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The effect of heat and moisture stress on wheat and possible mitigation strategies using CERES-wheat model

KARANJOT SINGH GROVER, R. K. PAL*, P. K. KINGRA and S. K. MISHRA**

Department of Climate Change and Agricultural Meteorology,

Punjab Agricultural University, Ludhiana – 141004, Punjab, India

**Punjab Agricultural University, Regional Research Station, Bathinda – 151 001, Punjab, India*

***Punjab Agricultural University, Regional Research Station, Faridkot – 151 203, Punjab, India*

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e mail : rkpal1985@pau.edu

सार – CERES-गेहूं मॉडल का उपयोग करके गर्मी और नमी के तनाव और संभावित शमन रणनीतियों के प्रभाव का अध्ययन करने के लिए रबी ऋतु 2016-17 के दौरान PAU क्षेत्रीय अनुसंधान स्टेशन, बठिंडा और फरीदकोट में बहु-स्थान प्रयोग किए गए। बिजाई की दो तारीखों 21 नवंबर और 9 दिसंबर को स्प्लिट प्लॉट डिजाइन में गेहूं की फसल बोई गई, दो कल्टीवर यानी PBW-725 और PBW-658 में 5 सिंचाई स्तर होने की सिफारिश की गई (I1), स्किप्ड एट क्राउन रूट इनिशिएशन - CRI (I_2), स्किप्ड एट फ्लावरिंग (I_3) स्किप्ड एट डो (I_4) और स्किप्ड एट I_2, I_3 और I_4 (I_5)। परिणामों से पता चला कि बुवाई की तारीखों और सिंचाई के स्तर में वृद्धि, उपज और उपज योगदान करने वाले कारक महत्वपूर्ण पाए गए, जबकि कल्टीवर्स के साथ गैर-महत्वपूर्ण। अनाज की पैदावार, बायोमास की पैदावार, प्रभावी टिलर, अनाज की संख्या और पत्ती क्षेत्र सूचकांक के मामले में देरी से बुवाई की तुलना में सामान्य बुवाई की गई फसल के बेहतर परिणाम सामने आए हैं। I_4 के बाद अनुशंसित सिंचाई स्तर (I_1) के साथ अधिकतम अनाज की उपज हुई, जबकि I_5 के साथ सबसे कम। जबकि वैकल्पिक रूप से, अनुशंसित सिंचाई स्तर के साथ अधिक उपज देखी गई और सिंचाई की आवृत्ति कम होने के कारण इसमें कमी आई। इसके अलावा, मॉडल उत्पादन ने सर्वोत्तम संभव अनाज उपज का संकेत दिया जब बुवाई 11 से 30 नवंबर के बीच की गई और इसे अधिकतम बुवाई का समय माना गया। जबकि, 30 नवंबर से 30 दिसंबर तक बुवाई में देरी के कारण अनुकारी अनाज की पैदावार लगातार कम होती दिखाई दी। बुवाई की तारीखों में, मॉडल ने I_1 पर अनाज की अधिक उपज भी दिखाई, जबकि I5 सिंचाई स्तर पर सबसे कम। अनाज की अधिकतम उपज को 40 मिमी सिंचाई के साथ अनुकारी किया गया। अतः परिणामस्वरूप अध्ययन क्षेत्र के लिए अनुशंसित सिंचाई के साथ 11 से 30 नवंबर के बीच गेहूँ की फसल की बुवाई और अधिकतम उपज हेतु 40 मिमी सिंचाई की मात्रा की सलाह दी जाती है।

