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Simulating the effect of sowing dates and different irrigation levels on wheat cultivars using DSSAT-CSM-CERES wheat model

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Abstract
To study the effect of different sowing environments and irrigation levels on wheat cultivars, a multi-location experiment was conducted at PAU Regional Research Station, Bathinda (BTI) and Faridkot (FDK) districts of Punjab during *Rabi* season 2016-17. Results revealed that the CERES-wheat model showed lesser deviation in simulated value over normal with the crop sown on 21st November, while, higher deviation with delayed sowing on phenology and yield of wheat for both the locations. Higher days of phenology, yield and leaf area index (LAI) were observed with recommended irrigation level (I_1) and decreased as the irrigation frequency was reduced a found least with I_5 when irrigation was skipped a CRI, flowering and dough stages. Due to greater variations of more than 50 per cent between observed and simulated value, the CERES-wheat-model was not found able to simulate days to emergence and LAI, while, model performed well in respect of anthesis, maturity with lesser error. The model was found able to simulate yield also as R^2 was found to be highly significant and positive for grain yield (BTI 0.98 and FDK 0.92) and biomass yield (BTI 0.96 and FDK 0.87), respectively. The higher value of d-Stat for grain yield (BTI 0.98 and FDK 0.97) biomass yield (BTI 0.98 and FDK 0.96), respectively, indicated lesser error between observed and simulated value.

Keywords: CERES-wheat, sowing dates, cultivars, wheat, irrigation levels

Introduction
Globally, wheat (*Triticum aestivum* L.) is the main crop in all the cereals, which is grown by the majority of the people as one of the most important food crop and has first rank in terms of crop area as well as production. Worldwide, wheat is grown on an area of about 220.12 million hectares in a wide range of environment, with an annual production of 749.46 million tonnes and productivity of 3405 kg ha^{-1} (FAOSTAT, 2016) [1]. India is the second largest wheat producing nation where area under wheat was 30.23 million hectares with production of 93.50 million tonnes and yield of 3093 kg ha^{-1} during 2015-16 (Anonymous 2016) [2]. In Punjab, it occupied an area of 3.50 million hectares with a production of 16.08 million tonnes and productivity of 4596 kg ha^{-1} during 2015-16 (Anonymous 2017) [3]. The geographical area of Punjab is only 1.53 % of the country and contributes 17% of total wheat production in India (Prabhjyot-Kaur *et al* 2015) [4]. Increasing heat stress due to climate change and limited water availability for irrigating the crop are the main challenge for the future wheat production. However, the wheat demand is estimated to reach 109 mt by 2020, needing effective efforts to alleviate the results of climatic abnormalities (Datt *et al* 2009) [5]. Heat and moisture stress are important environmental constraints, which are estimated to cause reductions of about 50% of plant production (Kamal *et al* 2010) [6]. Practically, in field situations, the heat stress is generally followed by the moisture stress. Therefore, it is most important to understand the impact of abiotic stresses such as heat and moisture stresses on crops performance and production, which control the plant yield and development (Balouchi 2010) [7]. The integrated responses of weather conditions like temperature, water availability and management practices plays important and significant role in agricultural crop production (Holden *et al* 2003) [8]. But, it is not easy to apply in field condition, whereas, dynamic crop models, that have decision making tools can be an easier tool for suitable and low-cost substitute by saving both the time and vast expenditure of experiment. CERES-wheat is broadly used as a technological tool for strategically preparing the judgement (Sarkar and Kar 2006) [9], furthermore, it is useful for deficit irrigation conditions, while simulating crop growth (Hoogenboom *et al* 2010 [10], Pal *et a.l* 2015 [11]).

