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Research Paper

Simulation and validation of response of 'Shalimar wheat 2' (*Triticum aestivum*) to sowing dates and nitrogen levels under rainfed conditions using DSSAT-CSM-CERES-wheat model

SHAHID BASHIR DAR[1], RAIHANA HABIB KANTH[2], WASEEM RAJA[3], SHABIR AHMAD BANGROO[4], ZAHIDA RASHID[5] AND PARMEET SINGH[6]

Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Regional Research Station and Faculty of Agriculture, Wadura, Jammu and Kashmir 193 201

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ABSTRACT

A-2 year experiment was carried out at Wadura, Kashmir, Jammu and Kashmir during 2015–16 and 2016–17 in a split-plot design, keeping 3 sowing dates (15 October, 30 October and 15 November) in mainplots and 4 nitrogen levels (0 kg, 50, 100 and 150 kg N/ha) in subplots, to simulate the response of Shalimar Wheat-2 var. wheat (*Triticum aestivum* L.) to sowing dates and nitrogen levels under rainfed conditions using DSSAT-CSM-CERES-Wheat. The pooled results of 2 years revealed that the highest grain yield of 4.46 t/ha, straw yield of 8.30 t/ha and biological yield of 12.8 t/ha were obtained when sowing was done on 15th October. The grain, straw and biological yields decreased by 17.33, 12.58 and 14.25% with delay in sowing from 15 October to 15 November, respectively. Genetic coefficients of newly evolved wheat cultivar 'Shalimar Wheat 2' were generated for calibration and validation of model CERES-wheat Ver.4.6 (DSSAT). The DSSAT-CERES-Wheat model performed well, as revealed by high correlation coefficient (r), low root mean square error (RMSE) and low mean absolute percentage error (MAPE) in simulating the days to anthesis (r, 0.99; RMSE, 3.9; MAPE, 1.84), maturity (r, 0.97; RMSE, 3.9; MAPE, 1.51), leaf area index (r, 0.90; RMSE, 0.2; MAPE, 6.22), grain yield (r, 0.92; RMSE, 0.39; MAPE, 17.85), and biological yield (r, 0.89; RMSE, 1.03; MAPE, 7.71). Also, a good line of fit (1:1) was found between the simulated and observed grain yield with R^2 of 0.89.

***Key words*: CERES-wheat, Genetic coefficients, Nitrogen, Simulations, Sowing date, Yield

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the world's most widely cultivated food crop. It accounts for nearly 30% of global cereal production, covering an area of 220 million hectare (m ha) registering production of 781 million tonnes (USDA 2019). India cultivates wheat on 29.55 m ha area that accounts for 13.4% of global area with overall production of 101.20 million tones, i.e. 12.98% of wheat production (GOI, 2018). Crop production in dryland regions is mainly determined by precipitation and is extremely vulnerable to changes in precipitation patterns and amounts. In such water-limited environments soil-water content at sowing is important in determining wheat germination, emergence and plant establishment. Thus, the choice of sowing date is an important management option to optimize grain yield (Mukherjee, 2014). Nitrogen (N) fertilization practices on the other hand can provide a sufficient N supply for plants to achieve the potential yield allowed by the actual climatic conditions (Lemaire *et al.,* 2008; Jat *et al.*, 2013). Under rainfed agriculture, lack of water in the root zone can make the applied N unavailable to plant and subject to leaching and runoff later. Therefore, there is a need for a more demand-based application of N fertilizer depending on the absorption capacity of the soil and plant under the prevailing climatic and soil physic-chemical conditions.

Crop-simulation models can be utilized to evaluate management alternatives for increasing yield, considering regular seasonal fluctuations and climate-related risks and to

