Print ISSN : 0972-8813
e-ISSN : 2582-2780

[Vol. 22(2) May-August 2024]

Pantnagar Journal of Research

(Formerly International Journal of Basic and Applied Agricultural Research ISSN : 2349-8765)

G.B. Pant University of Agriculture & Technology, Pantnagar

PANTNAGAR JOURNAL OF RESEARCH

Vol. 22(2) May-August 2024

CONTENTS

Calibration and performance evaluation of the APSIM and CERES-Wheat model in the foot hills of Western Himalayas

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ABSTRACT: APSIM-Wheat and CERES-Wheat, which simulates yield has been calibrated for wheat using experimental data of 2017-18 crop season under *Tarai* region of Uttarakhand.The calibration was performed against anthesis (DAS), physiological maturity (DAS), grain and biomass yield for the three treatments of sowing dates (*viz.,*15th November, 25th November and 05th December), three levels of irrigation (number of irrigations five, four and three) for two wheat varieties (HD-2967 and PBW-502).The calibrated APSIM-Wheat and CERES-Wheat model were then applied validated for rabi season of 2018-19. The CERES model shows superior performance compared to the APSIM model across several metrics. For days to anthesis, CERES RMSE values range from 2.75 to 3.69, while APSIM's are 3.78 to 5.77. For physiological maturity, CERES % RMSE values are 4.82 to 5.34, and APSIM's are 5.13 to 6.35. Biological yield R^2 values for CERES are 0.91 to 0.94, while APSIM's are 0.84 to 0.85. Grain yield RMSE values for CERES range from 2.11 to 3.16, compared to APSIM's 3.03 to 5.14, indicating that CERES predictions are closer to experimental data.

Key words: APSIM-Wheat, calibration, CERES-Wheat, validation, wheat

Wheat is India's second most significant staple grain (with average production 102.46 million tonnes, average area 30.28 million hectares and average productivity 33.84 qt/ha- E&S Division, DA&FW 2022) after rice, having a broad latitudinal distribution. It thrives in regions with moderate temperatures and sub-humid to semi-arid conditions and can tolerate a range of temperatures from very low to moderately high. Wheat is cultivated near the equator and at latitudes up to 60°N and 40°S. The wheat crop in Uttarakhand covered 311,860 hectares, produced 954,868 tonnes, and had a productivity of 30.62 quintals per hectare (Agriculture Statistic Department of Uttarakhand 2020-21)

Crop modeling, which describes how crops respond to meteorological, edaphic, and biological conditions, is essential for developing innovative crop management strategies and ensuring agricultural sustainability in the face of a changing climate (Martina *et al.,* 2014). Crop simulation models based on physiology have been effectively employed for crop yield forecasting at the field level to better understand complicated biophysical systems (Holzworth *et al.,* 2011; Nain *et al.,* 2004). Various models have been created with the primary goal of understanding yield gaps and optimizing yield potential. These include APES (Donatelli *et al*., 2002), APSIM (Keating *et al.,* 2003), CERES (Ritchie *et al.,* 1998), CROPGRO (Godwin and Singh, 1998), CropSyst (Rosenzweig and Parry, 1994; Willmott *et al.,* 1985), DAISY (Sayre *et al.,* 1997), DSSAT(Bassu *et al.,* 2009), HERMES (Asseng *et al.,* 2014), RZWQM (Ma *et al*., 2011), SPASS (Wang and Engel, 2000, 2002), STICS (Brisson *et al.,* 2003), SWAP (Chen *et al.,* 2010, Eitzinger*et al.,* 2004; Ma *et al.,* 2015), SOYGRO (Monsi and Saeki, 2005) and WOFOST (Eitzinger*et al.,* 2004; Holzwortha*et al.,* 2011). The CERES and APSIM wheat crop growth simulation models have been proven effectively under a variety of environmental circumstances (Ahmed *et al.,* 2016). Crop simulation models are location and crop specific until and unless calibrated under local conditions therefore should not be applied in other regions without performing calibration and validation (Pareek *et al.,*2022).Crop simulation models are critical for bridging the agronomical-information in to mathematical form. Because of the mathematical and conceptual relationship that regulates plant growth, simulation was made possible with these crop models. A model consists of one or more equations designed to represent the behavior of a system (Graves *et al.,* 2002). Crop simulation models describe how crops interact with their surroundings in a multiple way. As a result, we can measure the impact of elements of climate and soil on crop growth and sustainability (Timsina *et al.,* 2008; Kumar *et al*., 2014). For such researches, models are applied after calibration and validation under local conditions.

