		
Latitude	LAT	Degree
Longitude	LONG	Degree
Elevation	ELEV	m
Average air temperature	TAV	°C
Height of temperature measurement	TMHT	m

Height of wind measurement	WMHT	m
CO_2 concentration		Ppm
Horizon-wise		
Lower limit drained	LL(L)	cm^3cm^3
Upper limit drained	DUL(L)	cm^3cm^3
Soil water content	SAT(L)	cm^3cm^3
Saturated hydraulic conductivity	SWCN(L)	$cmhr^{-1}$
Bulk density moist	BD(L)	gcm^{-3}
Organic carbon	OC(L)	%
Clay (<0.002 mm) `	CLAY(L)	%
Silt(0.05 to 0.002 mm)	SILT(L)	%
Coarse fraction (>2 mm)	STONES(L)	%
Total nitrogen	TOTN(L)	%
pH in buffer	PHKCL(L)	
Cation exchange capacity	CEC(L)	$Cmolkg^{-1}$
Root growth factor 0 to 1	SHF(L)	
List of measured data		
Daily weather data measured at Agromet observatory CCSHAU, Hisar		
Maximum temperature	TEMPMAX	°C
Minimum temperature	TEMPMIN	°C
Solar radiation	SOLARAD	$MJm^{-2}day^{-1}$
Rainfall	RAIN	mm
Wind speed	WRUN	kmh^{-1}
Relative humidity (morning)		%
Relative humidity (afternoon)		%
Dew point temperature	TDEW	°C
Photosynthetic active radiation (PAR)	PAR	$MJm^{-2}day^{-1}$
Soil characteristics parameters collected from dept. of soil science, COA, CCSHAU, Hisar		
Soil texture	SLTX	
Soil local classification	SLDESC	
Soil family SCS system	TACON	
Soil depth	SLDP	m
Colour, moist	SCOM	
Albedo (fraction)	SALB	Fraction
Evaporation limit	U	cm
Drainage rate (fraction day^{-1})	SWCON	Fraction day^{-1}
Runoff curve number	CN2	
Mineralization (0 to 1 scale)	SLNF	
Photosynthesis factor (0 to 1 scale)	SLPE	
pH in buffer determination method	SMPX	
Potassium determination method	SMKE	
Management data		
Sowing date	YRPLT	
Emergence date	IEMERG	
Planting method (TP/direct seeded)	PLME	
Planting distribution (row/broadcast/hill)	PLDS	
Row spacing	ROWSPS	cm
Row direction (degree from north)	AZIR	
Plants per hill	PLPH	
Seed rate	SDWTRL	$kgha^{-1}$
Sowing depth	SDEPTH	cm
Irrigation dates	IDLAPL(J)	

Irrigation amount	AMT(J)	mm
Method of irrigation	IRRCOD(J)	
Fertilizer application dates	FDAY(J)	
Fertilizer amount N	ANFER(J)	$kgha^{-1}$
Fertilizer type	IFTYPE(J)	
Fertilizer application method	FERCOD(J)	
Fertilizer incorporation depth	DFERT(J)	cm
Tillage date	TDATE(J)	
Tillage implement	TIMPL(J)	
Tillage depth	TDEP(J)	cm
Residue management	LNRES	
Chemical applications	LNCHE	
Environment modification	LNENV	
Harvest details		
Harvest	HDATE(J)	
Harvest stage	HSTG(J)	
Harvest component	HCOM(J)	
Harvest percentage	kg ha^{-1}	%

Calibration of the model

Model calibration requires the adjustment of model parameters so that simulated values compare well with the observed ones. This CERES-Barley model necessitates a total of seven cultivar-specific genotypic coefficients. The coefficients details are given below in Table -2