[1]**Corresponding author's Email**: sbd.agron@gmail.com
[1]Extension Officer, Agriculture Production and Farmers Welfare Department, Jammu and Kashmir (UT)-191 113; [2]Professor, Division of Agronomy, FOA, Wadura, Jammu and Kashmir 193 201; [3]Professor, Division of Agronomy, FOA, SKUAST-K.; [4]Assistant Professor, Division of Soil Science, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, FOH, Shalimar, Jammu and Kashmir 190 006; [5]Assistant Professor Dryland Agricultural Research Station, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir, [6]Programme Coordinator Krishi Vighan Kendra, Shopian, Sher-E-Kashmir University of Agricultural Sciences and Technology of Kashmir, J&K

extrapolate the experimental outcomes, both spatially and temporally. Simulation techniques provide a framework for supporting and validating research under varying agro-climatic conditions. The Decision Support System for Agrotechnology Transfer (DSSAT) is a comprehensive decision-support system that includes the Cropping System Model (CSM)-CERES-Wheat model (Hoogenboom *et al.,* 2010). The CSM-CERES-Wheat model can be used to simulate the growth and development of dryland and irrigated wheat across a range of latitudes in northern and southern hemispheres (Nain and Kersebaum, 2007). CERES-Wheat has the capacity to simulate the effects of cultivar, planting density, weather, soil water and nitrogen on the crop development and yield (Ghaffari *et al.,* 2001). CSM-CERES-Wheat allows users to compare simulated result with observed consequences. Validation of crop-dynamic model for any crop and any area to predict the crop-growth parameters as well as yield components in advance which are important for planning cropping system and crop management.

MATERIALS AND METHODS

A field experiment was conducted during the winter (*rabi*) season of 2015–16 and 2016–17 with different sowing dates and nitrogen levels at Regional Research Station and Faculty of Agriculture, SKUAST-K, Wadura, Kashmir (34^o 20 N, 74^o 24 E, 1,588 m above mean sea-level). The experiment was laid out in split-plot design with 3 sowing dates (D_1-15 October; D_2-30 October; and D_3-15 November) in main plots and 4 nitrogen levels (N_3) 0 (N_0) (N_1) 50 100 (N_3) and 150 kg N/ha) in subplots, replicated 4 times. The climate of the experimental site is temperate, characterized by moderately hot summers and very cold winters. The area receives 690 mm mean annual rainfall, most of which occurs during December–April. Wheat variety 'SW 2' was sown with seat rate 100 kg/ha at 23 cm spacing. All other agronomic practices were followed as per standard recommendations.

The DSSAT-CERES-Wheat (V 4.6) model, a part of DSSAT-cropping system model, was used for simulation. The model can simulate the growth and development of wheat across a range of latitudes, and has been documented extensively in both the northern and southern hemispheres (Jones *et al.,* 2003; Hoogenboom *et al.,* 2004; Timsina *et al.,* 2008; Arora *et al.,* 2007 Eajaz *et al.*, 2017). The model computes biomass accumulation as a function of radiation-use efficiency and photo-synthetically active intercepted radiation.

The model was run to simulate phenology (days taken to anthesis and maturity), leaf-area index, grain yield and biological yield, using set of data of 1 treatment of field experiment (15 October sowing) in the first experiment of the 2015–16 growing season. The genetic coefficients for a newly evolved cultivar 'Shalimar Wheat 2' (SW 2) were derived using iterations till a close synchrony was observed between observed and simulated phenology and yield of stress-free treatments (Table 1).

The model was evaluated by comparing the observed data and simulated data on various crop parameters. Different measures used to evaluate the performance of the model were correlation coefficient (r), root mean square error (RMSE), normalized RMSE, mean bias error (MBE) and mean absolute percentage error (MAPE) were computed as presented in Table 2. Besides, correlation and regression equations between the simulated and observed data were also worked out.

Analysis of variance was performed using Proc GLM procedure of SAS version 9.4 (SAS Institute, Inc., Cary, NC, USA) and significant mean differences were tested using Fisher's protected least significant difference (LSD) test at p=0.05.

RESULTS AND DISCUSSION

Grain, straw and biological yields

The grain, straw and biological yield (Table 3) were significantly higher in 15th October as compared to all other sowing dates. The highest pooled grain (4.46 t/ha), straw (8.30 t/ha) and biological (12.77 t/ha) yield were obtained when sowing was done on 15th October, which were significantly higher than 30th October and 15th November. The pooled grain, straw and biological yield decreased by 17.3, 12.6 and 14.2% from 15th October to 15th November, re-

Table 1. Genetic coefficients fitted for cultivar 'Shalimar Wheat 2'

Parameter	Calibrated value	Description
P1V	48	Days at optimum vernalization temperature required to complete vernalization
P1D	10	Percentage reduction in development rate in a photoperiod 10 h shorter than the optimum relative to optimum
P5	670	Grain-filling (excluding lag) period duration (GDD)
G1	21	Kernel number per unit canopy weight at anthesis/(g)
G2	44	Standard kernel size under optimum condition (mg)
G3	41.5	Standard non-stressed dry weight (total, including grain) of a single tiller at maturity
PHINT	80	Phyllochron interval (GDD).