APSIM (Agricultural Production Systems Simulator) is a software that simulates agricultural systems by connecting various sub-models (or modules) (McCown *et al.,* 1996). The APSIM-Wheat model required weather, soil and crop data, as well as management practices data (Mohanty *et al.,* 2012). In the model, factors such as climate, soil water availability, and soil nitrogen levels influence wheat growth and development. On a daily basis, the model sends information on its soil water and nitrogen intake to the Soilwat (soil water) and SoilN (soil nitrogen) modules (Zhao *et al.,* 2014). Crop cover data is supplied to the Soilwat module, which evaluates evaporation rates and runoff. During harvest, wheat stover and root residue are moved into the Residue and SoilN surface module. APSIM estimates soil water content daily and calculates various other processes in sequence. The SoilN module describes the dynamics of carbon and nitrogen in the soil. The APSIM Met module delivers daily meteorological data to all modules within an APSIM simulation.(Keating *et al.,* 2003).

The Decision Support System for Agrotechnology Transfer (DSSAT) is one of the most widely used crop modeling programs globally. It is designed to simulate crop growth, development, and yield on a uniform area of land, along with changes in soil water, carbon, and nitrogen over time (Jones *et al*., 2003). DSSAT, a software application that includes crop simulation models for over 42 crops (as of Version 4.7), provides features for effective model utilization (IBSNAT, 1993). It is a suite of different programs working together, with a crop simulation model at its core (Shi *et al*., 2015). Weather, soil, genetics and management practices are all covered in databases. The CERES-Wheat model mimics plant phenology, cereal growth, leaf, trunk and root growth, biomass buildup depending on light interception and environmental stress, soil water and N transformations and crop uptake. These two models (CERES-Wheat and APSIM-Wheat) are frequently used to simulate wheat crop production under climate change scenarios utilizing the package of agricultural practices. A comparative investigation was conducted in the present study to assess the accuracy of the results provided by both crop growth simulation models, (CERES-Wheat and APSIM-Wheat). Although these crop simulation models are tools for predicting yield and optimizing resources without conducting field experiments, comparative study of the output of these models in response to field experiment trials may aid in selecting the better model for other objectives such as resource optimization, climate change impact on crop yield and so on in a specific region (Anwar *et al.,* 2015;Asseng*et al.,* 2015; Mohanty*et al.,* 2012; Dong *et al.,* 2014). Keeping the above facts in mind, the current study has been designed.

MATERIALS AND METHODS

The wheat crop field experiments were conducted in the C6 block of the Norman E. Borlaug Crop Research Center at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, District Udham Singh Nagar (Uttarakhand) during the rabi seasons of 2017-18 and 2018-19 (Table 2). The experimental site is situated in the Tarai region at the foothills of the Himalayan Shivalik range, with coordinates of 29°02'N latitude, 79°28'E longitude, and an elevation of 244 meters above mean sea level. Pantnagar experiences a climate ranging from subtropical to tropical, characterized by hot, dry summers and cool winters. The monsoon season typically starts in the third week of June and continues until the end of September, contributing to Pantnagar's average annual rainfall of 1420 mm, with 80-90 percent occurring during the monsoon and the rest in winter (Goel *et al.*, 2024). May is the hottest month, with average temperatures reaching 46±1.5°C (Kiran, 2018). Winters, extending from November to February, can be very cold, with January temperatures dropping as low as 1.5±1.0°C (Figure 1 and 2). Occasional showers occur in both winter and summer. Maximum relative humidity, ranging from 90-95 percent, is observed during the monsoon and winter seasons. The meteorological data for this study, including minimum and maximum temperatures, bright sunshine hours, relative humidity, and rainfall, were obtained from the agro-meteorological observatory at Norman E. Borlaug Crop Research Centre, Pantnagar.

