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PERFORMANCE EVALUATION OF THE DSSAT-CERES-WHEAT MODEL UNDER WESTERN HARYANA AGROCLIMATIC CONDITIONS

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SUMMARY

The DSSAT (Decision Support Systems for Agrotechnology Transfer) crop growth model, specifically the CERES-Wheat model (v4.7.5), was used to simulate impacts of weather parameters on crop growth and yield. The study was conducted during *Rabi* seasons of 2017-18 and 2018-19 on Wheat crop at research farm, Department of Agricultural Meteorology, CCSHAU, Hisar. The main objective of this study was to evaluate wheat phenological stages and yield. The model was calibrated by using 2017-18 data and tunned their genetic coefficient and further validated with consecutive year 2018-19 data. Field experiment were layed out under three sowing dates *viz*. 1st week of November (D1), 3rd week of November (D2) and 1st week of December (D3) of four varieties WH-1105 (V1), HD-3086 (V2), HD-2967 (V3) and WH-1080 (V4) and tested on split plot design with three replications. The crop grain yield, biological yield, Harvest Index (HI), Leaf Area Index (LAI), days of anthesis and physiological maturity had been used for calibration and validation purpose. To evaluate CERES-Wheat model performance, different statistical metrics were used viz., Mean, Standerd Deviation (SD), Correlation (r), Mean Absolute Error (MAE), Mean Bias Error (MBE), Root Mean Square Error (RMSE), Percent Error (PE) and Index of Agreement (D). RMSE for the days of anthesis, days of physiological maturity, LAI, grain yield, biological yield and HI shown 9.44, 5.57, 0.32, 709.89, 1328.09 and 0.05, respectively. Index of agreement (D) for the days of anthesis, days of physiological maturity, LAI, grain yield, biological yield and HI shows 0.998, 0.999, 0.996, 0.996, 0.998 and 0.996, respectively. The results obtained from the DSSAT model may be helpful to simulate the effect of climate change on wheat crop. The model has capability for optimum wheat crop management, phenology prediction and future yield estimation. The model may also be used to improve and evaluate the current practices of wheat growth management to enhance wheat production.

Key words: Wheat, DSSAT, validation, calibration, genetic coffiecent and straw yield

Agriculture plays a key role in the economy of India. 57 % of Indian population for their livelyhood are engaged in agriculture and allied activities and it contributes 17.2% to the country's Gross value added. (Khan *et al.*, 2009). Wheat is the major staple food crop and play role to satisfy food demand globally. Wheat (*Triticum aestivum* L.) cultivation occurred around 217 mha highest acreage among all crops with an annual production of 731 mt. India, being blessed and enriched with a diverse agroecological conditions and the second largest producer of wheat worldwide. In India, total area under wheat cultivation is 30 mha and production was 99.70 mt about 14 % of global area and 13.6 % of global production under wheat cultivation. In Haryana cultivated area under wheat is 8.36 % of total cultivated area of India. Haryana is ensuring not only food security but also nutrition security. The International Panel of Experts on Global Climate Change (IPCC, 2007a, b) has provided evidence in favor of the reality of climate change. Global mean surface temperatures for 2046–2065 and 2081-2100 are projected to be in the range of 1-2 and 1-3.7 °C, respectively, based to the Five Coupled Inter-Comparison Project (CMIP5) model. Seasonal and daily variations in weather are chief determinants of crop growth and yield. Crop simulation models have capability to envisage crop growth response to weather, soils and crop management. The extent of the weather influence on crop yield depends not only on the magnitude of weather variables but also on weather distribution pattern over the full crop season. Hence, predicting crop yield using weather variables is foremost important (Azfar*et al.,* 2015). The validation of model was carried to test model applicability under variable thermal environments of Haryana for wheat growth and yield attributes. Considering the relationships between climate changes with crop production will help tactical decision for future agricultural adaptation. Air temperature and soil surface temperature were the supreme climatic factors that shape the key phenophases of spring wheat. Crop growth simulation models are quantitative toolbased on scientific knowledge that can evaluate the effect ofclimatic, edaphic, hydrological and agronomic factors on cropgrowth and yield. In addition to being calibrated and validated for use in wheat producing environments, the model can be extended for use in studies on the effects of climate change and natural resource management. The model performance was evaluated using % of error and RMSE and other statistical parameter and was able to predict the growth parameters like days to anthsis, day to maturity and grain yield with reasonably good accuracy.

