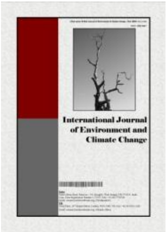

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Performance Evaluation of DSSAT CERES Wheat Model under Different Thermal and Irrigation Regimes at Prayagraj

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Authors' contributions

This work was carried out in collaboration among all authors. Author LPA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. SR and SG managed the analyses of the study. Author SG managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The present study was planned to determine the phenology and heat unit requirement of promising wheat varieties under different crop growing environment of Prayagraj, India. Delay in sowing of wheat results into reduction in the grain yield as the crop exposes to high temperature at phenological stages. A field experiment on wheat (variety PBW-502) was conducted at the farm nursery, College of Forestry, SHUATS, Prayagraj during *rabi* seasons of 2018-19 and 2019-20. The experiment was conducted in factorial randomized block design and replicated thrice with three dates of sowing and five irrigation levels. The yield attributes (grain and biological yield) were significantly influenced by sowing dates and irrigation levels. The significantly highest grain and biological yield were recorded in crop sown on 17th November as compared to other dates of sowing. Among different irrigation levels, grain and biological yield were significantly more in I5 (CRI+ tillering + jointing + anthesis + maturity) treatment over the other irrigation levels. DSSAT CERES-Wheat model suggests good model performance at optimum irrigation at Prayagraj under stress condition.

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Keywords: Crop growing environment; DSSAT; Irrigations, Triticum aestivum; weather parameters

1. INTRODUCTION

The second most significant cereal crop in the world is wheat (*Triticum aestivum L*.). Globally, it is a thermo-sensitive, long-day crop. Wheat productivity and growth are influenced by a variety of meteorological conditions, primarily temperature [1]. It necessitates mild temperatures during the vegetative stage and high temperatures during the maturation stage. Heat units are critical for crop development, and these can be created using increasing degree days (GDD). Increased temperature throughout the phenological stages of grain development will lead to lower yield due to delay in wheat sowing. When the temperature and heat units are above the base temperature, growth occurs. When the units are below the base temperature, no growth happens [1].

Wheat sowing time is an essential aspect that impacts crop phenology and the efficiency with which biomass is converted into economic output. Compared to late sowing, normal sowing has a longer growth duration and, as a result, allows for the accumulation of greater biomass, which is represented in higher grain production [2]. A larger yield can be achieved by increasing irrigation, which is vital for growth and development [3]. When temperatures rise during the reproductive stage of a newly seeded crop, water stress can occur, reducing output. The late-planted wheat crop necessitates more water than the early-planted wheat crop. The lack of water for irrigation supplies has become an issue in many regions. Farmers must maximize water availability, which demands knowledge of irrigation. Wheat crop output and its components are heavily reliant on irrigation management, according to numerous studies. Providing irrigation at important stages of crop growth (CRI, Tilllering, Jointing, Anthesis and Maturity) results in the highest crop output [4]. According to research, phenological stages can be completed in less time when crops are exposed to moisture stress [5].

In order to assess the growth, development, yield, irrigation, and N uptake of numerous crop species, the Decision Support System for Agro-technology Transfer (DSSAT) is the most extensively used model package [6]. Globally, the DSSAT model has been widely used to model crops in a variety of environmental situations, including diverse management approaches, climate changes, and irrigation management [7] & [8]. Wheat maturity was accelerated in North Indian conditions by a steady rise in ambient temperature due to delayed planting. As a result, knowing the duration of phenological stages in a certain crop-growing environment and their impact on crop yield becomes absolutely necessary. In order to find out the phenology and heat unit requirements of promising wheat variety grown in Prayagraj conditions with various crop environments, an experiment was designed.

2. MATERIALS AND METHODS

2.1 Experimental Details

A field experiment on wheat (PBW-502) was conducted at the farm nursery of College of Forestry, SHUATS, Prayagraj during the *rabi* seasons of 2018-19 and 2019-20. The experiment was conducted in factorial randomized block design with three dates of sowing (D1=17th November, D2=02nd December and D3=17th December) with five irrigation levels (I_1 = CRI, I_2 = CRI + tillering, I_3 = CRI + tillering +jointing, I_4 = CRI+ tillering + jointing + anthesis and I_5= CRI+ tillering + jointing + anthesis + maturity). A recommended common fertilizer dose of 120, 60 and 40 kg ha^{-1} of N, P and K, respectively was applied during both the experimental years.