The soil of experiment site has been described under the (Table 1)Mollisol order, sub-order udoll with great group hapludoll and soil series Haldi (Deshpande *et al.*, 1971) developed from calcareous parent material having moderate to course soil texture under predominance effect of long grasses in poorly to well drained condition.

APSIM-Wheat and CERES-Wheat models, which simulate yield, were calibrated for wheat using experimental data from the 2017-18 crop season. The calibration process considered anthesis (days after sowing, DAS), physiological maturity (DAS), grain yield, and biomass yield for three sowing date treatments (15th November, 25th November, and 5th December) and three irrigation levels (five, four, and three irrigations) for two wheat varieties. Although the usual sowing period for wheat crops in India is from late October to mid-November, sometimes the sowing is delayed due to the late harvesting of preceding kharif crops. (Pareek *et al.*, 2022). Sometimes, sowing also begins in the first and second week of December. Flood irrigation was applied in the wheat crop field with 60mm of water each time, excluding rainfall.

The calibrated models were then validated using data from the 2018-19 rabi season, applying the same treatments for sowing dates and irrigation levels for the two wheat varieties.The predicted values of growth, development and yield attributes generated using both the models have been analyzed statistically and compared with experimental field data.

Table 1: Physiochemical properties of the experimental plot's soil

Characters	Soil depth (cm)				
	0-15	15-30	30-60	60-90	90-120
Sand (%)	60.6	62.6	63.6	66.3	67.4
Silt (%)	21.2	20.8	20.2	18.4	18
Clay (%)	18.2	16.6	16.2	15.3	14.6
pH	6.4	6.8	7.4	7.1	7.5
SCEC (meq+/100g)	18.8	17.9	17.4	17.4	17.1
SOC (%)	0.46	0.38	0.33	0.3	0.28
BD (gcm^{-3})	1.51	1.47	1.47	1.46	1.44
SAT (cm^3cm^{-3})	0.41	0.42	0.42	0.42	0.44
LL (cm^3cm^{-3})	0.12	0.11	0.1	0.1	0.1
DUL (cm^3cm^{-3})	0.25	0.26	0.23	0.22	0.22

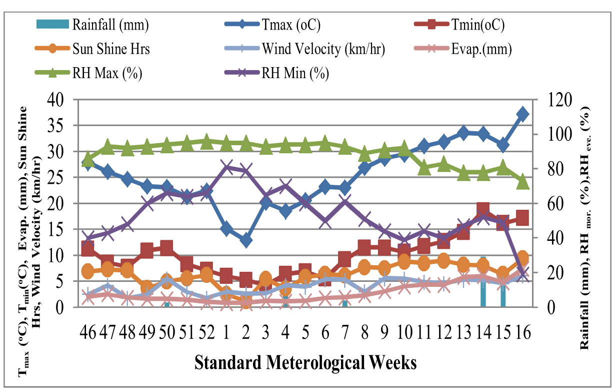

Fig.1: Average meteorological data recorded at CRC, GBPUA&T during wheat growing season from 2017-2018

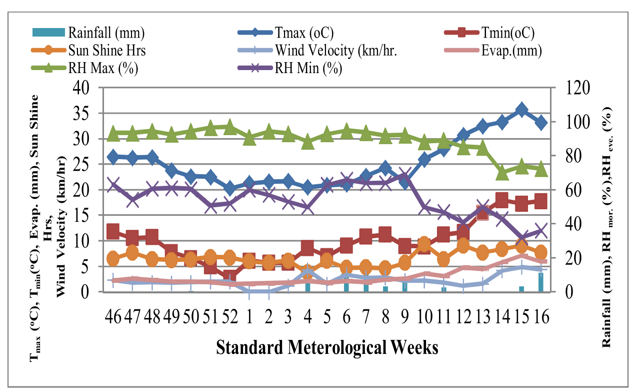

Fig.2: Average meteorological data recorded at CRC, GBPUA&T during wheat growing season from 2018-19