Table 2 : Categorization of genetic coefficient of Barley

Parameters	Description of Parameters
P1V	**Vernalization sensitivity coefficient:** Relative amount that development is slowed for each day of unfulfilled vernalization, assuming that 50 days of vernalization is sufficient for all cultivars
P1D	**Photoperiod sensitivity coefficient (% reduction/h near threshold)**: Relative amount that development is slowed when plants are grown in one hour photoperiod shorter than the optimum (which is considered to be 20 hours)
P5	**Grain filling duration coefficient [(Thermal time from the onset of linear fill to maturity (°C d)]:** Degree days above a base of 1°C from 20 °C days after anthesis to maturity
G1	**Kernel number coefficient:** Kernel number per unit weight of stem (less leaf blades and sheaths) plus spike at anthesis (g^{-1})
G2	**Kernel weight coefficient:** Kernel filling rate under optimum conditions ($mgday^{-1}$)
G3	**Tiller death or spike number coefficient:** Non-stressed dry weight (g) of a single stem (excluding leaf blades and sheaths) and spike weight (g) when elongation ceases
PHINT	**Phyllochron interval:** Thermal time required between emergences of two successive leaf tips (°C d)

Validation

CERES- Barley has been validated for grain productivity of various barley cultivars for which genotypic coefficients have been calculated. The CERES- Barley was validated for grain yield using data from several field experiments on barley conducted during and proceeding to the year of the ongoing investigation. The model was run and the predicted data was generated. The actual and predicted data were compared for validation.

Model evaluation

The model is evaluated by comparing the simulated and observed phenology, maximum leaf area index (LAI) and grain yield in the *rabi* 2019-20 crop season. For the calibration and testing of CERES-Barley model were used the *rabi* 2018-19, experimental growth, yield and yield parameters and validation with *rabi* 2019-20. The performance of the model was assessed using various statistical measures such as mean absolute error (MAE), mean bias error

(MBE), root mean square error (RMSE), and percent error (PE). The summary of measures, include the mean of observed (O) and simulated (P) values, deviation of observations (P-O). A smaller RMSE indicates less deviation of the simulated values from the observed values (McMaster *et al.* 1992). These measures describe only the quality of the simulation by using different equation.

$$MAE = \sum_{i=1}^{n} [1P_i - O_i 1]/n \quad ...(i)$$

$$MBE = \sum_{i-1}^{n} [P_i - O_i]/n \quad ...(ii)$$

$$RMSE = \left[\sum_{i=1}^{n} (P_i - O_i)^2/n\right]^{½} \quad ...(iii)$$

PE = (RMSE / Observed mean)*100 ...(iv)

Error % = {(P – O) / O} * 100

Where, O = observed, P = simulated

Results and Discussion

Calibration and Validation of Ceres-barley Simulation Results

CERES- Barley was validated for anthesis days, physiological maturity days, maximum leaf area index, and grain yield of different barley varieties, the genotypic coefficients of which were worked out in this study. The method for determining the genetic coefficients involved running the model with a range of coefficient values until good agreement between predicted and actual values was achieved and the Percent Error was less than 10%. A model's success is determined by the precision with which it is calibrated and validated. Table 3 shows the model parameters used for four barley cultivars (BH 393, BH 902, BH 946, and BH-885) in semi-arid conditions of Hisar. The parameters of the CERES-Barley model were calibrated using data from the 2018-19 school year. During the calibration process, crop development and phenological stages were found to be more sensitive to the P1V, P1D, and PHINT genetic coefficients, while crop growth or yield components were found to be more sensitive to the G1, G2, and G3 genetic coefficients. The calibration results are satisfactory, as shown in Table 3. The CERES-Barley model has been validated for 2019-20. The validation results, as shown in Tables 4, 5, 6 and 7 were also found to be satisfactory. As a result, a well-calibrated and validated CERES-Barley model can be developed for predicting crop growth, phenology, potential, and actual yield. Models were run by adjusting the seven genetic coefficients shown in Table, and the values of simulation results for anthesis, physiological maturity, LAI, and grain yield are shown in Table 3.

Table 3 : Evaluate the genetic coefficient of Barley varieties, grown under different environments used in CERES-Barley model.