MATERIALS AND METHODS

Experiment was conducted in the field of research farm, Department of Agricultural Meteorology, CCS HAU Hisar, Haryana during the period on 2017-18 and 2018-19 in the *Rabi* season. The field area was located adjacent to Agro meteorological observatory at 29°10´ N, 75°46´ E and 215.2 m latitude, longitude and altitude, respectively. Total thirty-six plots were tested in split plot design under three replications in three dates of sowing environment with four varieties in such a manner that main plots treatments consisted three planting dates *viz.* 1st week of November (D1), 3rd week of November (D2) and 1st week of December (D3) and in sub-plots consisted of four varieties WH-1105 (V1), HD-3086 (V2), HD-2967 (V3) and WH-1080 (V4).

DSSAT Model

Crop simulation models for more than 42 crops are included in the Decision Support System for Agrotechnology Transfer (DSSAT). The tools include application programs, utilities, database management systems for soil, weather, crop management, and experimental data. Jones *et al.*, (2003) and Hoogenboom *et al.*, (2019) describe how crop simulation models represents soil-plant-atmosphere dynamics in terms of growth, development and yield. Many applications at various temporal and spatial scales have made use of DSSAT and its crop simulation models. This covers water consumption, greenhouse gas emissions, on-farm and precision management, regional evaluations of the effects of climate variability and change, gene-based modeling and breeding selection, and long-term sustainability through the balances of soil organic carbon and nitrogen (White *et al.*, 2008 and Ottman *et al.*, 2013). Daily weather reports, data on the surface and profile of the soil, and comprehensive crop management are all inputs needed by the crop models. Crop species files, which are supplied by DSSAT, and cultivar or variation information, which the user must supply, define crop genetic information. Through the simulation of a bare fallow phase, simulations might begin at planting or before planting. Depending on the procedure and crop model, these simulations are run at a daily or, in certain situations, hourly time steps. At the end of each day, the crop’s vegetative and reproductive development stages are updated together with the plant and soil water, nitrogen, phosphorus, and carbon balances are updated. Users can compare simulated and observed results by using DSSAT’s ability to evaluate crop model outputs using experimental data. This is essential before using a crop model in any way, particularly if the model’s output is being used to inform recommendations or judgments in the real world. To evaluate a crop model, input the user’s minimum data, run the model and compare the results with data that was observed. DSSAT provides users with information to quickly assess new products, techniques and crops for adoption by simulating likely results of crop management initiatives (Ritchie *et al.*, 1998).

Crop management file

All the information needed to simulate different experiment treatments (planting season, location, and irrigation), conditions (field characteristics, data from soil analysis, initial soil conditions, irrigation, fertilizer, and harvest management), and simulation control is included in the crop management file.

Weather file

For the whole growing season, the model needs daily meteorological data. To set up and execute the simulation, the model needed the following parameters: daily solar radiation (SRAD MJ/m2/d), maximum and minimum temperatures (Tmax and

TABLE 1

Layer- wise soil information for input of CERES-Wheat model

S. No.	Soil parameter	Soil depth (cm)				
		0-15	15-30	30-60	60-90	90-105
1.	Master horizon	AP	A1	B1	B2	B2
2.	Clay (%)	16	22	24	28	29
3.	Silt (%)	15	17	22	21	20
4.	Stones (%)	-99	-99	-99	-99	-99
5.	pH in water	8.1	8.4	8.3	8.3	8.2
6.	Cation exchange capacity (c mol/kg)	11.4	12.4	13.4	17.4	17.7
7.	Total Nitrogen (%)	-99	-99	-99	-99	-99
8.	Lower limit of drainage	0.09	0.10	0.11	0.11	0.11
9.	Upper limit of drainage	0.183	0.196	0.203	0.215	0.218
10.	Saturation	0.41	0.41	0.41	0.41	0.41
11.	Bulk Density (g/cm^3)	1.49	1.51	1.50	1.50	1.50
12.	Saturated hydraulic conductivity (cm/h)	2.59	2.59	2.59	2.59	2.59
13.	Root growth factor (0.0-1.0)	1.0	0.65	0.42	0.25	0.16

TABLE 2

Categorization of genetic coefficients of CERES-Wheat DSSAT model (4.7.5)