Materials and methods

Study locations and climatic conditions

The field experiment was conducted at the two locations viz., Punjab Agricultural University (PAU) Regional Research Station, Bathinda and Faridkot during the *Rabi* season of the year 2016-17. The experiments were laid out in spilt plot design with two dates of sowing *viz*. 21st November (D_1) and 9th December (D_2), two cultivars *i.e*. PBW-725 (V_1) and PBW-658 (V_2) and five irrigation levels as I_1 (recommended), I_2 (skipped at CRI), I_3 (skipped at flowering) I_4 (skipped at dough) and I_5 (skipped at I_2, I_3 and I_4). Bathinda region falls under south western part of the state in 4th Agro Climatic zone (ACZ), while, Faridkot 5th ACZ of Punjab and their climate are classified as semi-arid. The average annual rainfall of Bathinda and Faridkot are 440 mm and 433 mm, respectively. Frosty night associated with chilled winds are common when night temperature touches 0°C during January-December and dust storms in May-June when the mercury touches over 47°C. The soil of the both the experimental sites (Bathinda and Faridkot) is sandy loam. The soil is dark coloured and moderately well drained.

Calibration and validation of CERES-wheat Model

The CERES-Wheat model is a simulation model, which is an inbuilt application program of the Decision Support System for Agrotechnology Transfer (DSSAT) (Godwin *et al* 1990 [12], Ritchie and Otter 1985) [13]. CERES-wheat model describes daily phenological development and growth in response to environmental factors (soils, weather and management). The genetic coefficients were derived from the experimental data at Bathinda by using data sets of ten treatments (viz. two sowing dates and five irrigation levels) with the help of GENCALC software (DSSAT v4.6) for PBW 725 and PBW 658 wheat cultivars. Moreover, coefficients were adjusted for both the cultivars separately in order to fit the model over actual field observations as model calibration (Table 1). Furthermore, in order evaluate the model for its usefulness, CERES-wheat model was validated with the *Rabi* season field data at Faridkot during the 2016-17. CERES-wheat model has been used for irrigation scheduling in terms of time of irrigation application at various phenophases.

Results and Discussion

Comparison of simulated and observed phenology of wheat for Bathinda and Faridkot as affected by sowing dates, cultivars and irrigation levels during Rabi 2016-17

The observed as well as simulated phenology of the wheat as affected by different sowing environments, cultivars and irrigation levels is presented in table 2 and depicted in fig. 1. Higher days of phenology like emergence, anthesis as well as physiological maturity were observed with recommended irrigation level (I_1) and decreased as the irrigation frequency was reduced a found least with I_5 when irrigation was skipped a CRI, flowering and dough stages. While, there was much variations was found in respect of simulated phenology. Moreover, significant differences were observed among sowing dates and irrigation levels, while, almost non-significant difference with cultivars on phenology. More days to simulated and observed physiological maturity was recorded with the early sown crop (21 November) and decreased with delayed sowing (09 December) except emergence. CERES-wheat model also showed an underestimation in respect of phenology of wheat. Due to greater variations of more than 50 per cent between observed and simulated emergence, the model was not found able to simulate days to emergence. Among the treatments, the value of d-Stat, R^2 and RMSE were obtained as 0.59 and 0.65, 0.10 and 0.88 and 6 DAS and 14 DAS for Bathinda and Faridkot, respectively for days to anthesis. Higher value of d-Stat (Bathinda 0.86, Faridkot 0.62) and R^2 (Bathinda 0.71 and Faridkot 0.95) with lower RMSE (Bathinda 5days and Faridkot 22 days) indicates lower variation with better agreement between observed and simulated days to physiological maturity of wheat. Pal *et al* (2015) [11].also calibrated and validated CERES-Wheat model for growth and yield parameters of wheat and showed that % RMSE values ranged from 5.9 – 15.6% for days to anthesis. While, Hundal and Prabhjyot-Kaur (1997) [14]. reported -6 to +3 days deviations for physiological maturity of wheat. Similar study was also conducted by Tatar and Yazgan (2001) [15], Kour *et al* (2010) [16]. and Pal *et al* (2015) [11]. showing decline in physiological maturity with delayed sowing.