Table 2. Statistical measures for model evaluation

Sl.No.	Statistical parameter	Formula	References
1.	Correlation coefficient	$\frac{\sum_{i=1}^{N}(O_i-\bar{O}\sum_{i=1}^{N}(P_i-\bar{P})}{\sqrt{\sum_{i=1}^{N}Oi-\bar{O})^2\sum_{i=1}^{N}(P_i-\bar{P})^2}}$	(Kirch, 2008)
2.	Root mean square error	$\sqrt{\frac{\sum_{i=1}^{N}(P_i-\bar{O})^2}{N}}$	(Thomann, 1982)
3.	Normalized root mean square error	$\sqrt{\frac{\sum_{i=1}^{N}(P_i-O_i)^2}{N}}\times 100/\bar{O}$	(Loague and Green, 1991)
4.	Mean bias error	$\frac{1}{N}\sum_{i=1}^{N}(P_i-O_i)$	(Panda *et al* 2003)
5.	Mean absolute percentage error	$\frac{1}{N}\sum_{i=1}^{N}\left\|100\frac{(P_i-O_i)}{O_i}\right\|$	(Panda *et al* 2003)

O_i and P_i are observed and predicted values respectively, $\bar{O}$ is the observed mean, $\bar{P}$ is the predicted mean

spectively. The decline in grain yield with delay in sowing may be due to shortening of the duration of each developmental phase and forced maturity of late-sown wheat (Table 3).

With the application of different nitrogen levels, the highest pooled grain of 4.53 t/ha, straw (8.75 t/ha) and biological (13.28 t/ha) yield were obtained when nitrogen was applied at 150 kg N/ha (N_3), which was significantly higher than the control and 50 kg N/ha, but remained statistically at par with 100 kg N/ha. The lowest grain, straw and biological yield were recorded in the lowest nitrogen level (0 kg N/ha). The lower grain yield in nitrogen-deficit treatments may be due to nitrogen stress resulting in severe physiological limitations like accelerated leaf senescence, damage to photosynthetic machinery and shortening of growth cycle, reduced carbon fixation and assimilate translocation or reduced grain set and development (Shahid and Ram, 2016). Moreover, the yield attributes like effective tillers, grains/ear and test weight were reduced, which were also responsible for reduced grain yields.

Table 3. Grain yield, straw yield and biological yields and of wheat as influenced by different sowing dates and nitrogen levels (pooled data of 2 years)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)
Sowing dates			
D_1 15th Oct.	4.46	8.30	12.77
D_2 30th Oct.	4.00	7.70	11.70
D_3 15th Nov.	3.69	7.26	10.95
SEm±	0.061	0.10	0.13
CD (P=0.05)	0.21	0.36	0.47
Nitrogen levels (kg N/ha)			
N_0 0	3.15	6.31	9.47
N_1 50	4.05	7.42	11.48
N_2 100	4.46	8.53	12.99
N_3 150	4.53	8.75	13.28
SEm±	0.07	0.10	0.13
CD (P=0.05)	0.20	0.31	0.38

Simulated and observed phenology and leaf-area index

The simulated and observed number of days taken to anthesis was 192 and 197 in 15 October, 178 and 182 in 30 October and 169 and 168 in 15 November (Table 4). The mean number of days taken to anthesis across different sowing dates and nitrogen treatments was 180 days after sowing (DAS) for the simulated data and 183 DAS for the observed data (Table 6) with a standard deviation (SD) of 10.1 and 12.3 days (d) and coefficient of variation (CV) of 5.6 and 6.7% for the simulated and observed days taken to anthesis. The model performance was found to be good in simulating the days to anthesis, as revealed by high correlation coefficient, r (0.99) and low RMSE (3.9 d), MAE (3.4 d), MBE (–3 d) and MAPE (1.84%) between the simulated and observed days taken to anthesis. Also, a good line of fit (1 : 1) was found between the simulated and observed days taken to anthesis with R^2 of 0.98 (Fig. 1).