Coffs.	Model's Parameter	V1	V2	V3	V4
P1V	Days, optimum vernalizing temperature, required for vernalization	19	30	30	29
P1D	Photoperiod response (% reduction in rate/10 h drop in pp)	86	57	50	58
P5	Grain filling (excluding lag) phase duration (°C.d)	690	695	700	720
G1	Kernel number per unit canopy weight at anthesis (#/g)	20	20	20	20
G2	Standard kernel size under optimum conditions (mg)	36	45	40	43
G3	Standard, non-stressed mature tiller wt (incl grain) (g d wt)	1.0	3.4	3.0	3.5
PHINT	Interval between successive leaf tip appearances (°C d)	70	80	70	90

Tmin, respectively), and precipitation (mm) (Holden *et al.*, 2003). Therefore, the department of agricultural meteorology at CCS HAU, Hisar provided the meteorological data for 2017–18 and 2018–19 (October–March). After being processed in Microsoft Excel 2007, the meteorological data was loaded into DSSAT's WeatherMan.

Soil file

According to Prasad *et al.*, (2015), soil samples were collected from every experimental replicate plot at varying depths from 0 to 15, 15 to 30, 30 to 60, 60 to 90, and 90 to 105 cm from the experimental field prior to the cropping period. The soil was then analyzed for pH, electrical conductivity (EC), percentage of total carbon and nitrogen, cation exchange capacity (CEC), and moisture levels. For every soil layer, the following soil data are needed: soil bulk density (BD, g/cm3), root distribution weighing factor (WR, unit less), saturated water content (SAT, cm3/cm3), drained upper limit of soil water content (DUL, cm^3/cm^3), lower limit of plant extractable water (LL, cm^3 /cm^3), and the initial soil water content at start of simulation (cm^3 /cm^3). The above information were computed and then collected through the department of soil science, CCSHAU, Hisar as indicate in the Table 1. Physical soil structures were also noted for each depth. The SBuild tool of the CERES-Wheat model was used to insert the soil data. On the basis of physio-chemical characteristics of the soil, different soil variable were used to automatically determine, such as the saturated soil water content, field capacity, permanent wilting point, initial soil water content at the beginning of the soil water balance simulation, and relative root weighing factor (Hoogenboom *et al.*, 2012).

Calibration and validation of model

Model calibration entails modifying certain model parameters and coefficients to relationships such that the model operates at the intended location. The model requires seven cultivar exclusive genetic coefficients.

TABLE 3

Various statistical test criteria involved for evaluation of CERES-Wheat model

S. No.	Statistical parameter	Formula	Reference
1.	Mean absolute error (MAE)	$\text{MAE} = \sum_{i-1}^{n} \left[\lvert P_i - O_i \rvert \right] / n$	Langensiepen *et al.,* (2008)
2.	Mean bias error (MBE)	$\text{MBE} = \sum_{i-1}^{n} \left[P_i - O_i \right] / n$	Panda *et al.,* (2003)
3.	Root mean square error (RMSE)	$\text{RMSE} = \left[\sum_{i=1}^{n} (P_i - O_i)^2 / n \right]^{1/2}$	Panda *et al.,* (2003)
4.	Percent Error %	PE = (RMSE / Observed mean) × 100	Panda *et al.,* (2003)
5.	Error %	E = {(P – O) / O} × 100	Panda *et al.,* (2003)

Crop and the circumstances surrounding it model calibration concerning soil and climate conditions is necessary. The model calibration was involved minimum data sets for calculations include phenology, growth and yield parameters (maximum LAI, grain yield and biological yield). The process of identifying the genetic coefficients involves executing the model with a range of values for each coefficient, until the simulated and observed values agreed with each other to the desired extent. Iterations for the coefficients were stopped when the agreement reached ±20 %. CERES-Wheat module was calibrated for (2017-18) and derived. They are validated for second year (2018-19) in field experiment data for different growth and yield parameters. All four genotype have different genetic coefficients, which were adjusted as described in Table2. Since crop genetic input data which elucidates how a cultivar reacts to its surroundings throughout its lifecycle, it was obtained interactively through the application of Hunt's method. (Hunt, 1993). The genetic coefficients in the genetic file were manually adjusted during calibration by comparing phenology and growth simulation results with observed results until the cultivar parameter modification gave the best performance where the simulated values were closest to the observed values (Andarzian *et al.,* 2015, Kumar *et al.,* 2014). The genetic coefficients were fixed and used for validation and further model application.