Comparison of simulated and observed yield and LAI of wheat for Bathinda and Faridkot as affected by sowing dates, cultivars and irrigation levels during Rabi 2016-17

The statistics of effect of sowing environments as well as irrigation levels on yield and LAI of wheat cultivars are given in table 3 and depicted in fig. 1. Overall, among treatments, CERES-wheat model showed lesser deviation in simulated value over normal with the crop sown on 21st November, while, higher deviation with delayed sowing for both the locations. From the response of simulation modeling, it was found that the accuracy of simulated value decreased with delayed sowings and model underestimated the grain and biomass yield as well as LAI. Moreover, the % deviation was observed to be higher in moisture stressed conditions i.e. when the irrigation was skipped at I_2 and $I_{5,}$ while, least variation with recommended irrigation (I_1) for both the locations. The % deviation between observed and simulated grain yield ranged from 0 to 16% and 01 to 23% and biomass yield ranged from 01 to 27% and 01 to 25% for Bathinda and Faridkot, respectively. The model was found able to simulate yield as R^2 was found to be highly significant and positive for grain yield (Bathinda 0.98 and Faridkot 0.92) and biomass yield (Bathinda 0.96 and Faridkot 0.87), respectively, with lesser RMSE. The higher value of d-Stat for grain yield (Bathinda 0.98 and Faridkot 0.97) biomass yield (Bathinda 0.98 and Faridkot 0.96), respectively, indicated lesser error between observed and simulated value. Similar result was also reported by Pal *et al.* (2008) [17].indicating that the significant correlation (0.89) between simulated and observed values. Nain *et al.* (2002) [18].also reported that the model could very well simulate the crop yields (RMSE<20%) and R2 more than 0.85. Pal *et al.* (2015) [11].also showed that the CERES-wheat model was found useful for wheat grain yield having lesser %RMSE and t-value ranged from 5.7 – 12.2% (t = -4.5 to 1.8) and also observed that the grain yield decreased with the delayed sowing. Although, the model was unable to simulate LAI due to having upto 63% deviations in simulated value over normal, the model performed well with recommended irrigation levels and deviations increased with lesser frequency of irrigations. Pal *et al* (2015) [11].also indicated that model fails to simulate leaf area index having % RMSE from 53.2 – 62.9%.

Table 1: Genetic coefficients developed for wheat genotypes (PBW 725 and PBW 658)