Coffs.	Model's Parameter	BH393	BH902	BH946	BH885
P1V	Days, optimum vernalizing temperature, required for vernalization	10	28	25	10
P1D	Photoperiod response (% reduction in rate/10 h drop in pp)	88	45	48	43
P5	Grain filling (excluding lag) phase duration (^{o}C.d)	450	580	520	550
G1	Kernel number per unit canopy weight at anthesis (#/g)	25	32	22	38
G2	Standard kernel size under optimum conditions (mg)	46	52	59	48
G3	Standard, non-stressed mature tiller wt (incl grain) (g d wt)	1.3	3.0	4.5	1.6
PHINT	Interval between successive leaf tip appearances (^{o}C d)	98	90	95	90

Duration of Days to anthesis

The evaluation of observed and simulated anthesis days are shown in Table 4. According to the findings, the actual duration of anthesis ranged from 80 (D_4V_1) to 100 (D1V4) days. Similarly, the model's predicted duration ranged from 75 (D_4V_1) to 104 (D_1V_3) days. Under all growing conditions and with all varieties, the days to anthesis deviation ranged from -5 (D_4V_1) to +7 (D_1V_3). The positive value of deviation denotes the model's overestimation of anthesis days, while the negative value of deviation denotes the model's underestimation of anthesis days. The RMSE value for days to anthesis is 1.12, indicating that the simulated values deviate less from the observed values. A lower RMSE value indicates that the model performed well in this parameter. During the crop season 2019-20, the observed and simulated values of all four varieties in various growing environments were very close to the 1:1 line which showed the over estimation of model and confirms the positive MBE(Fig 1a). Under all the treatments % error varied between -6.3(D_4V_1) to 7.2(D_1V_3).

The MAE(0.25), MBE(0.25), R(0.93) and PE(1.07) simulated for anthesis days indicating good agreement between actual and predicted model data.

Duration of Physiological Maturity days

The evaluation of observed and simulated Physiological maturity days are shown in Table 4. The results tell that the actual duration of maturity varied from 112 (D_3V_4) to 139 (D_1V_4) days. Similarly, the model's predicted duration ranged from 112 (D_4V_3), (D_4V_4) to 141 (D_1V_2) days. Under all growing conditions and for all varieties, the days to maturity departure ranged from -9 (D_4V_1) to +8 (D_1V_2). The positive value of deviation denotes the model's overestimation of maturity days, while the negative value denotes the model's underestimation of maturity days. Days to maturity has an RMSE of 0.75, indicating that the model performed well in this parameter. In the crop season 2019-20, the observed and simulated values of all four varieties in different growing environments were very close to the 1:1 line which showed the underestimation of model and confirms the negative MBE (Fig 1b). The percent error ranged from -8.0 (D_4V_1) to 6 (D_1V_2) under all the treatments.

The MAE(0.18), MBE(-0.18), R(0.95) and PE(0.59) simulated for maturity days are in good agreement with observed values and indicate that actual and predicted model data are in good agreement.

Table 4: Observed and simulated value of days to Anthesis and Physiological maturity in Barley varieties under different growing environments

Treatments	Anthesis				Physiological maturity			
	Observed (O)	Simulated (P)	Deviation (P-O)	Error %	Observed (O)	Simulated (P)	Deviation (P-O)	Error %
D1V1	99	96	-3	-3	130	129	-1	-0.8
D1V2	98	103	5	5.1	133	141	8	6
D1V3	97	104	7	7.2	139	140	1	0.7
D1V4	100	103	3	3	138	139	1	0.7
D2V1	95	91	-4	-4.2	128	123	-5	-3.9
D2V2	97	98	1	1	132	134	2	1.3
D2V3	98	99	1	1.4	132	133	1	0.8
D2V4	98	97	-1	-1	135	132	-3	-2
D3V1	86	84	-2	-2.3	118	114	-4	-3.7
D3V2	93	92	-1	-1.1	124	124	0	0
D3V3	94	93	-1	-1.4	119	122	3	2.2
D3V4	94	91	-3	-3.2	122	123	1	1.1
D4V1	80	75	-5	-6.3	112	103	-9	-8
D4V2	83	85	2	2.4	113	115	2	2.1
D4V3	84	85	1	1.2	114	112	-2	-2
D4V4	86	82	-4	-4.7	115	112	-3	-2.3
Observed Mean	**92.63**				**125.25**			
Simulated Mean	**93.05**				**124.6**			
R	**0.93**				**0.95**			
MAE	**0.25**				**0.18**			
MBE	**0.25**				**-0.18**			
RMSE	**1.12**				**0.75**			
PE	**1. 07**				**0.59**			