Table 2: Experimental details

S. No.	Component	Symbols
A	Season of experiment	*Rabi*, 2017-18 and 2018-19
B	Crop	Wheat
C	Date of sowing	
1	D_1	15th November
2	D_2	25th November
3	D_3	5th December
D	Variety	
1	V_1	HD-2967
2	V_2	PBW-502
E	No. of Irrigation	
1	I_1	5 Irrigation (at CRI, Tillering, Booting, Flowering and MilkingStage)
2	I_2	4 Irrigation (at CRI, Tillering, Flowering and Milking Stage)
3	I_3	3 Irrigation (at CRI, tillering and Flowering Stage)
F	Details of layout	
1	Design	Factorial RBD
2	Variety	2
3	Date of sowing	3
4	No. of Irrigation	3 levels
5	Treatment combination	18 (Replicated 3 times)
6	Total no of plots	54
7	Spacing	20cm (R × R)
8	Plot size	5m × 4m

RESULTS AND DISCUSSION

Calibration and Validation of APSIM-Wheat and CERES-Wheat model

With the help of experimental data by using three treatments of sowing dates (15thNovember, 25th November and 05th December) and three irrigation levels (number of irrigations three, four and five) variety specific genetic coefficients (wheat cv. HD-2967 and PBW-502) were calibrated (Table 3 and Table 4 for APSIM-Wheat and CERES-Wheat models, respectively). The genetic coefficients were calibrated iteratively with independent data sets *viz.,* date of sowing, anthesis, physiological maturity, biomass and grain yield.

Both the crop growth simulation models APSIM-wheat and CERES-Wheat were calibrated and validated with the experimental data set for the years of 2017-18 and 2018-19 for three dates of sowing (15thNovember, 25th November and 05th December) and three levels of irrigation (number of irrigations five, four and three). Calibration was performed against the anthesis (DAS), physiological maturity (DAS), biological yield (q/ha) and grain yield (q/ha). Model parameters were adjusted by hit and trial method until the predicted values matches with the observed data. Validation was done by comparing the simulated and observed phenological as well as yield attributes with the help of statistical parameters. The results simulated by APSIM-Wheat and CERES-Wheat models have been compared using statistical indicators i.e., RMSE, percent RMSE and coefficient of determination (R^2).

Comparison between simulated results of CERES-Wheat and APSIM-Wheat

Anthesis

The days taken to anthesis were recorded for both the wheat varieties HD-2967 and PBW 502(Table-5). Observed values ranged between 77 to 85 days in the year 2017-18 for wheat variety HD-2967. APSIM-wheat and CERES-wheat model simulated 81 to 87 days and 78 to 87 days, respectively.Days taken to anthesis simulated by CERES-wheat model were close to observed data.In the rabi season of 2017-18 for PBW-502 variety days taken to anthesis were recorded 78 to 87 days (Table5). APSIM model simulated days taken to anthesis between 81 to 90 days while CERES wheat model simulated 79 to 89 days. In the rabi season of 2018-19 for wheat variety HD-2967 days taken to anthesis was observed 76 to 85 days while crop models simulated as 80 to 90 days and 77 to 88 days by APSIM and CERES model, respectively. For wheat variety PBW-502 observed values for days taken to anthesis were recorded 77 to 86 days while simulated values by APSIM and CERES wheat model ranged between 77 to 88 and 77 to 86 days, respectively. For CERES model RMSE values lies between 2.75 to 3.69 and for APSIM model RMSE values ranged between 3.78 to 5.77.Therefore, less error values in case of CERES model indicates that the CERES model predicted days taken to anthesis more accurately. % RMSE and R^2 values also showing the same trend.

