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Evaluation of CSM-CERES-wheat in simulating wheat yield and its attributes with different sowing environments in *Tarai* region of Uttarakhand

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Abstract: Crop Environment Resource Synthesis (CSM-CERES)-Wheat model was used to simulate responses of two wheat varieties with various sowing environments. In this context, during the year 2007-08 and 2008-09, experiments on three sowing dates *viz.* November 20, December 15, and January 9 and two varieties (PBW-343 and WH-542) with three replications were conducted at the Norman E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture & Technology, Pantnagar (29°N, 79.29°E with 243.80 m above msl). Soil, plant, management and climatic data were collected from the experimental field. The data of 2007-08 and 2008-09 were used for model calibration and validation, respectively. Results revealed that the for model outputs were in good agreement with their corresponding observed values with 20th November sown crop than other sowings of crop in terms of phenological events, biomass accumulation and grain yields. However, variety PBW-343 showed close proximity between simulated and observed outcomes with all sowing dates. The percent root mean square error (% RMSE) values ranged from 5.9 – 15.6%, 2.2 – 7.6% for days to attain anthesis and physiological maturity, respectively. Moreover, %RMSE and t-value ranged from 5.7 – 12.2% (t= -4.5 to 1.8), 1.6 – 3.3% (t= -4.1 to 4.5) and 1.9 – 5.8% (t= -3.7 to 1.5) for product weight, vegetative weight and product harvest index, respectively. Inspite of that, model fails to simulate maximum leaf area index having % RMSE from 53.2 – 62.9%. These results indicate that CERES-Wheat model can be used as a tool to support decision-making for wheat production in *Tarai* region of Uttarakhand.

Keywords: CERES-Wheat, Sowing dates, Wheat varieties

INTRODUCTION

Wheat is the most widely cultivated food crop and ranks first in the world among the cereals both in respect of area 221.17 m ha and production 716.82 mt during 2013-14 (USDA, 2014). In India, it is the second important staple food crop next to rice with projected area, production and productivity of 30.00 m ha, 93.51 mt and 3.12 t ha^{-1}, respectively during 2013 -14 (USDA, 2014). It is also an important crop in *Tarai* region of Uttarakhand having an area of 0.37 m ha, with a total production of 0.87 mt and productivity of 2369 kg ha^{-1} (DAC, 2012). This winter golden grain cereal is a major contributor to the food security and provides more than 50 per cent calories to the people who are dependent on this staple food crop. The wheat production in the country is highly variable due to inter seasonal weather variability. The demand of wheat has been projected to be to 109 mt by 2020 which needs sincere efforts to mitigate the effect of climatic aberrations (Datt *et al*., 2009).

Research as well as technological innovations in the fields of biological, physical, and chemical science which is directly or indirectly linked with agricultural production system (Bannayan *et al.,* 2007; Andarzian *et al.,* 2008), can improve understanding and management of the agricultural system in a holistic way by using crop simulation models. The performance of different varieties with various sowing environments can be simulated through crop models (Ghaffari *et al.,* 2001, Bannayan *et al.,* 2003, Heng *et al.,* 2007 and Bassu *et al.,* 2009).

The Decision Support System for Agrotechnology Transfer (DSSAT) is a wide-ranging decision support system (Hoogenboom et al., 2010) which consists of the Cropping System Model-Crop Environment Resource Synthesis (CSM-CERES)-Wheat (Ritchie et al., 1998), that provides validation of crop model outputs and allow users to compare simulated result with observed consequences. Validation of crop dynamic model for any crop and any area will be greater applicable to predict the crop growth parameters as well as yield components in advance which are important for planning as well as management.

CSM-CERES-wheat is broadly used as a technological

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tool in favor of strategic decision-making (Sarkar and Kar, 2006), moreover, it can be used for dryland as well as irrigated conditions to simulate the growth and development of wheat (Jones *et al.,* 2003, Nain and Kersebaum, 2007 and Hoogenboom *et al.,* 2010). The model has been evaluated and applied in favour of tropical (Timsina *et al.,* 1995), subtropical (Hundal and Kaur, 1997 and Heng *et al.,* 2000) as well as temperate conditions in Asia (Timsina and Humphreys, 2006 and Zhang *et al.,* 2013), in order to provide improved knowledge and information of agricultural system. With these crop models, it became possible to simulate a living plant through the mathematical and conceptual relationship which governs its growth in the Soil-Water-Plant-Atmosphere Continuum.