*Whereas MAE (Mean absolute error), MBE (Mean bias error), RMSE (Root mean square error), R (correlation) and PE (Percent error)

Table 5: Observed and simulated value of LAI (Leaf Area Index) and Grain Yield (Kg/ha) in Barley varieties under different growing environments

Treatments	LAI				Grain yield kg/ha			
	Observed (O)	Simulated (P)	Deviation (P-O)	Error %	Observed (O)	Simulated (P)	Deviation (P-O)	Error %
D1V1	6.4	7.2	0.8	12.3	5249	4854	-395	-7.5
D1V2	6.6	7	0.4	6.1	4543	3668	-875	-19.3
D1V3	6.3	7.6	1.3	20.6	5291	4448	-843	-15.9
D1V4	5.8	6	0.2	3.4	4499	3644	-855	-19.0
D2V1	5.9	5.1	-0.8	-13.6	4125	3435	-690	-16.7
D2V2	4.2	3.3	-0.9	-21.4	4571	4769	198	4.3
D2V3	3.2	3.5	0.3	9.4	4087	3847	-240	-5.9
D2V4	3.2	2.8	-0.4	-12.2	4711	5239	528	11.2
D3V1	3.1	2.3	-0.8	-25.8	5226	4825	-401	-7.7
D3V2	4.5	3.5	-1	-22.2	4016	4858	842	21.0
D3V3	4.1	3.8	-0.3	-7.3	5101	4867	-234	-4.6
D3V4	3.2	2.6	-0.6	-18.8	5015	4924	-91	-1.8
D4V1	5.7	5.1	-0.6	-10.5	4815	6083	1268	26.3
D4V2	5.2	6	0.8	15.4	3735	4972	1237	33.1
D4V3	5.2	6.5	1.3	25	4371	5179	808	18.5
D4V4	4.2	4.3	0.1	2.4	4353	5158	805	18.5
Observed Mean	**4.84**				**4606.8**			
Simulated Mean	**4.72**				**4673.13**			
R	**0.92**				**0.23**			
MAE	**0.01**				**66.31**			
MBE	**-0.01**				**66.31**			
RMSE	**0.04**				**265.25**			
PE	**0.51**				**5.75**			

*Whereas MAE (Mean absolute error), MBE (Mean bias error), RMSE (Root mean square error), R (correlation) and PE (Percent error)

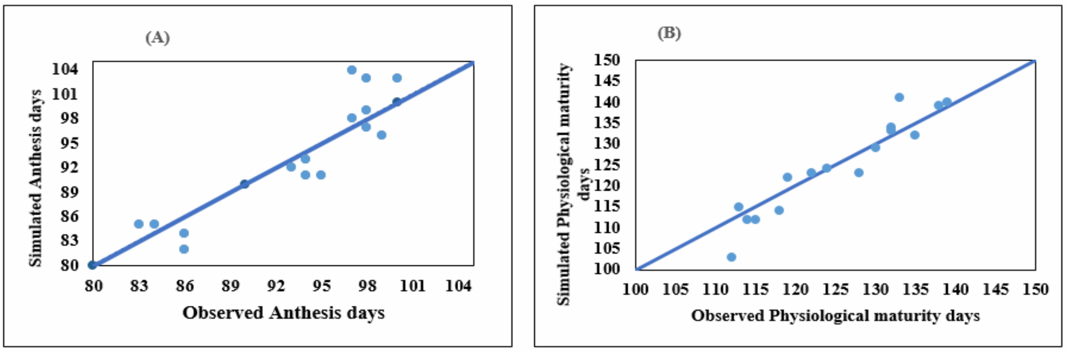

Fig. 1 : Comparison of simulated and observed Anthesis days (A) and physiological maturity (B) of barley under different growing environments during 2019-20