Table 3: Parameterization of crop genotype used in the model for wheat variety HD-2967 and PBW-502 using APSIM model

Parameters or variables	Acronym	Value		Units
Phenology	Name	HD-2967	PBW-502	
Emergence: end of juvenile	TT_EMERG_TO_ENDJUV	890	892	^{0}C days
End of juvenile: floral initiation	TO_ENDJUV-_TT_INTI	54	54	^{0}C days
Floral initiation: flowering	TT_INTI_TT_START_GRAIN	460	468	^{0}C days
Flowering: start grain filling	TT _START_END_GRAIN	150	155	^{0}C days
Start grain filling: end grain	TT _START_TO_END_GRAIN	385	390	^{0}C days
End grain: maturity	TT _END_GRAIN_TO_MATURITY	50	52	^{0}C days
Maturity: harvest ripe	TT _ MATURITY_TO_RIPE	1	1.2	^{0}C days
Genetic				
Potential grain growth rate during grain filling	POTENIAL_GRAIN_FILLING_RATE	0.002	0.001	g grain^{-1}day^{-1}
Potential grain growth flowering to grain filling	POTENIAL_GRAIN_GROWTH_RATE	0.001	0.001	g grain^{-1}day^{-1}
Leaf development	PHYLLOCRON	105	98	
Vernalization sensitivity	VERN_SENS	1.35	1.65	
Photoperiod sensitivity	PHOTO_SENS	3.0	2.3	
Radiation and water use				
Radiation use efficiency	RUE	1.28	1.16	g MJ^{-1}day^{-1}
Transpiration use efficiency coefficient	TRANSP_EFF_CF	0.007	0.007	kPa
Wheat water lower limit	LL	0.2	0.2	m^{3}m^{-3}
Rate of soil water extraction	KL	0.08	0.08	

Physiological Maturity

Observed and simulated values for physiological maturity of both the wheat varieties HD-2967 and PBW-502 in the rabi season of 2017-18 and 2018-19 are presented in Table 6. In the rabi season of 2017-18 observed values were recorded in the range 127 to 138 days for wheat variety HD-2967. Simulated values lied in the range 129 to 144 days and 127 to 140 days by APSIM and CERES model respectively. In the rabi season of 2018-19 the observed values for physiological maturity for HD-2967 variety were recorded as 126 to 137 days for different treatments of sowing dates and irrigation levels. APSIM model simulated days taken to physiological maturity between 129 to 142 days while CERES wheat model simulated 127 to 140 days.For the CERES model, the % RMSE values range from 4.82 to 5.34, while for the APSIM model, the % RMSE values fall between 5.13 and 6.35. This indicates that the CERES model, with its lower % RMSE values, more accurately predicts the number of days to physiological maturity. The RMSE and R^2 values also support this trend in both the rabi season of 2017-18 and 2018-19 the values simulated for physiological maturity by CERES wheat model were close to the experimental field data.

Table 4: Modified genotypic coefficients used for simulation modeling (calibration) for wheat using CERES-Wheat Model

Code	Parameters	Genotypic coefficient	
		HD-2967	PBW- 502
P1V	Vernalisation coefficient	05	04
P1D	Photoperiodism coefficient	76	64
P5	Grain filling duration coefficient	525	640
G1	Kernel no. coefficient	25	17
G2	Kernel wt. coefficient	29	49
G3	Tiller wt. coefficient	7.4	7
PHINT	Phyllochron interval	69	88

