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Calibration and Validation of Reproductive Stages of Wheat Varieties with CERES-Model under Sowing Environments in Irrigated Conditions of Jammu, India

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Impact of heat stress during March and April months have significant reflections on the occurrence of phenological stages of wheat. The current investigation aimed to analyze the impact of three varieties of wheat planted in three different environments (dates of sowing) and three levels of nitrogen to study their effects with respect to the occurrence of reproductive stages. Field experiments were conducted with three wheat varieties *viz.*, HD 2967, RSP 561 and WH 1105, which were sown in 3 sowing environments/dates, *viz.*, 25th October-early, 14th November-normal and 4th December-late and 3 levels of nitrogen, *viz.*, 100, 125 and 150 kg/ha randomized in 3 replications under a split-split plot design in *rabi* season 2015–16 and 2016–17. The experiment was sown at the Agromet Research Farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (SKUAST-J), Chatha. Experimental conditions and results obtained from the experiments were used as a database for calibration of Crop Environment Resource Synthesis (CERES)-a Wheat model under Decision Support System for Agrotechnology Transfer (DSSAT) version 4.6 package for studying the effects of changing climatic conditions on wheat phenology. The varietal specific genetic coefficients were calibrated and validated for all the 3 wheat varieties. On comparison of the results obtained from the calibration and validation data of various wheat varieties; the researchers came to a very good and valid conclusion to predict the days of occurrence of various phenological stages of wheat. The parametres R^2, d-stat, RMSE and nRMSE were used for comparing CERES-Wheat model results with the actual data and the values were excellent.

Keywords: DSSAT 4.6, Heat stress, Nitrogen levels, Phenology, Thermal indices

Introduction

In India, wheat crop is considered as the 2nd staple food after rice which is grown in about 31 million hectares area with the annual production and productivity to the tune of 99.70 mt and 3.60 t/ha, respectively.[1] Under the existing changing climatic conditions, the researchers are facing very challenges to acquire elevated grain yield of various crops to feed the growing population in the entire globe. The various agronomic interventions *viz.,* sowing environments, varieties; fertilizer management which are also non-monetary inputs, involve very less expenditure and could be well handled and could be used as a tool for enhancing wheat yield in Jammu area of J&K UT. Intergovernmental Panel on Climate Change[2] (IPCC) from its vide study inferred that there will have a key impact on the production of various crops due to changing climatic conditions which are occurring globally. A yield loss to the tune of 20–30% has been expected in developing countries by the year 2050, which will be primarily due to the predicted temperature increase of 2–3°C.[3] A decrease in wheat yield to the tune of about 450 kg/ha in N-W plain zone has been estimated by various researchers with 0.5°C rise in winter temperature.[4] The agronomic management practices like a suitable non-monetary adjustment in time of planting could be a better adjustment so that the various critical physiological stages of wheat crop could coincide with the suitable environmental conditions during the entire crop growth cycle, which might result in obtaining higher production and productivity of wheat crop under irrigated sub-tropical conditions.[5,6]

During the last one and a half decade, the Indo-Gangetic plains are experiencing higher temperatures

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in the range of 3–6°C during March/April months, which resulted in early maturity of wheat crop by 10–20 days; thereby the production of wheat crop has been dropped by about 4 MTs.[7,8] In the various major wheat growing areas, a temperature of 35°C during the grain development/reproductive stages, which have reduced the yield. For each degree rise in temperature in the plains, a yield loss of 3 to 17 per cent is estimated by researchers in the plains of N-W India and Pakistan.[9] The most imperative time during the wheat growth period is the 2nd fortnight of March and in this period the temperature higher than its normal could cause a drastic decline in the production/productivity of the crop.[10] A reduction in wheat yield to the tune of 0.6–8.9% was also reported with per 1°C rise in temperature.[11,12]

Due to these climatic changes, it is necessary to amend the sowing calendar of wheat crop which might cope up with these natural changes, and could prevent the early occurrence of reproductive stages like anthesis and physiological maturity which are in vogue due to these naturally modified climatic conditions. Meanwhile, suitable varieties of wheat can also be selected and might be evaluated under changing climatic scenario.[13,14] However, the role of various wheat varieties planted at different sowing environments and their effect on duration of reproductive stages is not yet well understood particularly for this region.