ABSTRACT. Multi-location experiments were conducted at PAU Regional Research Station, Bathinda and Faridkot during the Rabi season 2016-17 to study the effect of heat and moisture stress and possible mitigation strategies using CERES-wheat model. Wheat crop was sown in spilt plot design with two dates of sowing *viz*., 21st November and 9th December, two cultivars, *i.e*., PBW-725 and PBW-658 having 5 irrigation levels as recommended (I_1), skipped at Crown Root Initiation-CRI (I_2), skipped at flowering (I_3) skipped at dough (I_4) and skipped at I_2, I_3 and I_4 (I_5). The results revealed that growth, yield and yield contributing characters were found significant among sowing dates and irrigation levels, while, non-significant with cultivars. Normal sown crop has shown better results in terms of grain yield, biomass yield, effective tillers, grain number and leaf area index than delayed sowing. Maximum grain yield was obtained with recommended irrigation level (I_1) followed by I_4, while least with I_5. Alternatively, higher yield attributes was observed with recommended irrigation level and decreased as irrigation frequency was reduced. Furthermore, model output indicated best possible grain yield when the sowing was used between 11th to 30th November and considered as optimum sowing window. While, with the delay in sowing from 30th November to 30th December, the simulated grain yield showed decreasing trends consistently. Among sowing dates, the model also showed higher grain yield at the I_1, while, the lowest at I_5 irrigation level. The highest grain yield was simulated with the application of 40 mm irrigation amount. So, as a result sowing of wheat crop between November 11 to 30 with recommended irrigation and 40 mm irrigation amount is recommended for the study region in order to have optimum yield.

Key words – Sowing window, Cultivars, Irrigation levels, Heat and moisture stress, CERES-wheat model, Temperature deviation.

1. Introduction

Wheat (*Triticum aestivum* L.) is the major crop among all cereals, considered as one of the most important food crop and has first rank in terms of crop area as well as production. Worldwide, wheat was grown on an area of about 214.29 million hectares (mha) in a wide range of environment with an annual production of 734.05 million tonnes and productivity of 3425 kg ha^{-1} (Anonymous, 2018a). India is the second largest wheat producing nation having area, production and productivity of 29.58 mha, 99.7 million tonnes and 3371 kg ha^{-1}, respectively (Anonymous, 2018a). In Punjab, wheat occupied an area of 3.51 mha with a production of 17.83 million tonnes and productivity of 5077 kg ha^{-1} during 2017-18 (Anonymous, 2018b).

Heat stress is a function of the degree and rate of increase in temperature and period of exposure to the raised temperature. It occurs, when the growing temperature exceeds the optimal range, which may be detrimental and cause irremediable damage (Ludwig and Asseng, 2006). The grain yield of wheat is significantly affected by photosynthesis reduction, while the vegetative stage is comparatively less sensitive to heat stress than reproductive stage in wheat.

Practically, in the field situations, the heat stress is generally followed by the moisture stress. Therefore, it is most significant to understand the impact of abiotic stresses such as heat and moisture stresses on crops performance and production. Moisture deficit is an important component limiting plant growth and yields. It leads to changes in the physiological and biochemical processes, which control the plant yield and development (Balouchi, 2010). The adequate supply of irrigation water and suitable sowing date are important factors in affecting the wheat productivity.

The great challenge for the coming decades will therefore be the task of increasing food production with lesser irrigation availability, particularly in arid and semi-arid regions (FAO, 2003). Accurate knowledge of the sowing window for any particular variety at a specific region is critical to achieve a higher grain yield (Ortiz-Monasterio *et al.*, 1994). So, the choice of sowing date is an important management option for optimizing grain yield in those regions. Crop simulation models are considered an easier tool for suitable and low-cost substitute by saving both the time and vast expenditure of experiment. Crop simulation models have been used to investigate the performance of different cultivars at a range of sowing dates in relation to different soil-climate scenarios (Bassu *et al.*, 2009). Cropping system models that have been evaluated with local experimental data can be valuable tools for extrapolating the experimental results to other years and locations (Mathews *et al.*, 2002). Keeping in view of the above facts, the present study was planned to determine the effect of heat and moisture stress on wheat and possible mitigation strategies using CERES-wheat model on wheat.