Similarly, the simulated and observed number of days taken to maturity was 241 and 245 in 15th October, 229 and 233 in 30th October and 220 and 220 in 15th November (Table 6). The mean number of days taken to maturity across different sowing dates and nitrogen treatments was 230.1 days after sowing (DAS) for the simulated data and 234.1 DAS for the observed data (Table 4), with a standard deviation (SD) of 8.7 and 9.0 days (d) and coefficient of variation (CV) of 3.8 and 3.8% for the simulated and observed days taken to maturity. The model performance was found to be good in simulating the days to maturity, as revealed by high correlation coefficient, r (0.97) and low RMSE (3.9 d), MAE (3.5 d), MBE (–2.7 d) and MAPE (1.51%) between the simulated and observed days taken to maturity (Table 6). Also, a good line of fit (1:1) was found between the simulated and observed days taken to maturity with R^2 of 0.97 (Fig. 2).

The simulated and observed leaf-area index (LAI) was 3.5 and 3.7 in 15th October, 3.6 and 3.5 in 30th October and 3.2 and 3.5 in 15th November (Table 4). The mean LAI across different sowing dates and nitrogen treatments was 3.5 for the simulated data and 3.5 for the observed data (Table 6), with a standard deviation (SD) of 0.6 and 0.5 and coefficient of variation (CV) of 16.7 and 14.7% for the

Table 4. Validation results of phenology (anthesis and maturity) and LAI using DSSAT-CSM-CERES-Wheat model under varying sowing dates and nitrogen levels during (Mean of 2 years data)

Treatment	Anthesis (days)		Maturity (days)		Leaf-area index	
	Sim	Obs	Sim	Obs	Sim	Obs
D_1N_0	192	196	241	243	2.9	2.9
D_1N_1	192	197	241	245	3.5	3.7
D_1N_2	192	198	241	245	3.7	4.0
D_1N_3	192	199	241	246	4.0	4.0
D_2N_0	178	181	229	231	2.7	2.7
D_2N_1	178	182	229	233	3.6	3.5
D_2N_2	178	183	229	233	4.0	4.0
D_2N_3	178	183	229	234	4.2	4.0
D_3N_0	169	167	220	218	2.4	2.6
D_3N_1	169	168	220	220	3.2	3.5
D_3N_2	169	170	220	222	3.6	3.8
D_3N_3	169	170	220	223	3.7	3.9

Sim, simulated data; Obs, observed data

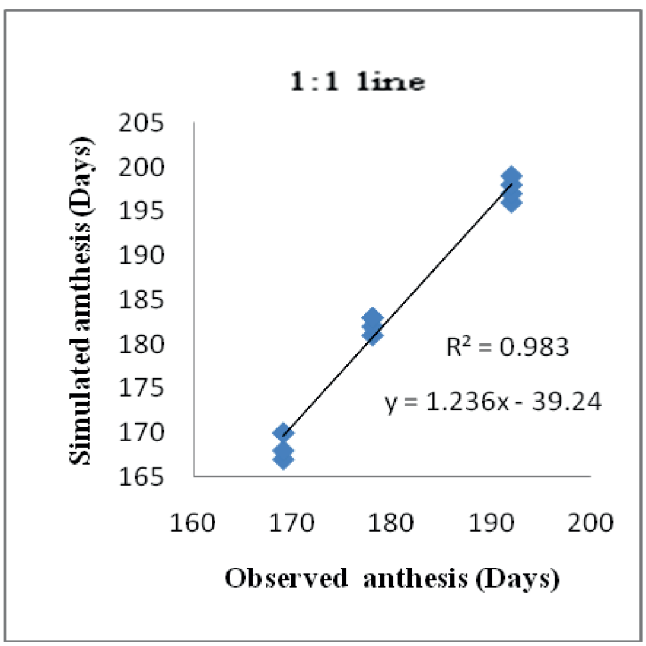

Fig. 1. Comparison of simulated and observed grain yield under varying sowing data and nitrogen levels (mean of 2 years data)