2.2 Agrometeorological Indices

The Agrometeorological observatory SHUATS, Prayagraj, recorded daily meteorological data, including maximum and minimum temperatures (°C), rainfall (mm), relative humidity (percent), sunshine duration (hours), wind speed (km/hr) and other variables. Following formulae were used to construct agrometeorological indices like Growing Degree Days (GDD), Phenol-Thermal Index (PTI), and Heat Use Efficiency for both biological (HUE_{BY}) and grain yields (HUE_{GY}):

In order to compute the growing degree days, daily mean temperatures and the base temperature of the crop being considered are used together.

The growing degree days are calculated with daily mean temperature and base temperature of considered crop.

Growing degree days (^oC days) = $(Tmin + Tmax/2 - Tb$

Where,

Tmin = Daily minimum temperature (^oC),

Tmax = Daily maximum temperature (^{o} C)

And

Tb = Base temperature for wheat crop (5^oC).

Heat use efficiency were calculated as

$HUE_{GY}= GrainYield\ (Kg\ /ha)\ /AccumulatedGDD$

$HUE_{By=}\ BiologiclYield\ (Kg\ /ha)/\ AccumulatedGDD$

Pheno-thermal index is the ratio of degree days to the number of days between two phenological stages, and was calculated as:

$PTI\ =\ Gddbetweentwophenologicalstages/\ No.ofdaystakenbetweentwophenophases$

Statistical analysis has been done by using the pooled data for two seasons (2018-19 & 2019-20) for different phenological stages, agrometeorological indices, yield & biomass with help of OPSTAT software [9].

2.3 CERES-wheat Model

The Decision Support System for Agrotechnology Transfer (DSSAT) has an inbuilt application programme called the CERES-Wheat model, which is a simulation model. Plant development and yield are simulated in response to various environmental conditions (soils, weather and management). Adjusting crop parameters to account for phenological characteristics and yield using experimental fields in 2018-2019 allowed for accurate calibration of CERES wheat model. Table 1 shows the calculated crop genetic coefficients. As an added measure of model utility, the CERES-wheat model was verified using field data from the wheat crop in 2019-20, which compared the actual results to those predicted using various sowing dates and irrigation times. MSE, RMSE, Model Efficiency, and the Agreement Index were used to gauge the model's correctness.

3. RESULT AND DISCUSSION

3.1 Crop Phenological Stages

Temperature has a significant impact on plant growth and phenological stages, thus it's important to pay attention to it. Wheat is grown in *rabi* season, these crops are prone to high temperature at reproductive stages under varied environmental circumstances. Table 2 shows the days leading up to various phenological stages of the wheat crop, depending on when it was sown and how much irrigations was applied. In comparison to alternative sowing dates, the timely sown crop (17^{th} November) required fewer days to achieve CRI and tillering stages. In the timely sown crop (17^{th} November), temperatures were higher at CRI and tillering stages than at other sowing dates. While the other phenophase i.e. jointing to physiological maturity took more number of days to attain in normal date of sowing, followed by 02^{nd} December and 17^{th} December grown crop. Crops sowed on November 17^{th}, December 02^{nd}, and December 17^{th} required 120 days, 113 days, and 109 days, respectively, to reach physiological maturity. Analyses of irrigation data showed that it had little effect on CRI stage. The days needed to reach physiological maturity were 113 days in irrigation level I1, 114 days in irrigation levels 2 and 3 (I2 & I3), and 115 days in irrigation levels four and five (I4&I5). Observed similar results for varied dates of sowing and irrigation methods [3].

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3.2 Growing Degree Days (GDD)

The GDD was calculated from CRI stage to physiological maturity. Table 3 has shown the impact of date of sowing and irrigation on GDD. It has been observed that there was a direct relation of temperature on plant growth development. With the exception of physiological maturity, the GDD declined as the planting date was postponed (Table 3). It may be because there were less growing days in a late-planted crop. GDD was 1527.6^0C, 1476.6^0C, and 1526.4^0C for crops sown on November 17^{th}, December 2^{nd} and December 17^{th} respectively, from the time of sowing until maturity. Similar results of heat units under delayed sowing were reported by [10] as well. From the tillering stage until anthesis, irrigation treatments were crucial. When compared to alternative planting dates, an early wheat crop exhibited sufficient heat unit requirements.