Model evaluation

The model predicts the timing of various phenological stages from emergence to physiological maturity, daily growth of plant components, LAI, final yield, yield components and harvest index. Based on a comparison of the statistical properties of simulated and observed data, the model performance evaluation approach was developed. Using an Excel worksheet and the statistical component of the DSSAT software, the observed yield means were compared. The details of these coefficients are given in Table 2. The performance of model was evaluated using statistical measures as given by Willmott (1982). These include mean absolute error (MAE), mean bias error (MBE) and root mean square error (RMSE) which was calculated as shown in the table 3. Furthermore, Using an Excel worksheet, the correlations (r) to equate the simulated and observed yields were also calculated.

RESULTS AND DISCUSSION

Crop phenology

Treatment wise error percentage for days to athesis was ranged between -2.8 (D3V3) to +18.9 (D1V1).The comparison of observed and simulated days to anthesis is presented Table 4. Highest error percentage was recorded under V_1 in all date of sowing variety as compared to other treatments and model shows over estimation for almost of treatment majority of predictions are above the 1:1 line. The observed duration of days to anthesis varied between 101 (D3V4) to 111 (D1V3) days among different planting date and varieties during 2018-19. Similarly the corresponding values as the simulated by the model ranged 103 (D3V3) to 130 (D1V1) days for anthesis. Various statistical simulation model test criteria were worked out for days to anthesis results are presented in Table 4. The simulated days of anthesis showed good agreement with the observed values with relatively low simulated standard deviation,(112.50), mean absolute error (MAE) (0.54), mean bias error (MBE) (0.54), root mean square error (RMSE) (9.44) and percent error (PE) (8.92) for days to anthesis. Index of agreement (D) was also found better with the value 0.998 for days to anthesis. Similar results also shown by Patel *et al.*,(2010) and Biswas (2013). Model confirms the positive MBE (Fig. 1a). All prediction for days to anthesis was within ± 20 % of observed values

Treatment wise error percentage for days to physiological maturity was ranged between -0.7 (D2V3) to +7.8 (D1V1). The comparison of observed and simulated days to physiological maturity is presented Table 4. The observed duration of days to physiological maturity varied between 154 (D1V1) to 135 (D3V4) days among different planting date and varieties during 2018-19. Similarly the corresponding values as the simulated by the model ranged 139 (D3V2) to 166 (D1V1) days for physiological maturity. Highest error percentage was recorded under V1 in all date of sowing variety as compared to other treatments and model shows over estimation for almost of treatment.Various statistical simulation model test criteria were worked out for days to physiological maturity and results are presented in Table 4. The simulated days of physiological maturity showed good agreement with the observed values with relatively low simulated standard deviation, mean absolute error (MAE) (0.32), mean bias error (MBE) (0.32), root mean square error (RMSE) (5.57) and percent error (PE) (3.80) for days to physiological maturity respectively. Index of agreement (D) was also found better with the value 0.999 for days to physiological maturity. The majority of predictions are above the 1:1 line, which showed the overestimation of model for almost all the treatment and confirms the positive MBE (Fig. 1b). All prediction for days to physiological maturity was within ± 10 % of observed values Similar results also shown by Pal *et al.*, (2015).

TABLE 4

Test criteria in evaluation of model by CERES-Wheat model simulated days to anthesis, physiological maturity and LAI from their observed