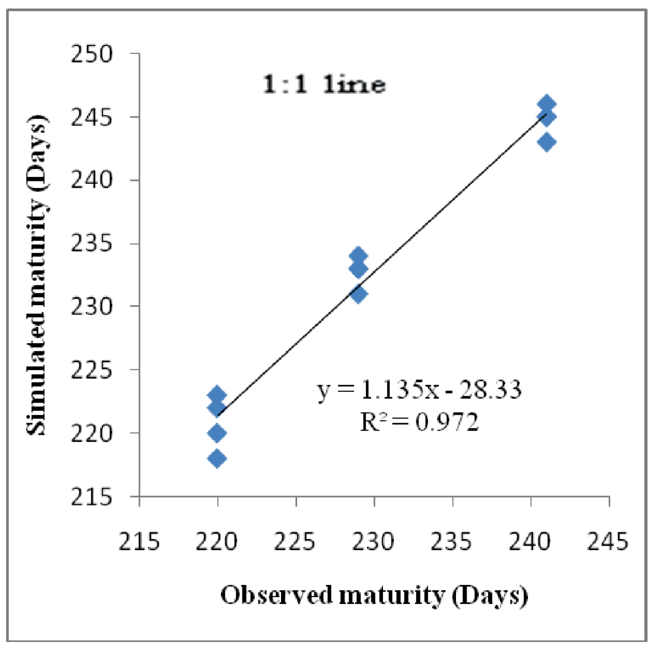

Fig. 2. Comparison of simulated and observed maturity under varying sowing data and nitrogen (mean of 2 years data)

simulated and observed LAI respectively. The model performance was found to be good in simulating the LAI as revealed by high correlation coefficient, r (0.90) and low RMSE (0.2), MAE (0.2), MBE (–0.05 d) and MAPE (6.22%) between the simulated and observed LAI (Table 6). Also, a good line of fit (1:1) was found between the simulated and observed LAI with R^2 of 0.91 (Fig. 3).

The variation between simulated and observed days to anthesis and maturity has been quoted by several researchers, namely Andarzian *et al.* (2015) reported RMSE of 3.5 and 3.0 days for time to anthesis and maturity as compared to observed data. Eajaz *et al.* (2017) found model performance good and reported low RMSE of 3.40 and 4.10 days for anthesis, 3.7 and 3.3 days for maturity and 0.47 and 0.43 for LAI during 2014–15 and 2015–16, respectively, between the simulated and observed data for culivar 'HD 2967' at the Punjab Agricultural University, Ludhiana. Similarly, Timsina *et al.* (1995) reported that, the time to anthesis and maturity was over estimated by the model with an RMSE of 8.6 and 8.7 days, respectively, for variety 'RR 21' and 'HD 2009' at Pantnagar, while Hundal and Kaur (1997) reported RMSE of 4.0 and 3.8 days between

Table 5. Validation results of grain and biological yields using DSSAT-CSM-CERES-Wheat model under varying sowing dates and nitrogen levels during (mean of 2 years data)

Treatment	Grain yield (t/ha)		Biological yield (t/ha)	
	Sim	Obs	Sim	Obs
D_1N_0	3.82	3.33	11.06	10.21
D_1N_1	4.63	4.44	12.68	12.40
D_1N_2	4.91	5.00	13.31	14.12
D_1N_3	5.09	5.07	13.75	14.34
D_2N_0	3.37	3.19	10.06	9.40
D_2N_1	4.33	3.97	12.24	11.30
D_2N_2	4.67	4.38	13.02	12.79
D_2N_3	4.85	4.45	13.45	13.32
D_3N_0	2.60	2.92	7.83	8.79
D_3N_1	3.75	3.75	10.24	10.74
D_3N_2	4.11	4.00	11.14	12.07
D_3N_3	4.47	4.07	12.03	12.19