The present study was made to evaluate the performance of the CSM-CERES-Wheat model to simulate growth, development, and yield of wheat as well as application of CSM-CERES-Wheat model in order to determine suitable sowing environment on wheat yield under irrigated conditions in *Tarai* region of Uttarakhand.

MATERIALS AND METHODS

Study area: Ground truth data were recorded from the experiments, conducted at the Norman Ernest Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture & Technology, Pantnagar (29° N, 79.3° E and 243.8 m above msl) Uttarakhand with two wheat varieties viz. PBW-343 and WH-542 and three sowing environments *i.e.* 20th November, 15th December and 09th January during 2007-08 and 2008-09). These cultivars were selected as they were recommended for this region and are still widely cultivated. The number of days to attain anthesis and physiological maturity were determined from randomly selected five plants in all the plots visually by the number of days taken from the sowing date to attain anthesis and physiological maturity. For grain and straw yield, plants in net plot were threshed separately with 12-14% moisture content that was recorded in kg plot^{-1} and finally expressed in kg ha^{-1}. The detail of soil information used for CERES-wheat model and climatic conditions of the experimental site have been shown by Pal *et al.* (2012).

Models used: In the present study, we used CERES (Crop Environment Resource Synthesis)-wheat Cropping System Model (CSM) for simulation of wheat crop characters in terms of number of days to attain anthesis & physiological maturity, product weight, vegetative weight and product harvest index (HI). In this context, genotypic coefficients for the wheat varieties i.e. PBW-343 and WH-542 were derived (Table 1) with the help of GENCALC software (DSSAT) from the experimental data of 2007-08 by using data sets of three treatments (20th November, 15th December and 09th January sowings) and independent data sets *viz.* dates of sowing, anthesis & physiological maturity, above ground biomass, yield & its attributing characters. Initially, GENCALC determine the values of phenological coefficients, (PHINT, P1V, P1D and P5), thereafter, values of the coefficients for growth and grain development (G1, G2 and G3) in order to attain the best possible match between predicted and observed data for the selected phenotypic and yield components. The CERES-wheat model was well calibrated based on experimental data of 2007-08 and validated using 2008-09 field trail data with the help of genotypic coefficients of wheat for varieties PBW-343 and WH-542 (Table 1) in the climatic conditions of *Tarai* region of Uttarakhand.

Statistical analysis: Percent root mean square error (% RMSE) and t-Test analysis was carried out to examine the magnitude of relationship between simulated and observed parameters of wheat varieties with different sowing environments, moreover, the level of significance was checked at 5% and 1% of probability in terms of dates of sowing (degrees of freedom: 3) and varieties (degrees of freedom: 5).

RESULTS AND DISCUSSION

Weather conditions during study period: The average minimum temperatures recorded between 8.7 to 10.7°C and 10.2 to 11.7°C, while, average maximum temperature were found to be between 23.8 to 26.4°C and 25.6 to 28.5°C in 2007-08 (Fig. 1a) and 2008-09 (Fig. 1b), respectively. On the other hand, mean air temperature ranged 16.3 – 18.6°C and 17.9 – 20.1°C in the year 2007-08 and 2008-09, respectively. During the study period, average relative humidity ranged 61.7 to 66.0% and 61.7 to 67.5% in 2007-08 and 2008-09, respectively. Among sowing dates, total 27.4mm rainfall was recorded in 2007-08 and 35.6 – 38.0mm in 2008-09, however, average bright sunshine hours was recorded between 6.2 – 7.0 and 6.7 – 7.8 in the year 2007-008 and 2008-09, respectively.