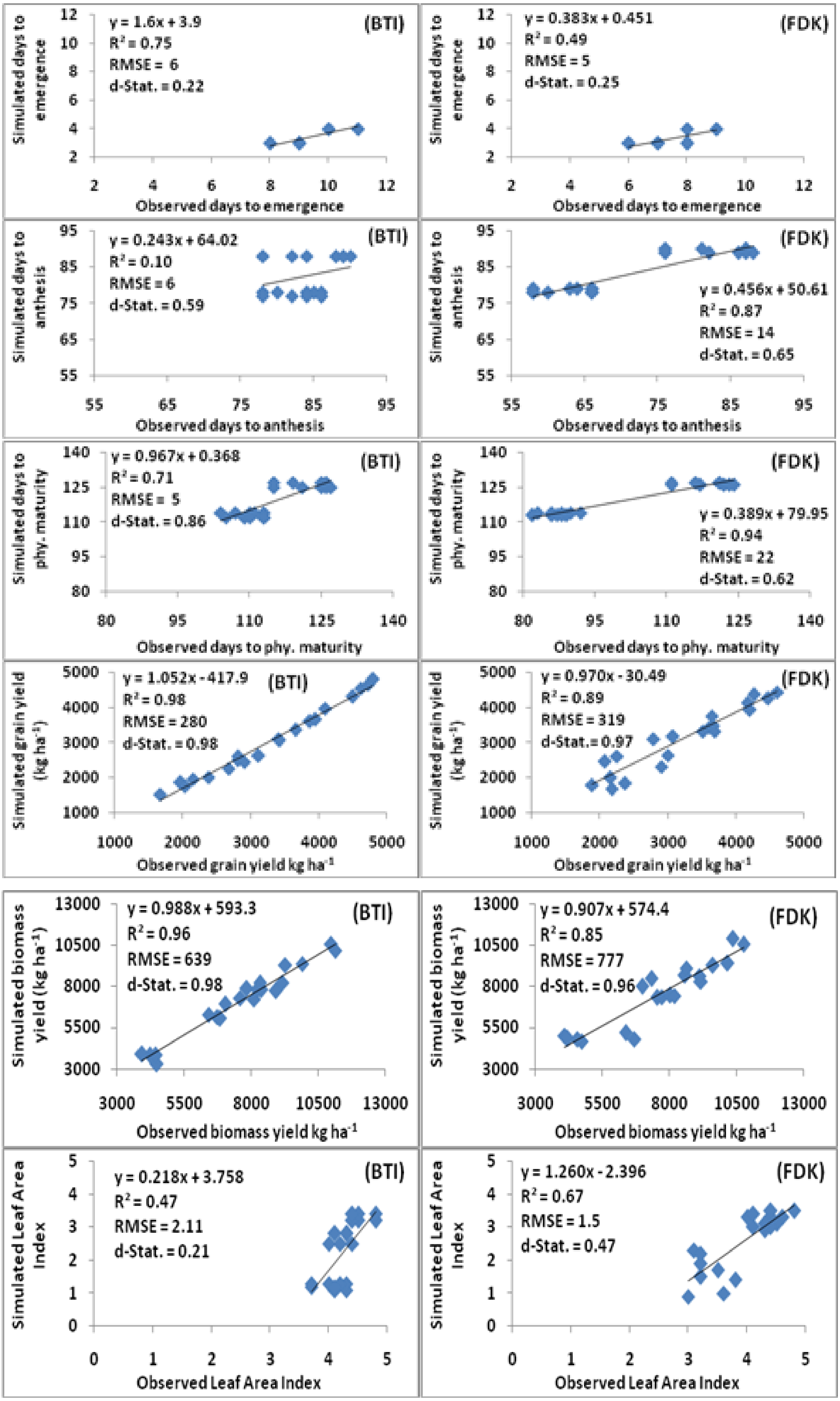
Parameters	Variety/ Coefficient	
	PBW 725	**PBW 658**
Vernalisation coefficient (P1V) °C.d	5	5
Photoperiodism coefficient (P1D) % reduction in rate	71	73
Grain filling duration coefficient (P5) °C.d	490	510
Kernel number coefficient (G1) #/g	23	22
Kernel weight coefficient (G2) Mg	47	45
Tiller weight coefficient (G3) G dwt	3.4	3.2
Phyllochron interval (PHINT) °C.d	90	94

Table 2: Statistics of DSSAT-CERES model for different sowing environments, cultivars and irrigation levels on phenology of wheat at Bathinda and Faridkot. During Rabi 2016-17