Treatment	Anthesis (days)			Physiological maturity (days)			Maximum LAI		
	Oi	Pi	Error %	Oi	Pi	Error %	Oi	Pi	Error %
D1V1	109	130	18.9	154	166	7.8	2.97	3.40	14.44
D1V2	108	112	4.0	152	155	2.0	2.95	3.30	11.86
D1V3	111	110	-0.6	156	156	0.0	3.02	3.60	19.32
D1V4	106	113	6.6	150	156	4.2	2.98	3.10	4.08
D2V1	107	125	16.5	149	158	6.3	2.74	3.00	9.29
D2V2	105	110	4.4	148	148	0.0	2.70	2.50	-7.55
D2V3	106	109	2.8	151	150	-0.7	2.78	2.50	-9.91
D2V4	104	111	7.1	146	149	2.3	2.66	2.20	-17.15
D3V1	104	116	11.9	140	147	5.3	2.40	2.40	-0.17
D3V2	103	104	0.6	137	139	1.5	2.39	2.12	-11.31
D3V3	106	103	-2.8	142	141	-0.5	2.43	2.23	-8.05
D3V4	101	105	4.0	135	140	3.4	2.41	2.10	-12.87
Observed mean			105.83		146.56				2.70
SDo			2.71		6.74				0.25
Simulation mean			112.33		150.42				2.70
SDs			8.09		8.15				0.54
r			0.50		0.86				0.90
MAE			0.54		0.32				0.00
MBE			0.54		0.32				0.00
RMSE			9.44		5.57				0.32
PE			8.92		3.80				11.98
Index of agreement (D)			0.998		0.999				0.996

Whereas , Pi = Simulated values Oi = Observed values, SDs (Standard deviation of simulated value), SDo (Standard deviation of observed value), Mean absolute error (MAE), Mean bias error (MBE), Root mean square error (RMSE), r (correlation) and PE (Percent error), D1 = 1st week of November, D2 = 3rd week of November D3 = 1st week of December,V1 = WH-1105, V2 = HD-3086, V3 = HD-2967 V4 and WH-1080 (V4).

Maximum LAI

The values of error percent in the model simulated maximum LAI from their correspondingly observed values in wheat crop are presented in Table 4. The observed LAI varied from 2.41 (D3V4) to 3.02 (D1V3)among different dates of sowing and variety respectively. Similarly the corresponding values as the simulated for LAI by the model ranged 2.10(D3V4) to 3.60 (D1V3).Error percent ranged between -17.15 (D_2V_4) to 14.44 (D_1V_1) in LAI. Simulation performance of different treatment combinations was reasonably good.Various model test criteria were worked out for LAI and results are presented in Table 4. The simulated values for LAI also showed good agreement with the observed values with low simulated standard deviation, mean absolute error (MAE) (0.00), mean bias error (MBE)(0.00), root mean square error (RMSE)(0.55) and percent error (PE) (11.98). Index of agreement (D) for LAI was found better with the value of 0.996. The majority of simulated values were nearer to the 1:1 line which shows the equally underestimation and overestimation of model and confirms the positive MBE (Fig. 1c). Similar results also shown by Biswas (2013).

Grain yield

Treatment wise error percentage for grain yiled was ranged between -10.0 (D3V4) to +18.5 (D1V2). The comparison of observed and simulated days to anthesis is presented Table 5. The observed grain yield varied between 5710kg/ha (D3V4) to 6365kg/ha (D1V1) days among different planting date and varieties during 2018-19. Similarly the corresponding values as the simulated by the model ranged 5141kg/ha (D3V4) to kg/ha 7537 (D1V2). Various statistical simulation model test criteria were worked out for grain yieldresults are presented in Table 5. The simulated days for grain yield (kg/ha)showed good agreement with the observed values with low simulated standard deviation, mean absolute error (MAE) (21.85), mean bias error (MBE) (21.85), root mean square error (RMSE) (709.89), correlation (r) (0.94) and percent error (PE) (11.63), respectively. Index of agreement (D) for grain yield (kg/ha) was found better with the value of 0.996.All the prediction of biological yield was within ± 10 % of observed values. The majority of prediction was far away from the 1:1 line which showed the over estimation for early sown crop and under estimation of model for late sown crop (Fig. 1d). Model performance is good to moderate in predicting grain yield for all treatments.Choudhury *et al.,* (2018) aimed to evaluate the DSSAT (v4.6) crop model evaluation results showed closer estimation of crop growth duration, grain and biomass yields. Relationship between simulated and observed grain yields, at calibration and validation process are strong having higher correlation value.

Straw yield

The observed straw yield varied between 7580 (D_2V_2) kg/ha to 8080 (D_1V_3) kg/ha and simulated yield varied between 5572 (D2V_1) kg/ha to 8603 (D_1V_3) kg/ha. Error percent ranged for straw yield (kg/ha) lies between -6.4 (D_1V_3) to 26.5 (D_2V_1).