Biological yield

Biological yield was recorded for both the wheat varieties HD-2967 and PBW-502 in the rabi season of 2017-18 and 2018-19(Table7). For wheat variety HD-2967 observed data ranged between 84.92q/ha and 116.75 q/ha. Simulated data was found to be 88.92 q/ha to 119.02 q/ha and 85.20 q/ha to 118.04 q/ha by APSIM and CERES wheat model respectively. In rabi season of 2017-18, biological yield of wheat variety PBW-502 was recorded 82.72 q/ha to 109.30 q/ha while simulated biological yield by both the crop growth simulation models was found to be 84.15 q/ha to 113.65 q/ha and 83.20 q/ha to 110.07 q/ha by APSIM and CERES wheat model, respectively. Biological yield for wheat variety HD-2967 was observed 87.29 q/ha to 115.52 q/ha in rabi season of 2018-19. Simulated yield was

Table 5: Model evaluation indices of evaluating comparative performance of APSIM-Wheat and CERES-Wheat models in predicting anthesis (DAS) for wheat varieties in rabi 2017-18 and 2018-19

	2017-18						2018-19					
	HD-2967Anthesis (DAS)			PBW-502 Anthesis (DAS)			HD-2967Anthesis (DAS)			PBW-502 Anthesis (DAS)		
Treatments	Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C
D1I1	85	87	87	87	90	29	85	90	88	86	88	86
D1I2	83	81	84	85	82	84	83	87	83	84	81	84
D1I3	79	77	79	81	82	81	81	84	81	81	78	81
D2I1	82	80	82	85	82	84	83	80	83	84	81	84
D2I2	81	82	81	83	80	83	81	84	81	82	84	81
D2I3	78	82	77	79	77	80	78	78	77	79	79	79
D3I1	80	83	80	83	85	83	81	84	81	82	84	83
D3I2	79	77	80	81	82	81	79	79	78	80	82	81
D3I3	77.	81	78	78	81.	79	76	80.	77	77.	77	77
Model evaluation indices												
RMSE	APSIM	3.78			4.51			5.77			4.14	
	CERES	3.05			3.69			3.00			2.75	
% RMSE	APSIM	4.24			4.78			6.21			5.67	
	CERES	3.44			4.03			4.04			3.34	
R^2	APSIM	0.81			0.82			0.84			0.82	
	CERES	0.84			0.86			0.87			0.85	

Table 6: Model evaluation indices of evaluating comparative performance of APSIM-Wheat and CERES-Wheat models in predicting physiological maturity (DAS) for wheat varieties in rabi 2017-18 and 2018-19

	2017-18						2018-19					
	HD-2967 Maturity (DAS)			PBW-502 Maturity (DAS)			HD-2967 Maturity (DAS)			PBW-502 Maturity (DAS)		
Treatments	Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C
D1I1	138	144	140	139	145	140	137	142	140	138	143	141
D1I2	135	135	135	136	139	136	135	138	135	136	139	136
D1I3	132	133	133	133	133	134	132	134	133	133	131	133
D2I1	135	135	135	136	139	136	134	130	134	135	138	135
D2I2	133	134	132	133	133	132	131	131	130	132	132	133
D2I3	129	126	129	130	132	130	129	132	129	130	134	130
D3I1	132	129	131	134	131	134	131	131	130	132	132	131
D3I2	130	127	130	131	132	131	129	132	129	130	134	130
D3I3	127	129	127	128	130	129	126	129	127	128	130	129
Model evaluation indices												
RMSE	APSIM	5.89			5.02			4.82			5.68	
	CERES	3.67			4.45			4.15			4.62	
% RMSE	APSIM	6.35			5.92			5.13			5.82	
	CERES	4.82			5.02			5.02			5.34	
R^2	APSIM	0.84			0.83			0.81			0.83	
	CERES	0.86			0.87			0.84			0.85	

D1-15th November. 25th November and 05thDecember, I1- Five Irrigations, I2-Four irrigations, I3-Three irrigations Obs.-Observed, Sim.-Simulated, Sim.A-Simulated by APSIM model and Sim.C-Simulated by CERES model

found 90.52 q/ha to 118.26 q/ha and 88.40 q/ha to 116.04 q/ha by APSIM and CERES model, respectively. For wheat variety PBW-502 biological yield was observed 86.38 q/ha to 107.72 q/ha while APSIM model simulated 89.67 q/ha to 108.25 q/ha for rabi season of 2018-19. Simulated yield by CERES-wheat model was 88.01 q/ha to 108.40 q/ha.