	Days to emergence					Days to anthesis					Days to maturity				
Variable	**Obs.**	**Sim.**	**R^2**	**RMSE**	**d-Stat.**	**Obs.**	**Sim.**	**R^2**	**RMSE**	**d-Stat.**	**Obs.**	**Sim.**	**R^2**	**RMSE**	**d-Stat.**
BATHINDA															
D1	9	3	0.04	6	0.13	86	88	0.04	5	0.44	122	126	0.05	6	0.45
D2	10	4	0.06	6	0.12	83	78	0.01	6	0.43	110	113	0.03	5	0.42
CD (p=0.05)	0.21	-	-	-	-	0.43	-	-	-	-	0.61	-	-	-	-
V1	10	4	0.81	6	0.18	84	83	0.15	5	0.64	116	120	0.76	5	0.84
V2	9	4	0.80	6	0.25	84	82	0.07	6	0.55	116	120	0.72	5	0.87
CD (p=0.05)	NS	-	-	-	-	0.43	-	-	-	-	0.1	-	-	-	-
I1	9	4	0.82	6	0.22	88	83	0.92	6	0.55	120	120	0.96	1	0.99
I2	9	4	0.82	6	0.22	82	83	0.5	4	0.50	114	120	0.90	6	0.81
I3	10	4	1.00	6	0.25	86	83	0.99	5	0.66	118	120	0.978	2	0.97
I4	10	4	0.8	6	0.27	88	83	0.99	6	0.46	119	120	0.95	2	0.98
I5	10	4	1	6	0.15	78	83	0.91	7	0.61	110	120	0.96	10	0.64
CD (p=0.05)	NS	-	-	-	-	0.72	-	-	-	-	0.68	-	-	-	-
FARIDKOT															
D1	7	3	0.12	4	0.24	84	89	-		0.46	119	126	0.5	8	0.46
D2	7	4	-	5	0.17	62	8	0.7	16	0.28	87	114	0.6	26	0.15
CD (p=0.05)	0.14	-	-	-	-	0.77	-	-	-	-	0.80	-	-	-	-
V1	8	4	0.81	4	0.35	74	84	0.88	12	0.68	104	120	0.94	19	0.65
V2	8	4	0.43	5	0.15	62	78	-	16	0.29	876	113	-	26	0.13
CD (p=0.05)	NS	-	-	-	-	NS	-	-	-	-	0.85	-	-	-	-
I1	8	4	0.5	4	0.20	73	82	0.99	10	0.75	102	118	18	18	0.67
I2	8	3	0.41	4	0.16	68	82	0.99	14	0.64	96	118	0.99	23	0.61
I3	8	4	082	5	0.26	69	82	0.98	14	0.67	99	118	0.99	21	0.64
I4	8	4	0.47	4	0.31	73	82	0.99	10	0.74	100	118	1	20	0.66
I5	8	4	0.47	4	0.31	64	82	0.99	18	0.54	92	118	0.99	26	0.55
CD (p=0.05)	NS	-	-	-	-	0.75	-	-	-	-	1.0	-	-	-	-

Table 3: Statistics of DSSAT-CERES model for different sowing environments, cultivars and irrigation levels on yield and LAI of wheat at Bathinda and Faridkot. during *Rabi* 2016-17

	Grain yield (kg/ha)					Biomass yield (kg/ha)					Leaf Area Index				
Variable	Obs.	Sim.	R2	RMSE	d-Stat.	Obs.	Sim.	R2	RMSE	d-Stat.	Obs.	Sim.	R2	RMSE	d-Stat.
BATHINDA															
D1	3519	3340	0.99	213	0.99	7946	7296	0.97	758	0.97	4.4	2.5	0.59	2.13	0.211
D2	3034	2722	0.98	333	0.96	7262	6892	0.97	491	0.98	4.1	2.1	0.4	2.09	0.18
CD (p=0.05)	108.42	-	-	-	-	320.26	-	-	-	-	0.09	-	-	-	-
V1	3225	2988	0.99	273	0.98	7474	6980	0.95	679	0.97	4.3	2.2	0.41	2.18	0.19
V2	3328	3074	0.98	286	0.98	7734	7208	0.98	595	0.98	4.3	2.4	0.56	0.03	0.23
CD (p=0.05)	NS	-	-	-	-	NS	-	-	-	-	NS	-	-	-	-
I1	4370	4260	0.99	149	0.97	10.32	9865	0.83	6	0.82	4.6	3.0	0.76	1.61	0.25
I2	2667	2341	0.92	334	0.63	6762	6359	0.25	504	0.46	4.2	1.2	0.01	3.01	0.05
I3	3211	2809	0.98	408	0.64	8110	7636	0.50	552	0.59	4.4	3.0	0.96	1.42	0.18
I4	4178	3968	0.99	230	0.93	8548	7898	0.24	802	0.53	4.2	3.0	0.95	1.26	0.26
I5	1957	1776	0.86	192	0.77	4268	3711	0.37	697	0.24	3.9	1.2	0.22	2.66	0.11
CD (p=0.05)	125.7	-	-	-	-	381.76	-	-	-	-	0.13	-	-	-	-
FARIDKOT															
D1	3561	3601	0.96	206	0.98	8052	8041	0.92	599	0.977	4.1	25	0.86	1.66	0.41
D2	2970	2674	0.94	362	0.95	7321	6798	0.86	851	0.94	3.8	2.5	0.57	1.41	0.50
CD (p=0.05)	95.42	-	-	-	-	382.40	-	-	-	-	0.12	-	-	-	-
V1	3213	3057	316.35	0.97		7576	7424	0.91	622	0.97	4	2.5	0.48	1.58	0.40
V2	3075	2836	0.95	322	0.96	7544	6788	0.86	1016	0.92	3.8	2.5	0.82	1.32	0.59
CD (p=0.05)	NS	-	-	-	-	NS	-	-	-	-	NS	-	-	-	-
I1	4158	3945	0.99	216	0.93	10184	9763	0.84	479	0.81	4.4	3.1	0.62	1.30	0.15
I2	2541	2226	0.99	428	0.85	6698	6002	0.59	1415	0.37	3.4	1.2	0.21	2.19	0.20
I3	3171	2792	0.97	413	0.77	8065	7829	0.83	366	0.87	4.2	3	-	1.24	0.12
I4	3865	3818	0.78	227	0.89	8370	7697	0.94	704	0.68	4.2	3.3	0.07	0.85	0.26
I5	2100	2134	0.74	231	0.78	4508	4768	0.67	387	0.33	3.4	2	0.99	1.57	0.21
CD (p=0.05)	117.86	-	-	-	-	307.66	-	-	-	-	0.15	-	-	-	-