Biological yield

The values of error percent in the model simulated biological yield (kg/ha) from their correspondingly observed values in wheat crop are presented in Table 5. Error percent ranged for biological yield (kg/ha) lies between -17.32 (D_3V_2) to 7.84 (D_1V_3). Simulation performance of the model for all treatment combination was found satisfactory with minor over estimation in early and under estimation in delayed sown and timely sown.The comparison of observed and simulated biological yield (kg/ha) are presented in Table 5. The observed biological yield varied between 13435 (D_3V_4) kg/ha to 14430 (D_1V_3) kg/ha and simulated yield varied between 11138 (D_3V_4) kg/ha to 15562 (D_1V_3) kg/ha. The reasonable accuracy was found in yield prediction by the model. Various model test criteria were worked out for biological yield (kg/ha) results are presented in Table 5. The simulated days for biological yield (kg/ha) also showed good agreement with the observed values with low simulated standard deviation, mean absolute error (MAE) (63.15), mean bias error (MBE) (63.15), root mean square error (RMSE) (1328.09) correlation (r) 0.89 and percent error (PE) (9.57). Index of agreement (D)for biological yield (kg/ha) was found better with the value of 0.996.Model performance is good to moderate in predicting biological yield for all treatments. Similar finding were reported by Kassie *et al.,* (2016). All the prediction of biological yield was within ± 20 % of observed values. The majority of prediction was far away from the 1:1 line which showed the under estimation of model and confirms the negative MBE (Fig. 1e).

Harvest index

The values of error percent in the model simulated harvest index from their correspondingly

TABLE 5

Test criteria in evaluation of model by CERES-Wheat model simulated for grain yield (kg/ha), biological yield (kg/ha) and HI from their observed

Treatment	Grain yield (kg/ha)			Biological yield (kg/ha)			HI		
	Oi	Pi	Error %	Oi	Pi	Error %	Oi	Pi	Error %
D1V1	6365	7532	18.3	14145	13701	-3.14	0.45	0.50	11.11
D1V2	6360	7537	18.5	14130	14845	5.06	0.45	0.51	13.33
D1V3	6350	6959	9.6	14430	15562	7.84	0.44	0.47	6.82
D1V4	6175	6995	13.3	14025	14612	4.19	0.44	0.48	9.09
D2V1	6210	6815	9.7	13800	12387	-10.24	0.45	0.50	11.11
D2V2	6205	6939	11.8	13785	12985	-5.80	0.45	0.53	17.78
D2V3	6195	6178	-0.3	14085	13517	-4.03	0.44	0.46	4.55
D2V4	6020	6319	5.0	13680	12739	-6.88	0.44	0.50	13.64
D3V1	5900	5343	-9.4	13555	12703	-6.29	0.44	0.47	8.05
D3V2	5895	5329	-9.6	13540	11195	-17.32	0.44	0.48	10.34
D3V3	5885	5330	-9.4	13840	11973	-13.49	0.43	0.49	15.29
D3V4	5710	5141	-10.0	13435	11138	-17.10	0.43	0.51	20.00
Observed mean		6105.83			13870.83			0.44	
SDo		218.35			297.50			0.01	
Simulation mean		6368.08			13113.08			0.49	
SDs		891.44			1397.52			0.02	
r		0.94			0.89			0.56	
MAE		21.85			63.15			0.00	
MBE		21.85			-63.15			0.00	
RMSE		709.89			1328.09			0.05	
PE		11.63			9.57			11.74	
Index of agreement (D)		0.996			0.998			0.996	

Whereas , Pi = Simulated values Oi = Observed values, SDs (Standard deviation of simulated value), SDo (Standard deviation of observed value), Mean absolute error (MAE), Mean bias error (MBE), Root mean square error (RMSE), r (correlation) and PE (Percent error), D1 = 1st week of November, D2 = 3rd week of November D3 = 1st week of December,V1 = WH-1105, V2 = HD-3086, V3 = HD-2967 V4 and WH-1080 (V4).

observed values in wheat crop are presented in Table 5. The observed harvest index varied 0.43 (D3V3 and D3V4) to 0.450 (D1V1, D1V2, D2V1, and D2V2) among different dates of sowing. Similarly the corresponding values as the simulated for harvest index by the model ranged 0.46 (D2V3) to 0.53 (D2V2). All treatments in model simulation showed over estimation. Error percent ranged between 4.55 (D_2V_3) to 20.00 (D_3V_4). Simulation performance of different treatment combinations was reasonably good.Various model test criteria were worked out for harvest index and results are presented in Table 5 The simulated values harvest index also showed good agreement with the observed values with low simulated standard deviation, mean absolute error (MAE) (0.00), mean bias error (MBE)(000), root mean square error (RMSE)(0.05) and percent error (PE) (11.74) respectively. Index of agreement (D) for harvest index was found better with the value of 0.996. All the prediction of HI was within ± 20 % of observed values. The majority of prediction was far away and above from the 1:1 line which showed the over estimation of model (Fig. 1).