Agronomic crop management strategy evaluation could be well established through crop simulation models.[15] The estimation of consequences of changing climatic conditions could be done well through crop growth models.[16–18] DSSAT system of crop modelling has been found to be one of the most efficient system for crop modelling.[19,20]

Hence, considering these parameters, the study has been conducted with the objectives listed below:

(1) Estimation of the changes in duration of reproductive phenophases in varieties of wheat crop sown under various environments (dates of sowing) and N-levels; and

(2) To validate wheat phenophases as affected by different sowing environments through CERES-Wheat model.

Materials and Methods

Study Area and Experiments

Jammu province of Jammu and Kashmir UT is located in low altitude and lower hills of Shivalik range of Himalayas broadly falling under the north-west plain zone. The trials conducted in *rabi* seasons of 2015–16 and 2016–17 at Agromet Research Farm, SKUAST-J (Latitude 32°39′ N, longitude 74°58′ E and 332 m above mean sea level), J&K UT. Three wheat varieties (HD 2967, RSP 561 and WH 1105), three sowing environments (25th October-early 14th November-normal and 4th December-late) and three levels of nitrogen (100, 125 and 150 kg/ha) were randomly arranged in main, sub and sub-sub plots, respectively in split-split plot design with three replications.

Weather Parametres

Meteorological data was taken from the Agrometerological Observatory of SKUAST-J, Chatha which is located near the experimental site (Fig. 1). The occurrence of phenological stages; anthesis and physiological maturity was observed visually and noted.[21]

Agrometerological Indices

The formulae for various indices were computed by following the standard procedures as follows:

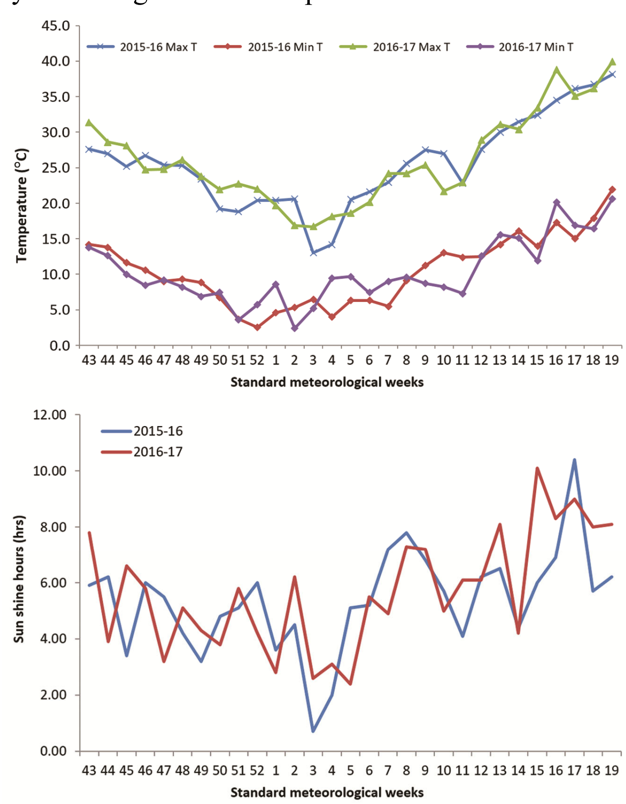

Fig. 1 — Maximum, minimum temperature (°C) and sun shine (hrs) during wheat growing seasons (*rabi* 2015–16 and 2016–17)

Growing Degree Days (GDD)[22]

$$GDD = \sum_a b \frac{[Tmax + Tmin]}{2} - T_b$$

where, T_{max} is the daily maximum temperature ($^{\circ}$C), T_{min} is the daily minimum temperature ($^{\circ}$C) and T_b is the base temperature (5°C).