y = 1.6x + 3.9
R² = 0.75
RMSE = 6
d-Stat. = 0.22
(BTI)
Simulated days to emergence
Observed days to emergence
y = 0.383x + 0.451
R² = 0.49
RMSE = 5
d-Stat. = 0.25
(FDK)
Simulated days to emergence
Observed days to emergence
y = 0.243x + 64.02
R² = 0.10
RMSE = 6
d-Stat. = 0.59
(BTI)
Simulated days to anthesis
Observed days to anthesis
y = 0.456x + 50.61
R² = 0.87
RMSE = 14
d-Stat. = 0.65
(FDK)
Simulated days to anthesis
Observed days to anthesis
y = 0.967x + 0.368
R² = 0.71
RMSE = 5
d-Stat. = 0.86
(BTI)
Simulated days to phy. maturity
Observed days to phy. maturity
y = 0.389x + 79.95
R² = 0.94
RMSE = 22
d-Stat. = 0.62
(FDK)
Simulated days to phy. maturity
Observed days to phy. maturity
y = 1.052x - 417.9
R² = 0.98
RMSE = 280
d-Stat. = 0.98
(BTI)
Simulated grain yield (kg ha-1)
Observed grain yield kg ha-1
y = 0.970x - 30.49
R² = 0.89
RMSE = 319
d-Stat. = 0.97
(FDK)
Simulated grain yield (kg ha-1)
Observed grain yield kg ha-1
y = 0.988x + 593.3
R² = 0.96
RMSE = 639
d-Stat. = 0.98
(BTI)
Simulated biomass yield (kg ha-1)
Observed biomass yield kg ha-1
y = 0.907x + 574.4
R² = 0.85
RMSE = 777
d-Stat. = 0.96
(FDK)
Simulated biomass yield (kg ha-1)
Observed biomass yield kg ha-1
y = 0.218x + 3.758
R² = 0.47
RMSE = 2.11
d-Stat. = 0.21
(BTI)
Simulated Leaf Area Index
Observed Leaf Area Index
y = 1.260x - 2.396
R² = 0.67
RMSE = 1.5
d-Stat. = 0.47
(FDK)
Simulated Leaf Area Index
Observed Leaf Area Index

Conclusion

From the response of simulation modeling, it was found that the accuracy of simulated value decreased with delayed sowings and model underestimated the phenology, yield as well as LAI. Due to lesser error were recorded between observed as well as simulated value, the model was found able to simulate phenology and yield of wheat except days to emergence and leaf area index, having lower RMSE, good positive correlation and higher d-Statistics. During the study crop model was found to be underestimated for almost all the wheat attributes and treatments. Moreover, significant differences were observed among sowing dates and irrigation levels, while, almost non-significant difference with cultivars. Moreover, the % deviation between observed and simulated value was observed to be higher in moisture stressed conditions, while, least variation was found with recommended irrigation (I_1) for both the locations.

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