CONCLUSION

Performance of CERES-Wheat model on growth and yield of wheat varieties under different growing sub-tropical environment of Hisar, Haryana during *Rabi* season of 2017-18 and 2018-19. The validation results revealed that comparison of observed and simulated days to Days to anthesis, physiological maturity, Maximum LAI, Grain yield, Biological yield and HI were in satisfactory agreement. The RMSE and PE shows that the efficiency of model to predict

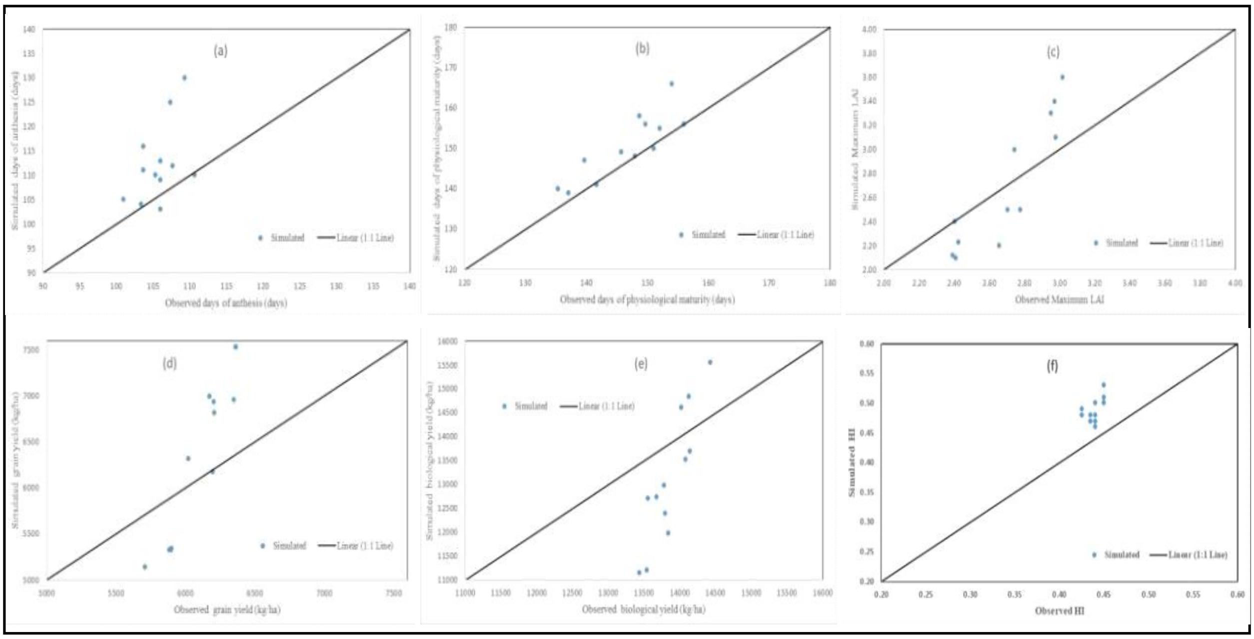

Fig. 1. Comparison of simulated and observed Days of anthesis(a) Days of physiological maturity(b), Maximum LAI(c), Grain yield(d), Biological yield (e) and HI (f) of wheat crop under varying planting time during 2018-19.

all growth and yield parapmeter. On the basis of outcome, farmers are suggested that late sown planting was not suitable for crop production for wheat crop in Sub-tropical region. The simulated biological yield and HI was underestimated and over estimated, respectively by the model. The simulated grain yield during for late sown crop was underestimated by the model. Simulation performance of the model was found satisfactory with reasonable agreement (±20 %) under different planting dates. The model has proven to be a useful tool for wheat crop management optimization, phenology prediction, and potential yield estimation.

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