Sim, simulated data; Obs, observed data

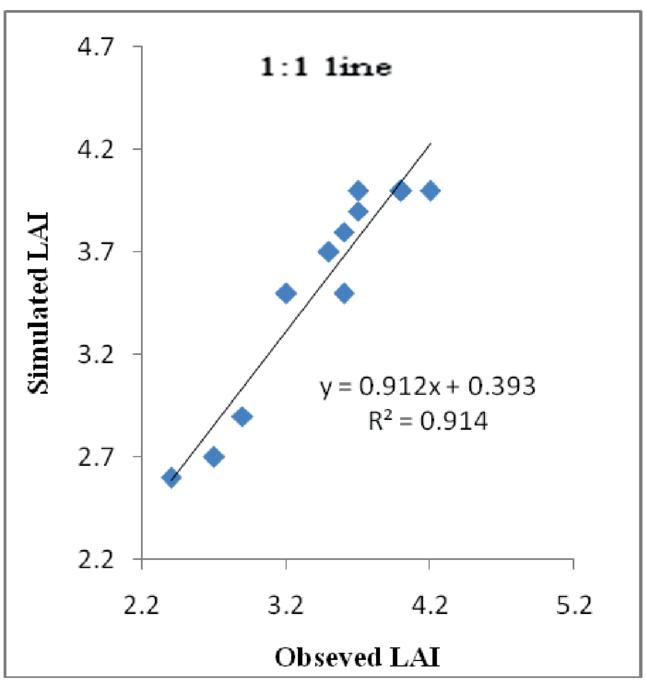

Fig. 3. Comparison of simulated and observed leaf-area index under varying sowing data and nitrogen (Mean of 2 years data)

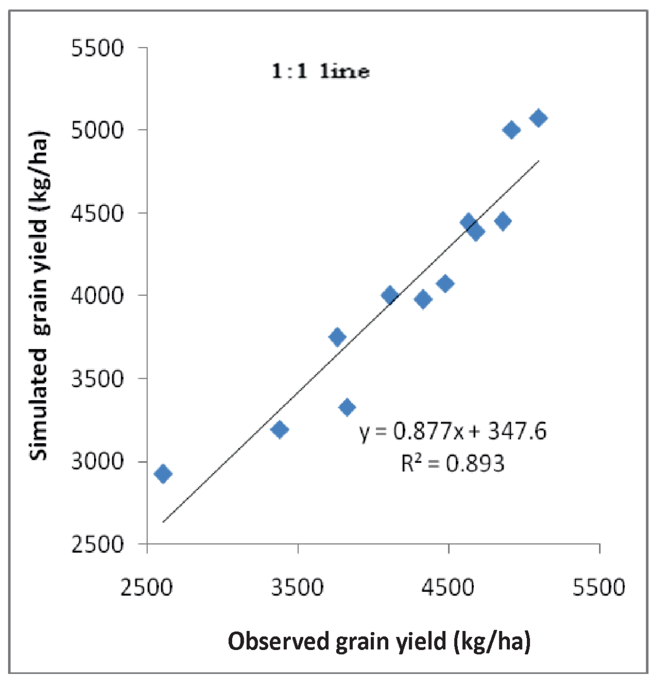

Fig. 4. Comparison of simulated and observed grain yield under varying sowing data and nitrogen (mean of 2 years data)

simulated and observed days to anthesis and maturity. Arora *et al.* (2007) reported RMSE of 0.1, 0.5, 0.9 between simulated and observed LAI for different sampling dates.

Simulated and observed grain and biological yields

The mean grain yield across different sowing dates and nitrogen treatments was 4.22 t/ha for the simulated data and 4.05 t/ha for the observed data (Table 6) with a standard deviation (SD) of 0.74 and 0.67 and coefficient of variation (CV) of 17.6 and 16.7% for the simulated and observed grain yield. The model performance was found to be good in simulating the grain yield as revealed by high correlation coefficient r (0.92) and low RMSE (0.39), MAE (299.3 d), MBE (170.0 d) and MAPE (7.85%) between the simulated and observed grain yield (Table 6). Also, a good line of fit (1:1) was found between the simulated and observed grain yield with R^2 of 0.89 (Fig. 4).