3.3 Yield and Heat Use Efficiency (HUE)

Sowing dates and irrigation levels had a considerable impact on grain and biological yield characteristics (Table 4). Crops sown on November 17 had significantly higher at grain and biological yields than late sown crop. Grain and biological yields were considerably higher in (I5), where five irrigations were given at different standard stages than other irrigation levels among different irrigation treatment.

Heat use efficiency measures how quickly a plant can reach the dry matter harvesting stage for every unit of heat input. Different dates of sowing and irrigation levels were used to calculate HUE for grain and biological yield. Heat use efficiency decreased in late-planted crops, as measured by grain and biological yield. In terms of grain and biological yield, the maximum HUE i.e. 2.29 kg ha-1°C days and 8.73 kg ha-1°C days respectively were found in crops sown on the 17^{th} of November, while the lowest HUE values were found in late-planted crops (17^{th} December crop). The fifth irrigation treatment (I5) exhibited significantly greatest HUE for grain production (3.5 kg ha-1°C days) as well as biological yield (9.8 kg ha-1°C days) among different irrigation treatments. As a result, HUE found that in both years, grain and biomass yields were best in well-irrigated techniques and lowest in water stress situations [10] & [11].

3.4 Pheno-thermal Index (PTI)

The PTI is expressed as growing degree days per growth days. It uses thermal units to represent phenological behaviour. The early sowed crop had the highest PTI, measuring 17.6^{0}C at maturity (Table 5). The findings revealed some differences in PTI across the phenological life cycle. Tillering and anthesis are the two stages where Pheno Thermal Index decreased. The results of the statistical study showed that the date of sowing has a considerable impact. There was no discernible difference in CRI or anthesis phases based on irrigation amounts [3,10,12].

Table 1. Calibrated genetic coefficients of wheat cultivar

Code	Parameters	PBW -502
P1V	Days at optimum vernalizing temperature required to complete vernalization.	15
P1D	Percentage reduction in development rate in a photoperiod 10 hour shorter than the threshold relative to that at the threshold.	100
P5	Grain filling (excluding lag) phase duration (^{o}C. d)	999
G1	Kernel number per unit canopy weight at anthesis (#/g)	50
G2	Standard kernel size under optimum conditions (mg)	60
G3	Standard, non-stressed dry weight (total, including grain) of a single tiller at maturity (g)	3.5
PHINT	Interval between successive leaf tip appearances (^{o}C. d)	150

Table 2. No. of days to achieve crop phenological stages of wheat on different date of sowing and irrigation levels (Pooled data of 2018-19 and 2019-20)

Treatments	CRI	TILLERING	JOINTING	ANTHESIS	MATURITY
			Sowing Time		
17 Nov	23	43.	66	82	120
02 Dec	24	45	65	80	113
17 Dec	25	45	64	77	109
CD at 5%	0.48	0.409	0.49	0.53	1.46
			Irrigation Levels		
I1	24	45	66	80	113
I2	24	45	65	80	114
I3	24	44	65	80	114
I4	24	44	65	79	115
I5	24	44	64	79	115
CD at 5%	N/A	0.52	0.64	0.69	N/A

Table 3. Accumulated heat units (°C day) of wheat on different date of sowing and irrigation levels (Pooled data of 2018-19 and 2019-20)

Treatments	CRI	TILLERING	JOINTING	ANTHESIS	MATURITY
		Sowing Time			
17 Nov	398.4	683.3	924.7	1118.8	1527.6
02 Dec	375.2	611.2	848.3	1019.3	1476.6
17 Dec	335.6	565.2	843.7	1006.1	1526.4
CD at 5%	6.7	5.3	6.5	8.7	20.9
		Irrigation Levels			
I1	369.2	630.4	880.0	1057.0	1472.8
I2	372.6	623.7	875.5	1054.3	1523.8
I3	367.8	620.0	872.4	1048.2	1514.0
I4	366.8	612.8	869.6	1040.5	1520.6
I5	372.4	612.7	863.7	1040.4	1519.4
CD at 5%	N/A	6.9	8.4	11.2	27.0