For the CERES model, the R^2 values range from 0.91

Table 7: Model evaluation indices of evaluating comparative performance of APSIM-Wheat and CERES-Wheat models in predicting biological yield of wheat varieties in rabi 2017-18 and 2018-19

		2017-18						2018-19					
		HD-2967 Biological yield (q/ha)			PBW-502 Biological yield (q/ha)			HD-2967 Biological yield (q/ha)			PBW-502 Biological yield (q/ha)		
Treatments		Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C
D1I1		116.75	119.02	118.04	109.30	113.65	110.07	115.52	118.26	116.04	107.72	108.25	108.40
D1I2		109.92	106.05	110.20	106.24	107.06	106.24	107.42	104.24	107.42	104.32	102.06	103.15
D1I3		97.32	94.54	97.32	94.74	94.70	94.74	101.82	103.07	102.04	98.42	99.98	98.42
D2I1		111.42	108.75	111.42	105.20	102.64	105.20	104.25	101.04	104.25	103.41	103.44	104.20
D2I2		105.74	102.67	105.74	101.65	98.45	101.65	102.86	102.18	101.77	102.71	102.24	102.71
D2I3		93.01	90.20	93.01	90.83	93.72	90.83	95.71	95.70	95.71	91.81	92.74	91.81
D3I1		101.56	98.42	102.56	95.72	92.72	96.20	101.53	98.97	101.67	94.90	97.76	95.20
D3I2		95.09	97.32	94.42	90.80	90.62	91.40	95.17	92.64	95.17	88.80	85.64	89.50
D3I3		84.92	88.92	85.20	82.72	84.15	83.20	87.29	90.52	88.40	86.38	89.67	88.01
Model evaluation indices													
RMSE	APSIM		5.34			4.93			3.14			2.06	
	CERES		3.25			3.70			2.61			1.69	
% RMSE	APSIM		6.14			5.06			4.87			3.56	
	CERES		4.45			4.75			3.14			2.77	
R^2	APSIM		0.83			0.85			0.84			0.85	
	CERES		0.94			0.92			0.91			0.92	

Table 8: Model evaluation indices of evaluating comparative performance of APSIM-Wheat and CERES-Wheat models in predicting grain yield of wheat varieties in rabi 2017-18 and 2018-19

		2017-18						2018-19					
		HD-2967 Grain yield (q/ha)			PBW-502 Grain yield yield (q/ha)			HD-2967 Grain yield yield (q/ha)			PBW-502 Grain yield yield (q/ha)		
Treatments		Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C	Obs.	Sim.A	Sim.C
D1I1		52.32	57.06	53.20	49.09	54.42	51.80	52.46	55.42	55.40	47.92	52.40	48.02
D1I2		50.31	53.32	50.31	47.13	5.047	47.13	47.84	44.72	47.84	46.10	50.20	46.94
D1I3		42.64	45.92	42.20	39.21	42.08	40.72	43.55	46.84	43.55	42.72	45.32	42.72
D2I1		49.81	49.81	49.81	47.17	44.22	47.17	48.19	45.31	48.19	46.84	43.81	46.84
D2I2		48.63	45.15	48.63	46.42	46.42	46.12	47.47	48.14	49.44	47.50	47.10	47.50
D2I3		40.76	42.44	39.61	37.42	39.42	37.42	40.36	40.22	45.24	40.57	42.31	41.55
D3I1		45.40	49.40	46.07	42.09	45.28	42.09	43.64	43.22	42.64	38.67	41.54	39.50
D3I2		43.04	45.67	44.84	40.44	43.42	40.44	42.55	42.36	42.55	36.65	40.14	37.05
D3I3		35.66	40.65	36.52	32.84	34.64	34.83	36.70	38.67	39.82	36.56	39.70	37.67
Model evaluation indices													
RMSE	APSIM		3.48			3.03			5.14			4.06	
	CERES		2.11			2.16			3.16			2.82	
% RMSE	APSIM		3.18			3.66			4.05			5.54	
	CERES		4.66			4.77			3.92			3.15	
R^2	APSIM		0.82			0.81			0.80			0.80	
	CERES		0.90			0.91			0.86			0.84	