Timely sown wheat crop (20 November) with an average seasonal air temperature of 16.3°C produced highest yield of 4580.3 kg ha^{-1} in 2007-08, while, it was 4080.3 kg ha^{-1} in 2008-09 with an average seasonal air temperature of 17.9°C. By means of every 25 days delay in sowings with an increase in average seasonal air temperature of 0.9 – 1.4°C, yield reduced by 13 to 29.0% in both the years (Pal *et al*., 2013).

Observed vs. simulated days to attain anthesis and physiological maturity (DAS): It is revealed from the data, that days taken to anthesis ranged between 81 to 90 and 69 to 89; however, days to attain physiological maturity ranged 106 to 123 and 97 to 122 for observed and simulated data, respectively (Figs. 2 and 3).

The crop sown on 20th November showed close proximity with the simulated anthesis values (t=-2.7; %RMSE=5.9) as well as physiological maturity (t=-3.2; %RMSE=2.2) values followed by rest of the sowing dates. Mitchell (1996) has also reported a close

Table 1. Genetic coefficients fitted for wheat crop cultivar PBW-343 and WH-542.

Crop file	Parameter	Calibrated value	
		PBW-343	WH-542
Species	PEG	10	10
	PECM	10	10
	P1DT	20	20
	P1VT	50	50
	P2(1)	80	80
	P4(1)	0.25	0.25
	P4(2)	0.10	0.10
	PDUR6	100	100
Ecotype	P1	200	200
	P2	200	200
	P3	200	200
	P4	200	200
	KCAN	0.85	0.85
	PARUV	2.8	2.8
	PARUR	2.8	2.8
Genotype	P1V	0	0
	P1D	92	91
	P5	560	557
	G1	22	23
	G2	43	43
	G3	2.3	2.9
	PHINT	95	88

Abbreviation: PEG: Germination phase duration (Hydrothermal units); PECM: Emergence phase duration (Thermal units per cm depth); P1DT: Photoperiod threshold (h above which no effect); P1VT: Vernalization threshold (d; only for determining response); P2(1): Duration terminal spikelet to jointing (DU); P4(1): Duration end ear growth to anthesis (frP4); P4(2): Duration anthesis to end anthesis (frP4); PDUR6: Phase duration 6 (post physio.maturity (°C.d); P1: Duration of phase end juvenile to terminal spikelet (GDD, Growing Degree Days); P2: Duration of phase terminal spikelet to end leaf growth (GDD); P3: Duration of phase end leaf growth to end spike growth (GDD); P4: Duration of phase end spike growth to end grain fill lag (GDD); KCAN: PAR extinction coefficient (#); PARUV: PAR conversion to dry matter ratio before the last leaf stage (g MJ^{-1}); PARUR: PAR conversion to dry matter ratio after the last leaf stage (g MJ^{-1}); P1V: Days at optimum vernalizating temperature required to complete vernalization; P1D: Percentage reduction in development rate in a photoperiod 10 h shorter than the optimum relative that optimum; P5: Grain filling (excluding lag) period duration (GDD); G1: Kernel number per unit canopy weight at anthesis (g^{-1}); G2: Standard kernel size under optimum condition (mg); G3: Standard non-stressed dry weight (total, including grain) of a single tiller at maturity (g); PHINT: Phyllochron interval (GDD)

agreement between observed and predicted days to achieve anthesis and physiological maturity. Variety PBW-343 possesses more accuracy (t=-3.5; % RMSE=9.6) than WH-542 (t=-3.7; %RMSE=10.7) for anthesis, and also similar trends was found in respect of physiological maturity (Table 2).

Model underestimated the days taken to anthesis and physiological maturity among all the dates of sowing and varieties. Number of days to attain anthesis and physiological maturity were found to be decreased as the sowings were delayed (Table 2). Reduction in days to attain anthesis and maturity of wheat crop with delay in sowing has also been reported by Kour *et al.* (2010).

Observed vs. simulated product weight and vegetative weight (kg ha^{-1}): The product weight ranges between 3070 to 4442 kg ha^{-1} and 3256 to 4255 kg ha^{-1}, however, vegetative weight ranged 3994 to 5221 kg ha $^{-1}$ and 4162 to 5171 kg ha^{-1} for observed and simulated data, respectively (Figs. 4 and 5).