Helio thermal units[23]

HTU = ∑GDD × sun shine hrs (actual)

Photo Thermal units (PTU)[24]

PTU = ∑GDD × maximum possible sun shine hrs

Photo Thermal Index (PTI)[25]

$$PTI = \frac{\text{Degree days consumed for a particular event}}{\text{Number of days to complete that event}}$$

Crop Growth Modelling

An international set up of researchers working in International benchmark Site Network for Agrotechnology Transfer Project (IBSNAT)[26,27] developed the decision support system for agrotechnology transfer (DSSAT) for facilitating application of various crop models in a approachable system for agronomical researches. Advanced version (4.6) of the model has been used in this study which had helped the researchers to predict growth, development and response of different varieties of wheat crop to various dates/sowing environments and levels of nitrogen.

One of the most highly reliable and widely accepted models is Cropping System Model (CSM); this model has worked well under diverse climatic conditions in various regions of the world.[28,29]

CERES-Wheat Model Input Files

The minimum data sets which is mainly required by CERES-Wheat model includes weather file (WTH) which includes detailed weather parameters, site information; soil file (SOL) which includes detailed information regarding the soil of the experimental area, crop management file (WHX) which contains crop data and other specific parameters (Table 1).

Calibration of CERES-Wheat Model

Genetic coefficients of different varieties of wheat were calibrated with the help of observed weather data and soil parametres and crop management data of *rabi* season of 2015–16 as per the various sowing environments and levels of nitrogen (Table 2). By running CERES-Wheat model, estimation of genetic coefficients of varieties of wheat was done with the best matched values; and the values were taken from the genetic coefficients file of CERES-Wheat model under nearly similar conditions (Table 3).

Validation of CERES-Wheat Model

Accuracy of CERES-Wheat model simulations assessed through the data of different varieties of wheat sown in various sowing environments and levels of nitrogen for *rabi* season 2016–17.

Table 1 — Depth wise physical and chemical characteristics of the soil

Depth (cm)	pH	CEC (meq/100 g)	OC (%)	Sand (%)	Silt (%)	Clay (%)
0–15	7.5	9.8	0.38	78.0	8.4	13.6
15–30	7.6	9.8	0.38	78.0	8.4	13.6
30–45	7.6	9.7	0.33	78.4	8.2	13.4
45–60	7.8	8.6	0.28	79.3	7.6	13.1
60–75	8.2	7.2	0.18	79.7	7.8	12.5
75–90	8.4	5.0	0.11	80.4	7.9	11.7

CEC: Cation exchange capacity; meq/100 g: Milliequivalents per 100 g of soil; OC: Organic carbon

Table 2 — Details of genetic coefficients of CERES-Wheat model

Genetic coefficients	Details
P1V	Days, optimum vernalizing temperature, required for vernalization (in days)
P1D	Photoperiod response (% reduction in rate/10 h drop in pp)
P5	Grain filling (excluding lag) phase duration (°C.d)
G1	Kernel number per unit canopy weight at anthesis (#/g)
G2	Standard kernel size under optimum conditions (mg)
G3	Standard non-stressed mature tiller wt (including grain) (g)
PHINT	The interval between successive leaf tip appearances (in degree days)

Table 3 — Genetic coefficients of wheat varieties used for CERES-Wheat version 4.6 model

Wheat varieties	Genetic coefficients						
	P1V	P1D	P5	G1	G2	G3	PHINT
HD-2967	36	60	520	19	42	2.9	135
RSP-1105	40	57	516	20	41	3.1	130
WH-1105	37	58	525	21	40	3.0	125

Table 4 — Average measured values of vegetative, reproductive and total growth period of wheat and calculated thermal indices in each period