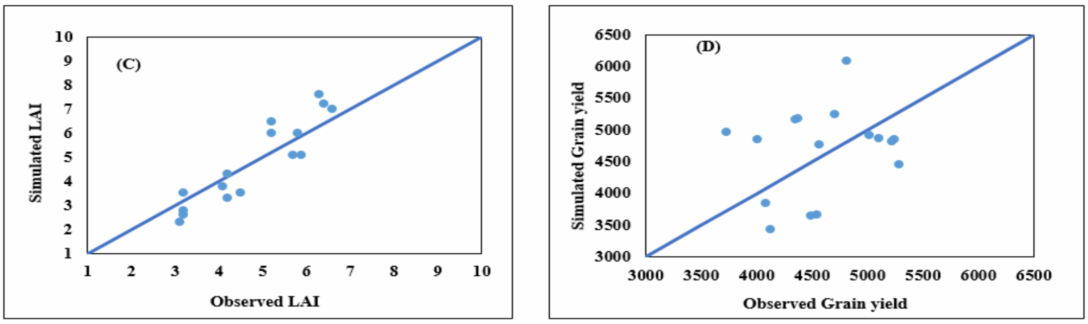

Fig. 2 : Comparison of simulated and observed LAI (C) and Grain yield (D) of barley under varying growing environments during 2019-20

Maximum LAI (Leaf Area Index)

The evaluation of observed and simulated maximum LAI, are presented in Table 5. The actual maximum LAI ranged from 3.1 (D_3V_1) to 6.6 (D_1V_2), while the model predicted maximum LAI ranged from 2.3 (D_4V_3) to 7.6 (D_1V_3). Under all growing environments and for all varieties, the maximum LAI deviation ranged from -1 (D_3V_2) to +1.3. (D_1V_3 & D_4V_3). The positive values of deviation in crop sown on the first fortnight of November and the second fortnight of December (except in D_4V_1) indicate an overestimation of maximum LAI, while the negative values of deviation in crop sown on the second fortnight of November (except D_2V_3) and the first fortnight of December illustrate an underestimation of maturity days by the model. The RMSE value for maximum LAI is 0.04, indicating that the model did a good job estimating maximum LAI. In the crop season *rabi* 2019-20, the observed and simulated values of all four varieties in various growing environments are nearly identical majority of predictions are below the 1:1 line, which showed the underestimation of model and confirms the negative MBE (Fig. 2C).Under all the treatments percentage error varied between -25.8 (D_3V_1) to 25 (D_4V_3).

The values of various statistical measures simulated for maximum LAI; MAE(0.01), MBE(-0.01),R(0.92) and PE(0.51) were in good agreement with the observed values and were within 10% of observed values, indicating good agreement between actual and predicted model data.

Grain yield

The evaluated observed and simulated grain yield, are presented in Table 5. The results showed that the actual grain yield ranged from 3737 kg/ha (D_4V_2) to 5291 kg/ha (D_1V_3) while the grain yield predicted by model ranged from 3435 kg/ha (D_2V_1) to 6083 kg/ha (D_4V_1). The grain yield departure ranged from -875 (D_1V_2) to +1268 (D_4V_1) in all growing environments and for all varieties. The positive value of deviation in crop sown on 1st fortnight of December and 2nd fortnight of December (except in D_3V_1, D_3V_3 and D_3V_4) stipulate the overestimation of grain yield and negative values of deviation in crop sown on 1st fortnight of November and 2nd fortnight of November (except D_2V_2 and D_2V_4) shows the under estimation of grain yield by model. The RMSE value for grain yield was 265.25, indicating that the model's performance or efficiency in predicting grain yield is within acceptable bounds. In the crop season 2019-20, the observed and simulated values of all four varieties in different growing environments were very close(Fig 2d). Under all the treatments % error varied between -19.3(D_1V_2) to +33.1 (D_4V_2).

The values of various statistical measures; MAE(66.31), MBE(66.31) and PE(5.75) simulated for grain yield is in good agreement with the observed values.