The model estimated product weight was very close to the observed values with 20th November sowing (t=-4.5; %RMSE=5.7) than crop sown on December 15th (t=1.8; %RMSE=8.9), while, the difference between observed and simulated values was found to be large in case of 09th January sowing (t=1.8; %

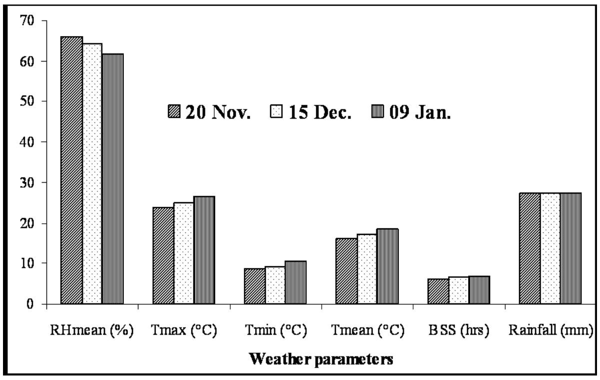

Fig. 1a. *Average weather data of various parameters during Rabi season of 2007-08 of Pantnagar (experimental site) agro-meteorological observatory.*

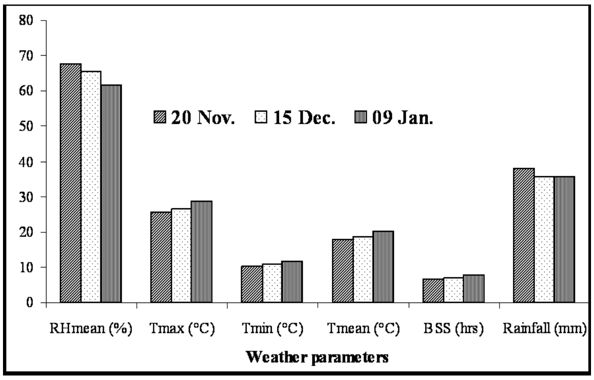

Fig. 1b. *Average weather data of various parameters during Rabi season of 2008-09 of Pantnagar (experimental site) agro-meteorological observatory.*

Table 2. Statistics between simulated and observed wheat crop components.

Phenophages	PBW-343	WH-542	Nov. 20	Dec. 15	Jan. 09
t-Test					
Days to attain anthesis (DAS)	-3.5**	-3.7**	-2.7*	-4.6**	-23.7**
Days to attain physiological maturity (DAS)	-3.1*	-4.2**	-3.2*	-4.5*	-12.0**
Maximum Leaf Area Index	-10.2**	-10.7**	-13.8**	-21.5**	-17.4**
Product weight (kg ha^{-1})	-0.2	1.2	-4.5**	1.8	1.8
Vegetative weight (kg ha^{-1})	1	1.1	-4.1*	4.3*	4.5*
Product Harvest Index	-0.3	1.4	-3.7*	1.5	1.2
%RMSE					
Days to attain anthesis (DAS)	9.6	10.7	5.9	6.9	15.6
Days to attain physiological maturity (DAS)	4.1	5.3	2.2	3.4	7.6
Maximum Leaf Area Index	53.2	62.9	59.9	56.7	53.8
Product weight (kg ha^{-1})	5.8	11	5.7	8.9	12.2
Vegetative weight (kg ha^{-1})	1.6	2.9	1.6	2	3.3
Product Harvest Index	3.1	5	1.9	3.9	5.8

%RMSE= percent root mean square error, *Significant at 0.05 *P* and ** Significant at 0.01 *P*