Particulars		Sowing Environments								
		Early (25th October)			Normal (14th November)			Late (4th December)		
		2015–16	2016–17	Mean	2015–16	2016–17	Mean	2015–16	2016–17	Mean
Growing Period (in days)	VGP	110.2	112.4	111.3	106.0	108.8	107.4	98.1	102.4	100.3
	RGP	48.3	50.1	49.2	43.2	42.5	43.8	37.2	39.2	38.2
	TGP	158.5	162.5	160.5	149.2	151.3	151.2	135.3	141.6	138.5
Growing degree days-GDD (°C day)	VGP	985.1	1067.0	1026.1	905.9	976.3	941.1	795.1	860.1	827.6
	RGP	748.1	739.5	743.8	703.8	682.2	693.0	724.6	789.1	756.9
	TGP	1733.2	1806.5	1769.9	1613.7	1658.5	1636.1	1519.7	1649.2	1584.5
Helio Thermal Units-HTU (°C days hour)	VGP	5132.6	5242.1	5187.4	4977.4	4887.1	4932.3	4467.7	4424.2	4445.9
	RGP	4018.8	4686.2	4352.5	3605.2	4648.5	4126.9	3729.2	4401.0	4065.1
	TGP	9151.4	9928.3	9539.9	8582.6	9535.6	9059.1	8196.9	8825.2	8511.1
Photo Thermal Units-PTU (°C days hour)	VGP	10642.3	11484.3	11063.3	9406.7	10628.2	10017.5	8947.6	9614.3	9280.9
	RGP	8077.1	8009.2	8043.2	8335.7	8207.7	8271.7	8246.7	8468.8	8357.8
	TGP	18719.3	19493.5	19106.4	17742.4	18835.9	18289.2	17194.3	18083.1	17638.7
Photo Thermal Index-PTI (°C days/day)	VGP	8.96	9.53	9.25	8.55	9.04	8.79	8.11	8.43	8.27
	RGP	14.96	14.79	14.88	16.37	16.24	16.31	18.58	20.23	19.41
	TGP	10.83	11.15	10.99	10.83	11.06	10.95	11.09	11.70	11.40

VGP- Vegetative growing period; RGP- Reproductive growing period; TGP- Total growing period

Model Evaluation

Accuracy of the model results were examined through various parameters like coefficient of variation (R^2), Wilmot's index of agreement (d)[30], Root Mean Square Error (RMSE)[31] and normalized RMSE (nRMSE).[32] If the values of regression are close to 1, the correlation between simulated and observed values is considered to be high.[33] Generally the models are considered to be acceptable if the R^2 values are greater than 60 per cent.[34] If the nRMSE values are < 10%, the fitting degree is very good. If nRMSE is in the range of 10–20%, it is considered to be good. But, when nRMSE value is > 20%, the appropriateness of the model is general.[35]

Results

Crop Growing Seasons and Weather Variability

The observed values of maximum and minimum temperature recorded to be 23.7 and 9.0, 24.2 and 9.2, 24.3 and 9.3°C during *rabi* season 2015–16 and 24.7 and 9.3, 24.6 and 9.3, 24.9 and 9.7°C during 2016–17 for early, normal and late sowing environments, respectively. The mean sunshine hours recorded were 5.1, 5.1 and 5.2 hours during *rabi season* 2015–16 and 5.4, 5.5 and 5.6 hours during 2016–17 for early, normal and late sowing times, respectively (Fig. 1).

Phenology of Wheat

Wheat crop sown in earlier environment (25th October) took higher days to complete growing periods than 14th November (normal) and 4th December (late) sowings. Also, early sown wheat (25th October) contained extra time to complete the phenophase *viz.*, grain filling period. In case of delayed sowing, the reproductive stage started earlier and also took less no. of days (39) to accomplish the grain filling stage, in comparison to early and normal sown wheat crop (Table 4). The reason behind the earlier accomplishment of the reproductive stage by the wheat crop sown under late conditions (04th December) could be due to higher values of maximum and minimum temperature than the normal temperature during these stages.