Table 4. Yield and heat use efficiency (HUE) of wheat on different date of sowing and irrigation levels (Pooled data of 2018-19 and 2019-20)

Treatments	Yield		Heat Use Efficiency	
	Grain (t/ha)	Biomass (t/ha)	HUE on grain yield basis (kg ha^{-1} °C day^{-1})	HUE on biological yield basis (kg ha^{-1} °C day^{-1})
		Sowing Time		
17 Nov	3.7	13.8	2.29	8.73
02 Dec	3.4	13.0	2.27	8.49
17 Dec	3.2	12.5	2.10	8.44
CD at 5%	0.09	0.8	0.06	0.12
		Irrigation Levels		
I1	1.42	11.3	0.9	7.3
I2	2.68	12.2	1.7	7.8
I3	3.49	13.4	2.2	8.6
I4	4.33	14.1	2.7	9.1
I5	5.54	14.6	3.5	9.8
CD at 5%	0.12	1.09	0.08	0.16

Table 5. Pheno thermal index (PTI) of wheat on different date of sowing and irrigation levels (Pooled data of 2018-19 and 2019-20)

Treatments	CRI	TILLERING	JOINTING	ANTHESIS	MATURITY
		Sowing Time			
17 Nov	17.6	10.8	15.5	16.5	17.6
02 Dec	15.0	8.46	14.5	144	13.7
17 Dec	12.5	8.41	14.4	13.4	16.3
CD at 5%	0.2	0.2	0.4	0.9	0.7
		Irrigation Levels			
I1	14.9	8.8	14.5	15.6	16.8
I2	15.2	9.16	14.9	15.4	15.2
I3	15.1	9.14	14.7	14.7	15.3
I4	15.2	9.4	14.4	14.1	14.8
I5	14.9	9.6	15.4	14.1	17.2
CD at 5%	N/A	0.3	0.6	N/A	0.9

3.5 Calibration of CERES-wheat Model

The calibration was done for phenological parameters like days to emergence, anthesis, maturity and leaf area index for the period 2018-2019 of wheat crop (Figure 1). The RMSE was found less between observed and simulated phenophases of wheat crop. Table 6 shows that model is able to simulate the grain yield for most of the treatments. The highest simulated grain yield by DSSAT was observed at maximum irrigation levels. For this study, DSSAT model underestimated yield of wheat crop for three different sowing time (Table 6). Similar findings were found at [13,14,15].

3.6 Validation of Model at Irrigation Scheduling on Yield

The calibrated genetic coefficients are used to validate the model for the period 2019-2020. The minimum wheat yield was observed at single irrigation and highest yield was recorded at maximum irrigation levels at critical stages of wheat (Table 7). The accuracy of DSSAT model results were checked by different statistical parameters. The MSE, RMSE, Model Efficiency & Agreement Index values has been shown in the table 7. The highest error was found in the I_1 treatment for different sowings. The minimum wheat yield was observed at single irrigation and highest yield was recorded at maximum irrigation levels at critical stages of wheat. According to [15] the validation showed better results under optimum irrigation with early date of sowing compared to late sowing and stress treatments with less irrigations.