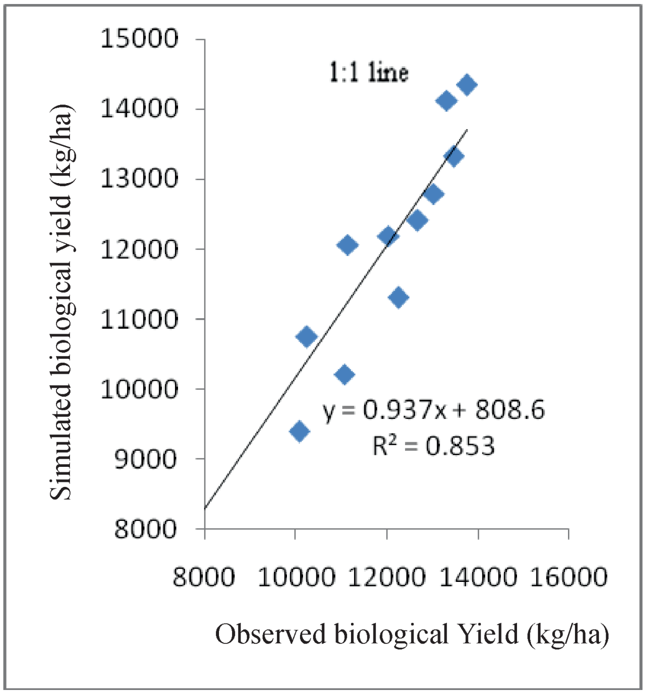

Fig. 5. Comparison of simulated and observed biological yield under varying sowing data and nitrogen levels (mean of 2 years data)

The mean biological yield across different sowing dates and nitrogen treatments was 11.73 t/ha for the simulated data and 11.80 t/ha for the observed data (Table 6), with a standard deviation (SD) of 1.81 and 1.76 and coefficient of variation (CV) of 15.4 and 15.0% for the simulated and observed biological yield. The model performance was found to be good in simulating the biological yield, as revealed by high correlation coefficient r (0.89) and low RMSE (1.03), MAE (26.2 d), MBE (–70.7 d) and MAPE (7.71%) between the simulated and observed biological yield (Table 6). Also, a good line of fit (1 : 1) was found between the simulated and observed grain yield with R^2 of 0.85 (Fig. 5).

Eajaz *et al.* (2017) reported deviation – 0.3 to + 0.2 t/ha and – 0.6 to + 0.8 t/ha between observed and simulated grain and biological yields, respectively. The RMSE values 0.49 and 0.35 tonne for grain yield and 0.72 and 0.65 tonne for biological yield during 2014–15 and 2015–16, respectively, between the simulated and observed data for culivar 'HD 2967'. Andarzian *et al.* (2015) reported RMSE of 0.58 and 0.47 between simulated and observed grain and biological yields as compared to observed data, while Timsina *et al.* (1995), Hundal and Kaur (1997), Heng *et al.* (2000), Nain *et al.* (2002) and Godwin *et al.* (2002) reported RMSE of 0.27, 0.31, 0.37, 0.08 and 0.08 t/ha, respectively, between simulated and observed grain yield. Similarly, Hundal and Kaur (1997) and Heng *et al.* (2000) reported RMSE of 1,110 and 1,500 kg/ha between simulated and observed biological yield.

It can be concluded that 15th October sowing of 'Shalimar wheat 2' was most suitable in terms of yield under rainfed conditions of temperate Kashmir. Application of 100 kg N/ha was adequate. The DSSAT-CSM-CERES

Table 6. Performance of DSSAT CSM CERES-Wheat model (V4.6) for simulating phenology and yield of wheat (mean of 2015–16 and 2016–17)

Parameters*	Simulated			Observed			Simulated vs Observed				
	Mean	SD	CV (%)	Mean	SD	CV (%)	r	RMSE	MAE	MBE	MAPE (%)
					2015-16						
Anthesis (DAS)	180	10.1	5.6	183.0	12.3	6.7	0.99	3.9	3.4	-3	1.84
Maturity (DAS)	230.1	8.7	3.8	234.1	9.0	3.8	0.97	3.9	3.5	-2.7	1.51
Leaf-area index	3.5	0.6	16.7	3.5	0.5	14.7	0.90	0.2	0.2	-0.05	6.22
Grain yield (t/ha)	4.22	0.74	17.6	4.05	0.67	16.7	0.92	0.39	299.3	170.0	7.85
Biological yield (t/ha)	11.73	1.81	15.4	11.80	1.76	15.0	0.89	1.03	26.2	-70.7	7.71

*SD, standard deviation; CV, coefficient of variation; r, correlation coefficient; RMSE, root mean square error; MAE, mean absolute error; MBE, mean bias error; MAPE, mean absolute percentage error (%)

wheat model proved to be a valuable option for simulating yield of wheat under different sowing dates and nitrogen levels, as evaluated by low values of RMSE, MBE, MAPE and high correlation coefficient and can be used as an alternative to high resource-oriented and cumbersome field experimentation.

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