Thermal Indices

Various sowing environments of wheat crop depicted different values of GDD, PTU and HTU;

however, the values consumed by early sown wheat to attain different growing periods were higher than 14th November and 4th December sown crops (Table 4). Whereas, the values of PTI were higher under normal and late sown crop than early wheat crop for reproductive growing period. Possible reasons behind this phenomenon of the higher values of agrometerological indices might be more number days for attaining various phenological stages in the wheat crop sown on 25th October (early) in comparison to the crop planted on 14th November (normal) and late (4th December) sown wheat.

Calibration of CERES-Wheat Model

CERES-Wheat model was used for the calibration of the wheat varieties sown under early, normal and late sowing environments *viz.*, 25th October, 14th November and 04th December dates and levels of nitrogen. The actual data for various parameters of *rabi* season 2015–16 was compared with model output data by iterative modifications in genetic coefficients until the measured and predicted values were closely matched (Table 3). R^2, RMSE, d-stat and nRMSE values for calibration of days to phenophases (anthesis and physiological maturity) of three varieties of wheat were in range of 0.91 to 0.97, 1.97 to 8.21, 0.80 to 0.99 and 1.89 to 5.43, respectively (Table 5).

CERES-Wheat Model validation

The period of days to attain to various phenological stages like anthesis and physiological maturity of varieties of wheat *i.e.,* HD 2967, RSP 561 and WH 1105 were very closely simulated by the model and were in close concurrence with actual field observations (Table 6).

The variation in observed and simulated values varied from 2 to 3 days for anthesis, whereas, days taken for physiological maturity by wheat varieties varied by about 3 to 9 days by the model; R^2 and d-stat values were acceptable.

Sowing Environments

Sowing environments has a pronounced effect on duration of accomplishment of anthesis and physiological maturity. R^2 values for calibration for number of days for attaining the phenological stages *i.e.*, anthesis and physiological maturity in wheat through CERES model was 0.95 and 0.86, respectively (Figs. 2 a & b). RMSE and nRMSE values for calibration of duration of anthesis in wheat were 2.6 and 2.4, respectively during *rabi* season 2015–16 (Fig. 2a). However, for calibration of physiological maturity of wheat, the values of RMSE and nRMSE were 5.5 and 3.7, respectively during *rabi* season 2015–16 (Fig. 2b). Days to anthesis and maturity were calibrated well through the model in 2nd

Table 5 — Calibration of phenology of wheat varieties through CERES-Wheat model

Varieties	Growth stages	Phenology (in days)		SD		R^2	RMSE	d-stat	nRMSE
		O	S	O	S				
HD 2967	Anthesis	110	111	5.91	6.61	0.97	1.97	0.89	1.89
	Maturity	148	146	8.65	8.72	0.91	3.49	0.80	2.36
RSP 561	Anthesis	107	110	6.30	5.77	0.96	3.23	0.89	3.01
	Maturity	147	144	7.68	8.32	0.97	3.13	0.91	2.13
WH 1105	Anthesis	108	110	6.86	6.61	0.96	2.30	0.87	2.13
	Maturity	151	145	13.78	8.26	0.97	8.21	0.99	5.43

O: Observed, S: Simulated

Table 6 — Validation of phenology of wheat varieties through CERES-Wheat model

Varieties	Growth stages	Phenology (in days)		SD		R^2	RMSE	d-stat	nRMSE
		O	S	O	S				
HD 2967	Anthesis	110	112	3.87	3.28	0.91	2.98	0.82	2.72
	Maturity	150	147	8.99	7.94	0.88	4.23	0.92	2.82
RSP 561	Anthesis	108	111	4.69	2.78	0.95	2.93	0.91	2.70
	Maturity	149	146	6.90	7.6	0.82	4.26	0.86	2.86
WH 1105	Anthesis	113	111	5.91	3.0	0.90	3.41	0.95	3.03
	Maturity	155	146	12.4	8.0	0.86	10.2	0.89	6.60