Conclusion

During the calibration process, the crop developments and phenological stages were found more sensitive to the P1V, P1D and PHINT genetic coefficients and crop growth or yield components were found more sensitive to G1, G2, and G3 genetic coefficients. The CERES-Barley model results for anthesis days were higher than the actual observed results and hence it overestimated anthesis days and for physiological maturity days were lower than the actual observed results and hence underestimated maturity days on comparison with the actual observed values. The Predicted day to anthesis showed PE (1.07), RMSE (1.12) and the predicted day to physiological maturity showed PE (0.59), RMSE (0.75) , all of which were within ± 10 per cent of observed values indicating a good agreement between actual and predicted model data. The CERES-Barley model results for maximum leaf area index were lower than actual observed results, implying that LAI was underestimated, and the CERES-Barley model results for grain yield were higher than actual observed results, implying that grain yield was overestimated. The predicted value of max. LAI showed PE (0.51) and RMSE (0.04), which were within 10% of the observed values and indicated that the predicted values were in good agreement with the observed values. The Predicted value of grain yield showed PE (5.75) was within 10% of the observed values and indicating that the predicted values were in good agreement with the observed values. But high RMSE (265.25) and MBE (66.31) showed low model performance in the estimation of grain yield.

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Conflict of Interest: None .

References

Abera, E.A. (2019). Calibration and validation of CERES-wheat in DSSAT model for yield simulation under future climate in Adet, North Western Ethiopia. *African Journal of Agricultural Research*, **14**(8), 509-518.

Aziz, M., Tariq, M., Nangia, V. and Ishaque, W. (2016). Optimization of Wheat and Barley Production under Changing Climate in Rainfed Pakistan Punjab. A Crop Simulation Modeling Study. *Annals of Arid Zone,* **55**(3&4), 1-13.

ICAR-IIWBR, (2019). Director's Report of AICRP on Wheat and Barley 2018-19, Ed, G.P. Singh. ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana, India, P 72.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D. and Hunt, L.A. (2003). The DSSAT Cropping System Model. *European Journal of Agronomy*, **18**, 235-265.

Jones, J.W., Tsuji, G.Y., Hoogenboom, G., Hunt, L.A., Thorntow, P.K., Wilkens, P.W., Imamura, D.T., Bowew, W.T. and Singh, U. (1998). Decision support system for agrotechnology transfer, DSSAT v3. Understanding Options for Agricultural Production, pp.157-177.

Mamta (2020). Development of integrated model and validation of DSSAT for wheat. *Ph.D. thesis*, CCSHAU, Hisar.

Mavromatis, T., Boote, K.L., Jones, J.W., Irmak, A., Shinde, D. and Hoogenboom, G. (2001). Developing Genetic Coefficients for Crop Simulation Models with Data From Crop Performance Trials. *Crop Science*, **41**, 40–51.

Ramawat, N. (2006). Simulation and validation of ceres-maize and ceres-barley models. *Phd. Thesis*, Chaudhary sarwan kumar Himachal Pradesh Krishi Vishvavidyalaya Palaampur, (H.P.).

Ramawat, N., Sharma, H.L. and Kumar, R. (2009). Simulating sowing date effect on barley varieties using ceres barley model in north Western Himalayas. *Indian Journal of Plant Physiology*, **14**(2), 147-155.

Ritchie, J.T., Singh, U., Godwin, D.C. and Bowen, W.T. (1998). Cereal growth, development and yield. *Understanding Options For Agricultural Production,* pp. 79-98. Kluwer Academic Publishers.

Rotter, R.P., Palosuo, T., Kersebaum, K.C., Angulo, C., Bindi, M., Ewert, F., Ferrise, R., Hlavinka, P., Moriondo, M., Nendel, C., Olesen, J.E., Patil, R,H., Ruget, F., Takac, J. and Trnka, M.(2012). Simulation of spring barley yield in different climatic zones of Northern and Central Europe, A comparison of nine crop models. *Field Crops Research*, **133**, 23–36.