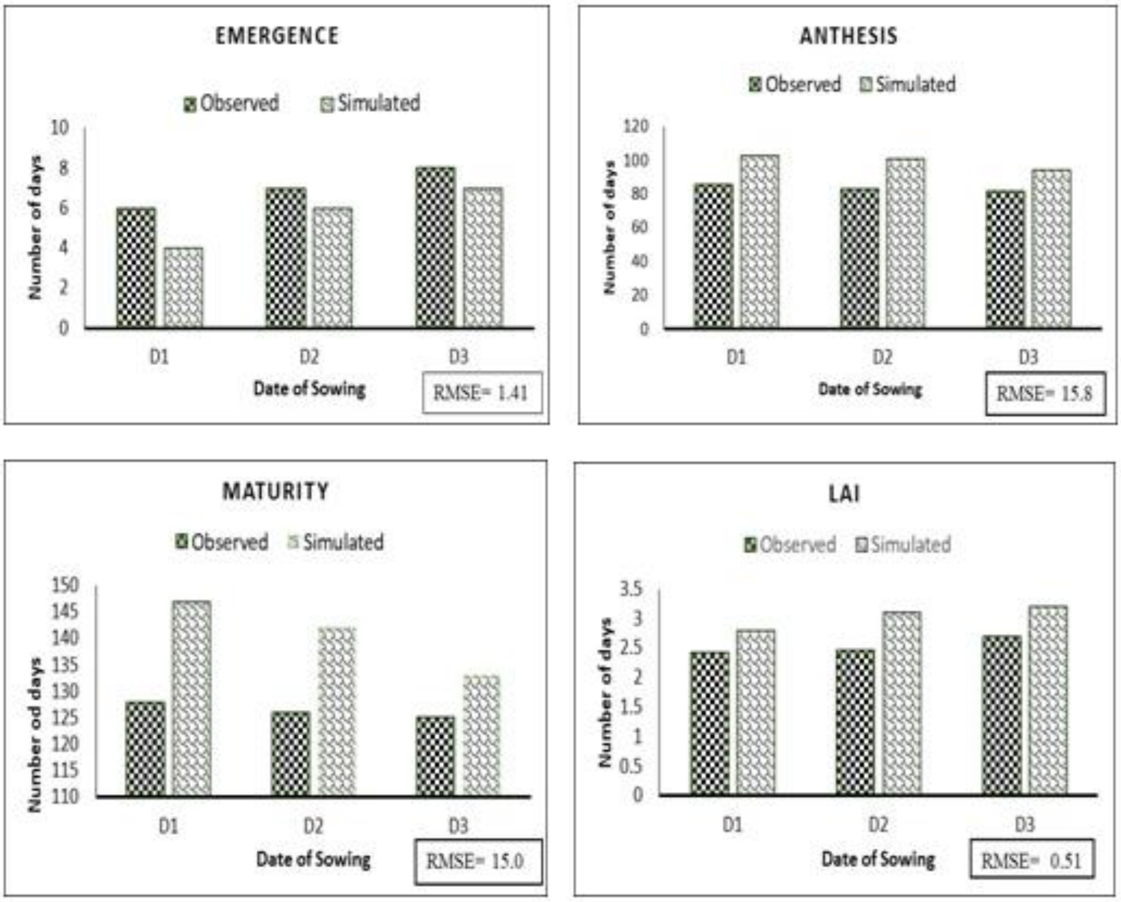

Fig 1. Comparison of observed and simulated phenological characteristics of wheat

Table6. DSSAT-CERES model for different irrigation scheduling at different date of sowing in wheat for 2018-2019 at Prayagraj conditions. (Calibration of the model)

Treatments	Observed	Simulated
17/11/2018		
I1	1720	1467
I2	2756	2848
I3	3653	3777
I4	4553	4731
I5	5916	5465
RMSE	254	
Model Efficiency	6.9	
Agreement Index	0.01	
02/12/2018		
I1	1370	1177
I2	2513	2439
I3	3490	3586
I4	4390	4450
I5	5406	5107
RMSE	170.2	
Model Efficiency	1.56	
Agreement Index	0.0005	
17/12/2018		
I1	1230	1281
I2	2390	2100
I3	3176	3420
I4	4196	4189
I5	5136	4958
RMSE	171	
Model Efficiency	1.37	
Agreement Index	0.0005	

Table 7. DSSAT-CERES model for different irrigation scheduling at different date of sowing in wheat for 2019-2020 at Prayagraj conditions. (Validation of the model)

Treatments	Observed	Simulated
17/11/2019		
I1	1813	938
I2	2720	2534
I3	3657	3576
I4	4417	4554
I5	5853	5571
RMSE	425.4	
Model Efficiency	1.53	
Agreement Index	0.002	
02/12/2019		
I1	1260	827
I2	2713	2474
I3	3457	3412
I4	4277	4162
I5	5540	5251
RMSE	262	
Model Efficiency	7.7	
Agreement Index	0.001	
17/12/2019		
I1	1163	945
I2	2360	2113

Treatments	Observed	Simulated
I3	3317	3379
I4	4153	4244
I5	5373	5103
RMSE	196.7	
Model Efficiency	1.74	
Agreement Index	0.0007	