O: Observed, S: Simulated

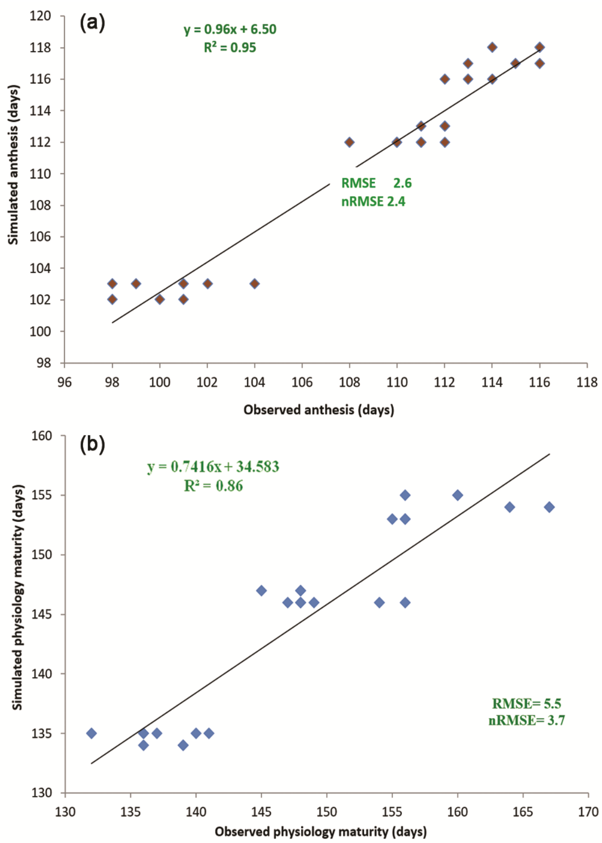

Fig. — 2(a) Calibration of days to anthesis of wheat (*rabi* 2015–16), and (b) Calibration of days to physiological maturity of wheat (*rabi* 2015–16)

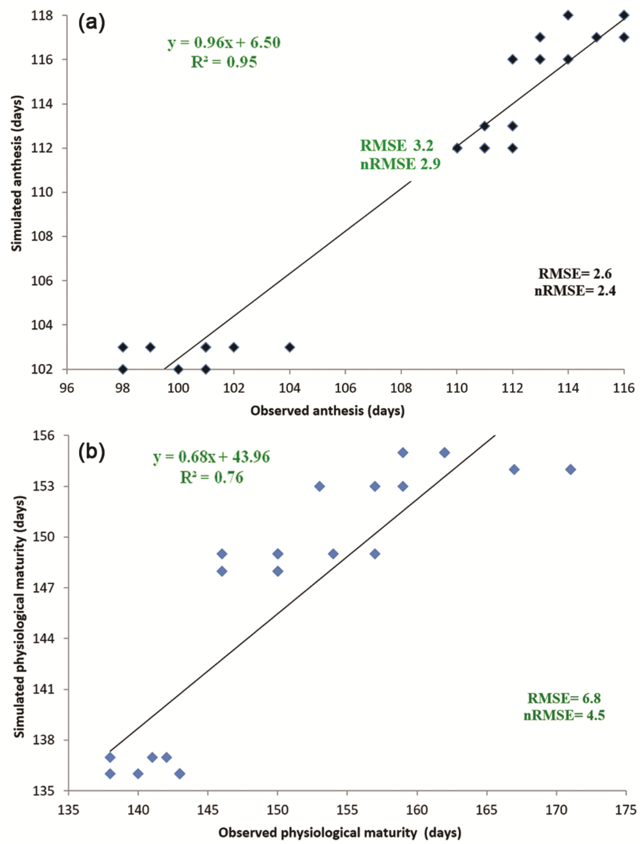

Fig. — 3(a) Validation of days to anthesis of wheat (*rabi* 2016–17), and (b) Validation of days to physiological maturity of wheat (*rabi* 2016–17)

year of experimentation (Figs. 3a & b). The R^2 value between simulated and observed days from sowing to anthesis and physiological maturity of wheat was to the tune of 0.79 and 0.76, whereas the values obtained for RMSE & nRMSE were 3.2 and 6.8 & 2.9 and 4.5, respectively.