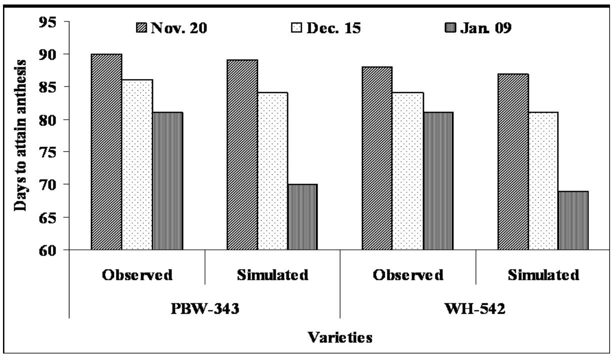

Fig. 2. *Comparison between measured and simulated values for days taken to anthesis (DAS) at different dates of sowing and varieties of wheat (Mean of 2007-08 and 2008-09).*

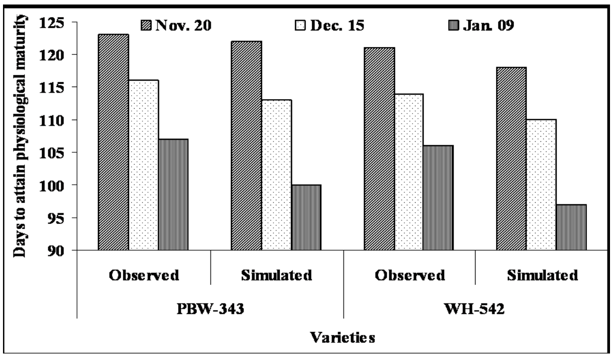

Fig. 3. *Comparison between measured and simulated values for physiological maturity (DAS) at different dates of sowing and varieties of wheat (Mean of 2007-08 and 2008-09).*

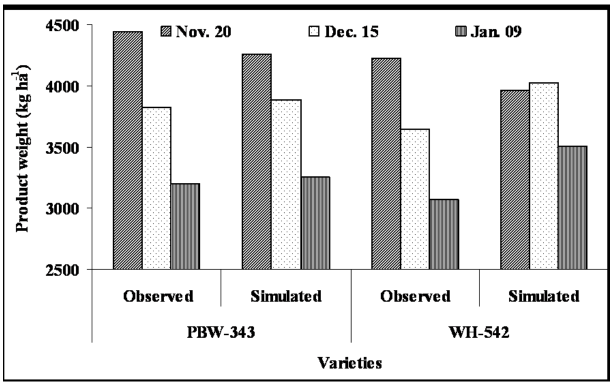

Fig. 4. *Comparison between measured and simulated values for product weight (kg ha^{-1}) at different dates of sowing and varieties of wheat (Mean of 2007-08 and 2008-09).*

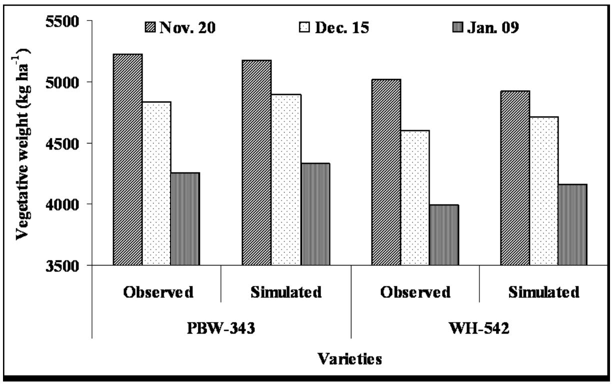

Fig. 5. *Comparison between measured and simulated values for vegetative weight (kg ha^{-1}) at different dates of sowing and varieties of wheat (Mean of 2007-08 and 2008-09).*

RMSE=12.2). On the other hand, for vegetative weight, less %RMSE was found with early sowing (1.6) than mid (2.0) and late sown crop (3.3). In case of product weight, the performance of the model was

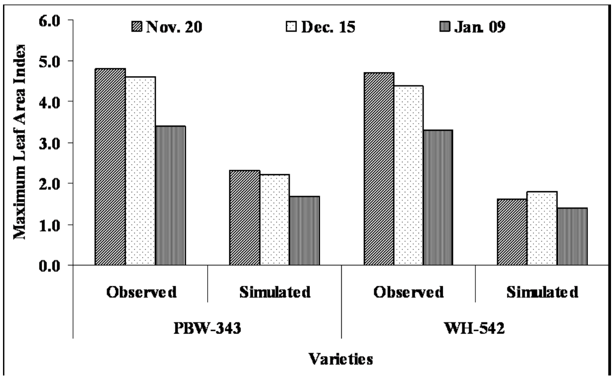

Fig. 6. *Comparison between measured and simulated values for maximum Leaf Area Index at different dates of sowing and varieties of wheat (Mean of 2007-08 and 2008-09).*