4. CONCLUSION

From the experiment it was concluded that substantial relationship was found between different irrigation levels and the date of sowing. It was observed that an early date of sowing has shown better results to reach the various phenological stages, as well as sufficient heating unit requirements and efficient heat usage. At various phases of growth, the agrometeorological indices show the impact of temperature and photoperiod on crops' phenological behavior, as well as the efficiency with which heat is used. In order to improve yield, farmers are advised to use the above findings on wheat crop treatment combinations and heat unit requirements under Prayagraj circumstances, for normal (17^{th} Nov) date of sowing. Weather conditions throughout the flowering stage was critical, and they might have an impact on grain yield for Prayagraj. DSSAT CERES-Wheat model predicts good model performance under stress conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Prajapat AL, Saxena R. Thermal requirements of wheat (Triticum aestivum L .) cultivars under different growing environments. International Journal of Chemical Studies. 2018;6(5):17–22.
2. Singh S, Pal M. Growth, yield and phonological response of wheat cultivars to delayed sowing. Indian J. Plant Physiol. 2003;8:277-287.
3. Bisht H, Singh DK, Mishra SAK, Sarangi A, Prajapati VK, Singh M, Krishnan P. Heat unit requirement of wheat (Triticum aestivum L.) under different thermal and moisture regimes. Journal of Agrometeorology. 2019;21(1):36–41.
4. Zare M, Parvizi H, Sharafzadeh S, Azarpanah A. Evaluation of wheat cultivars under various irrigation. Journal of Global Biosciences. 2015;4(2):1327-1334.
5. Ihsan MZ, El-Nakhlawy FS, Ismail SM, Fahad S, Daur I. Wheat phenological development and growth studies as affected by drought and late season high temperature stress under arid environment. Front. Plant Sci. 2016;7:1-14.
6. Hoogenboom G, Porter CH, Shelia V, Boote KJ, Singh U, White JW, Hunt LA, Ogoshi R, Lizaso JI, Koo J, Asseng S, Singels A, Moreno LP, Jones JW. Decision support system for agrotechnology transfer (DSSAT) version 4.7 DSSAT foundation, gainesville, florida, USA; 2017.
7. Rasse DP, Ritchie JT, Wilhelm W, Wei J, Martin EC. Simulating inbred-maize yields with CERES-IM. Agron. J. 2000;92:672-678.
8. Kadiyala MDM, Jones JW, Mylavarapu RS, Li YC, Reddy MD. Identifying irrigation and nitrogen best management practices for aerobic rice–maize cropping system for semi-arid tropics using CERES-rice and maize models. Agric. Water Manage. 2015;149:23-32.
9. Sheoran OP, Tonk DS, Kaushik LS, Hasija RC, Pannu RS. Statistical software package for agricultural research workers. Recent advances in information theory, statistics and computer applications by DS. Hooda and RC; 1998.
10. Gill KK, Babuta R, Kaur N, Kaur P, Sandhu SS. Thermal requirement of wheat crop in different agroclimatic regions of Punjab under climate change scenarios. Mausam. 2014;65(3):417–424.
11. Dar, Eajaz Ahmad, Brar AS, Yousuf A. Growing degree days and heat use efficiency of wheat as influenced by thermal and moisture regimes. J. Agrometeorol. 2018;20(2):168-170.
12. Ram H, Singh G, Mavi GS, Sofia VS. Accumulated heat unit requirement and yield of irrigatedwheat (*Triticum aestivum* L.) varieties under differentcrop growing

environment in central Punjab. J. Agrometeorol. 2012;14(2):147-153.
13. Patel C, Nema AK, Singh RS, Yadav MK, Singh SK, Singh SM. Evaluation of DSSAT-CERES model for irrigation scheduling of wheat crop in Varanasi region of Uttar Pradesh. J. Agrometeorol. 2017;19(2):120-124.
14. Medhi K, Neog P, Goswami B, Deka RL, Kurmi K, Sarmah K, Khanikar PG. Evaluation of CERES-Rice model for Upper Brahmaputra Valley Zone of Assam. J. Agrometeorol. 2017;19(3):270-273.
15. Patel HR, Patel GG, Shroff JC, Pandey V, Shek AM, Vadodaria RP, Bhatt BK. Calibration and validation of CERES-wheat model for wheat in middle Gujarat region. J. Agrometeorol. 2010;12(1):114-117.

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