D1-15th November. 25th November and 05thDecember, I1- Five Irrigations, I2-Four irrigations, I3-Three irrigations Obs.-Observed, Sim.-Simulated, Sim.A-Simulated by APSIM model and Sim.C-Simulated by CERES model

to 0.94, while for the APSIM model, the R^2 values fall between 0.84 and 0.85. This indicates that the CERES model, with its higher values, more accurately predicts biological yield. The RMSE and % RMSE values also support this trend. In both the rabi season of 2017-18 and 2018-19 the values simulated for biological yield by CERES wheat model were close to the experimental field data.

Grain yield

Grain yield of both the varieties HD-2967 and PBW-502 was recorded in rabi season of 2017-18 and 2018-19. For wheat variety HD-2967 observed yield was 35.66 q/ha to 52.32 q/ha for different treatments of sowing dates and irrigation levels in rabi season of 2017-18(Table8). APSIM model simulated the biological yield 40.65 q/ha to 57.06 q/ha while CERES model simulated 36.52 q/ha to 53.20 q/ha biological yield. For wheat variety PBW-502 observed yield was recorded 32.84 q/ha to 49.09 q/ha in rabi season of 2017-18. Simulated yield was found to be 34.64 q/ha to 54.42 q/ha by APSIM model while CERES model simulated 34.83 q/ha to 51.80 q/ha. In rabi season 2018-19 observed yield for HD-2967 was 36.70 q/ha to 52.46 q/ha. APSIM model simulated the grain yield 38.67 q/ha to 55.42 q/ha while CERES wheat model simulated 39.82 q/ha to 55.40 q/ha. For wheat variety PBW-502 observed yield was 36.56 q/ha to 47.92 q/ha in rabi season 2018-19 while simulated yield was found to be 39.70 q/ha to 52.40 q/ha and 37.67 q/ha to 48.02 q/ha for APSIM wheat and CERES- wheat model, respectively.

Critical analysis of the comparative results between these two models suggested that the simulated days taken to different phenophases*viz.,* anthesis and physiological maturity are closer to observed values then the simulated values by APSIM crop simulation model for both the varieties in the rabi 2017-18 and 2018-19. Biological and grain yield results predicted by the both the models also compared and concluded that after calibration CERES crop growth simulation model predicts more accurate results in comparison to APSIM wheat. For the CERES model, the RMSE values range from 2.11 to 3.16, whereas for the APSIM model, they fall between 3.03 and 5.14. This indicates that the CERES model, with its lower RMSE values, more accurately predicts grain yield. The $R^2$and % RMSE values also support this trend. In both the rabi seasons of 2017-18 and 2018-19, the values simulated for grain yield by the CERES wheat model were close to the experimental field data.Statistical parameters RMSE, percent RMSE and coefficient of determination (R^2) were calculated to compare the output of both the crop growth simulation models. On the basis of these statistical parameters, predicted results by the CERES-wheat model were closer to experimental data for both the years. Even though APSIM crop simulation model also simulated the output within the acceptable range and the model can be used to simulated the yield in the *Tarai* region.

CONCLUSION

Although both the models predicted the phenological events, biomass and grain yield in acceptable accuracy range therefore, these models are very useful tool to predict crop growth, development biomass and yield without conducting field trials. Critical analysis of the simulated output on the basis of statistical indicators showed that the predicted values of phenological events anthesis (DAS), maturity (DAS) and yield parameters i.e., biomass and grain yield by the CERES-Wheat model are closer to the field data then APSIM-Wheat model.

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Received: July 18, 2024
Accepted: August 02. 2024