Discussion

Wheat crop sown on 25th October took more days for reproductive stages; which could be because of the possible reason that wheat has sturdy vegetative growth during that phase and the genetic mechanisms that regulate flowering transition which resulted in delayed heading. Also the early sown wheat crop experienced lower maximum and minimum temperature during vegetative stage due to which the stage was prolonged. Earlier researchers have also reported higher days for heading in wheat crop sown on 25th October.[36] The duration of various phenophases of wheat were shortened under late sown conditions (4th December); which was mainly due to the fact that after the anthesis stage of wheat, there was an abrupt rise in temperature (maximum and minimum), which might have resulted in the shortening of the later growth stages especially reproductive stages which might have resulted in early maturity of wheat.[37]

The most possible reason for fewer number of days taken by wheat crop sown under normal sowing environment (14th November) for attaining reproductive stage as compared to 25th October (early) sown crop might be due to the fact that the temperature (maximum and minimum) were above their respective normals by about 3 & 1°C, respectively during 50% flowering (anthesis) stage in wheat crop sown on 14th November (normal) in Ist year of experimentation (2015–16). However, during the cropping season 2015–16, the wheat crop experienced about 2 & 1.5°C higher temperature (maximum & minimum), respectively above than their respective normals during the milking stage.

Various researchers had also reported a reduction in the duration of reproductive stage of wheat crop due to rising of temperature (3°C) during this stage and also considered it as the most critical stage.[10] A reduction in grain yield of wheat was also reported due to higher minimum temperature under irrigated conditions of Jammu region.[38,39] Comparatively lesser grain production of wheat crop sown on 14th November (normal) in *rabi* season of 2016–17 was also due to 2°C higher maximum temperature than normal during the grain development stage. Development of grains during reproductive stage is an important event; and during this period, early sown wheat crop (25th October) receive optimum temperature, and because of this fact the grain production of wheat crop was higher in the early sown (25th October) crop. Whereas, the crop sown on 4th December, experienced higher temperature during anthesis and physiological maturity; because of that the number of days for reproductive stage were reduced and thus also yield was decreased than early and normal period of sowings of wheat.[40]

Temperature above normals during the vegetative and grain development stage (reproductive stage) in the later sowings (14th November-normal and 4th December-late) might have resulted in quickly accomplishment of the phenological stages and thus accumulated comparatively lesser thermal indices values.[41]

The nRMSE values for all the three varieties were on excellent range (< 10%).[42] The R^2 values were above 0.80 of both anthesis and maturity for all the three varieties. Amongst the varieties, the differential response to days to anthesis and maturity might be due to genetic makeup of the varieties.[43]

Various researchers have noted a good agreement amid simulated and observed values for the reproductive phenophases like anthesis and physiological maturity in wheat with R^2 and RMSE values to the tune of 0.55, 0.68 and 4.4, 4.92 respectively.[43,44]

The validated values of d stat and R^2 to 0.60 & 0.73, respectively indicated that the model had been well calibrated and validated with respect to the das for attaining various phenophases of wheat crop under sub tropical irrigated conditions of Jammu region.[10]

Conclusions

The CERES-Wheat model could be applied for the simulation of growth and reproductive stages of wheat varieties under varied sowing environments. The duration of different phenophases could be well estimated through this model under irrigated sub tropical conditions of Jammu region. The best sowing environment for wheat crop comes out to be early sowing (25th October) for the better growth and development of wheat crop. And it also escapes the higher maximum and minimum temperature which generally prevails during the grain development stage of wheat crop. CERES-model also provides the insights about the response mechanism of varieties of wheat to be sown under different dates and levels of nitrogen. CERES-Wheat model's calibration and validation techniques could be well used as a management tool to determine the proper sowing date or variety and N-level, taking into account the unpredictability of weather and other linked factors.

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