2. Materials and method

2.1. *Experimental details and weather conditions of study locations*

To study the effect of sowing environments, cultivars and irrigation levels on yield attributing characters of wheat, multi-location trials were laid out at Punjab Agricultural University (PAU) Regional Research Station, Bathinda (30°58' N, 74°18' E) and Faridkot (30°40' N, 74°44' E) during the *Rabi* season of the year 2016-17. At both the locations, wheat crop was sown 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 recommended (I_1), skipped at Crown Root Initiation-CRI (I_2), skipped at flowering (I_3) skipped at dough (I_4) and skipped at I_2, I_3 and I_4 (I_5).

The study region of Bathinda comes 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 436 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) are sandy loam. During the study period, a total of 30.1 mm and 56.3 mm rainfall was received, while, the value of bright sunshine was ranged from 1.2-9.8 (6.1) and 0.8-9.2 (5.5) hr day^{-1} at Bathinda and Faridkot, respectively. Moreover, minimum temperature was observed in the range of 3.5-22.0 (10.4) and 3.4-23.6 (11.3) °C, while, maximum temperature from 16.5-41.2 (26.5) and 16.5-41.1 (26.2) °C at Bathinda and Faridkot, respectively. Similarly, minimum and maximum RH was found in between 32-73 (49) and 58-97 (81)% at Bathinda, while, from 15-71 (41) and 53-96 (85)% at Faridkot, respectively. Slightly lesser mean value of maximum temperature, mean RH having more rainfall supported better crop output at study location of Faridkot.

2.2. *Model application and data analysis*

The possible mitigation strategies for heat and drought stress were applied in terms of choosing seven

TABLE 1

Effect of dates of sowing and irrigation levels on wheat genotypes on yield attributing characters of wheat during *Rabi* 2016-17 at Bathinda (BTI) and Faridkot (FDK)

Treatments	Grain yield ($kg\ ha^{-1}$)		Biomass yield ($kg\ ha^{-1}$)		Test weight (g)		Grains $spike^{-1}$		Effective tillers m^{-2}		Maximum LAI	
	BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK
Dates of sowing												
D_1	3476	3483	7854	7985	37	37	38	37	418	373	4.12	4.07
D_2	3041	2970	7278	7280	35	34	36	36	393	363	3.82	3.81
CD (5%)	108.42	95.82	320.26	382.40	0.48	0.83	0.75	0.71	4.73	5.64	0.09	0.12
Genotypes												
V_1	3212	3213	7448	7576	36	36	37	37	408	377	3.94	3.98
V_2	3305	3240	7684	7689	36	35	37	37	404	359	3.99	3.91
CD (5%)	NS	NS	NS	NS	NS	NS	NS	NS	NS	5.64	NS	NS
Irrigation levels												
I_1	4353	4237	10294	10229	42	42	42	41	496	442	4.60	4.53
(I_2	2667	2604	6762	6859	34	33	36	37	350	323	3.20	3.34
I_3	3211	3257	8110	8211	38	38	39	39	466	415	4.26	4.23
I_4	4103	3940	8397	8560	41	41	41	40	459	409	4.38	4.30
I_5	1957	2093	4268	4304	24	24	25	28	259	253	3.40	3.32
CD (5%)	125.7	117.86	381.76	307.66	0.89	1.23	1.0	1.08	6.95	8.82	0.13	0.15

sowing environments (*i.e.*, 1st, 11th, 21st, 30th November, 9th, 20th and 30th December) and application of five irrigation amounts (*i.e.*, 20 mm, 40 mm, 60 mm, 80 mm and 100 mm to setup the optimum sowing time for the best possible yield under the optimum irrigation amount with the help of CERES-wheat model. Apart from this, we also used deviations in temperature from ±1 to ±3 °C to quantify the effect of temperature on grain yield. Moreover, for the above purpose, already calibrated and validated genetic coefficients by Grover and Pal (2018) have been used. For the simulation study, weather data in terms of minimum and maximum temperature, bright sunshine, minimum and maximum relative humidity and rainfall for the study location of Bathinda and Faridkot during rabi season 2016-17 were taken from the Agro-meteorological observatory of the respective stations. The simulated grain yield in respect of different sowing environments, various irrigation amount applications and temperature deviations were analyzed and compared in terms of root mean square error (RMSE), % RMSE and R^2 over actual yield using Micro-soft excel. However, the ground truth data was analyzed statistically using SPSS software and the checked significance level at 5 per cent probability.