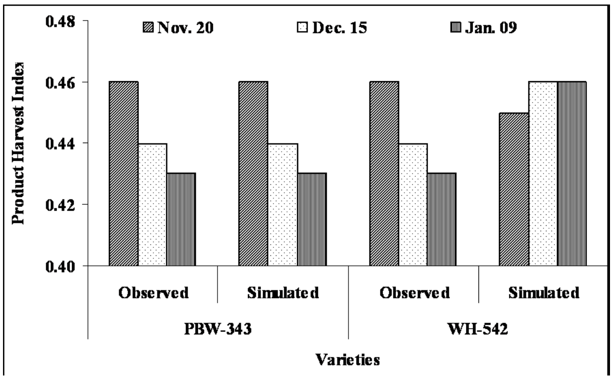

Fig. 7. *Comparison between measured and simulated values for product Harvest Index at different dates of sowing and varieties of wheat (Mean of 2007-08 and 2008-09).*

good for variety PBW-343 (t=-0.2; %RMSE=5.8) compared to that of variety WH-542 (t=1.2; % RMSE=11.0), however, similar circumstances was also observed with vegetative weight (Table 2). Nain *et al.* (2002) also reported that the model could very well simulate the crop yields (RMSE < 20%).

Model underestimated the product weight with sowing done on 20th November in both the years (Ouda *et al.,* 2005; Patel *et al.,* 2010) whereas it overestimated for the rest of the sowing dates (Dhaliwal *et al.,* 1997; Wajid *et al.,* 2007). From the response of simulation modeling, it was found that the accuracy of simulated value decreases with delayed sowings for all varieties. Similar result was also reported by Pal *et al.* (2008).

Observed vs. simulated maximum leaf area index (LAI) and product harvest index (HI): It is evident from the data that maximum leaf area index ranged 3.3 to 4.8 and 1.4 to 2.3 for observed and simulated data, respectively, while, product harvest index ranged 0.43 to 0.46 for both observed and simulated data (Figs. 6 and 7).

The model underestimated the values of maximum LAI among sowing dates and varieties. Similar results have been reported by Kaur *et al.* (2007) and Wajid *et al.* (2007). The model failed to estimate the maximum LAI and the difference between simulated and observed values was large. LAI decreased with delayed sowing {%RMSE=59.9 (Nov. 20), 56.7 (Dec. 15) and 53.8 (Jan. 09)}. Meza *et al.* (2008) reported reduction in leaf area index of maize crop with delayed sowings by using CERES-maize model.

In respect of HI the data of simulated and observed values are in close proximity to each other with crop sown on 20th November (t=-3.9; %RMSE=1.9) followed by rest of the sowing dates. The highest accuracy of predicted values over observed was accredited with the variety PBW-343 (t=-0.3; % RMSE=3.1) than WH-542 (t=1.4; %RMSE=5.0) [Table 2].

Conclusion

The results from this study showed an acceptable agreement between simulated and observed values for phonological events (except maximum leaf area index), total above ground dry biomass and grain yield of two wheat varieties for both model calibration and validation. The performance of CERES-wheat model was found better with crop sown on 20th November than 15th December and 09th January during both crop growing seasons (2007-08 and 2008-09) for almost all the crop characters. Among crop components, simulated values were very close to the observed for the variety PBW-343 than WH-542. Therefore, 20th November sowing date with the variety PBW-343 is recommended for foot hills of Western Himalayas region in order to obtain higher yield. CSM-CERES -Wheat has the potential in simulating development, growth and yield of wheat cultivars under various sowing dates, and this also indicated the possibility in using CSM-CERES-Wheat as a decision-supporting tool for wheat production in Western Himalayan regions.

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