3. Results and discussion

3.1. *Effect of sowing dates, cultivars and irrigation levels on growth parameters*

Effective number of tillers m^{-2} was found significantly more with crop sown on 21st November followed by 9th December, while, PBW 725 showed significantly higher tillers than PBW 658 at both the locations (Table 1). Moreover, more effective was obtained with the recommended irrigation (I_1), while, lesser with I_5 irrigation level in which irrigation was skipped at CRI, flowering and dough stage. Moreover, tillers was found to be reduced as the number of irrigation was skipped, it is because of moisture as well as heat stress effect during the crop growing period due to water scarcity. Similarly, higher value of LAI was also observed with the normal sown crop (BTI : 4.12 and FDK : 4.07) followed by 9th December sown crop (BTI : 3.82 and FDK : 3.81) (Table 1). Similar results were also reported by Pal *et al.* (2012) who found more LAI at normal sowing. Furthermore, LAI was also significantly affected by different irrigation levels and the higher value of LAI was recorded with recommended irrigation (I_1) (BTI : 4.60

TABLE 2

Simulated wheat grain yield (kg ha^{-1}) for the sowing window from 1st November to 30th December at Bathinda and Faridkot using CERES-wheat model

Varieties	Irrigation levels	Simulated grain yield (kg ha^{-1})													
		Nov 1		Nov 11		Nov 21 (Actual)		Nov 30		Dec 9 (Actual)		Dec 20		Dec 30	
		BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK
PBW-725	I_1	4510	3376	5289	4290	4795	4608	4441	4696	3864	3664	3569	3488	2901	2787
	I_2	2606	1793	3000	2453	2807	3073	2654	2848	2378	2176	1302	1615	1587	1823
	I_3	3369	2808	4132	3396	3411	3611	2945	4071	2904	2904	2168	1957	2274	2154
	I_4	4510	3376	4844	4251	4478	4264	4135	4005	3659	3686	2467	2877	2780	2787
	I_5	1648	1163	1396	1305	2151	2251	2003	2208	1671	1890	1077	1169	1151	1442
PBW-658	I_1	4246	3412	4932	3998	4590	4475	4273	4461	4165	4202	3337	3697	2700	3003
	I_2	2576	2032	2971	2403	2811	2792	2615	2770	2673	2373	1241	1597	1464	1958
	I_3	3152	2745	3835	3184	3417	3517	2788	3841	3111	2998	2046	2056	1966	2279
	I_4	4243	3412	4495	3954	4330	4167	3828	3680	3944	3644	2501	2795	2685	3003
	I_5	1530	1226	1334	1288	1967	2074	1865	1968	2038	2158	1039	1200	1118	1398
RMSE		286.31	967.78	474.37	507.91	-	-	360.89	263.24	-	-	1025.23	761.57	1017.03	747.02
% RMSE		8.24	27.78	13.65	14.58	-	-	10.38	7.56	-	-	33.72	25.65	33.45	25.16
R^2		0.98	0.95	0.94	0.97	-	-	0.97	0.91	-	-	0.84	0.93	0.90	0.94

and FDK : 4.53), while, least with I_5 irrigation level (Table 1).

3.2. *Effect of sowing dates, cultivars and irrigation levels on yield and yield attributes*

The data showed that the grain and biomass yield was significantly affected by date of sowing and irrigation level, but non-significant with genotypes (Table 1). The higher grain yield was obtained with normal sown crop (3476kg ha^{-1} and 3483kg ha^{-1} at Bathinda-BTI and Faridkot-FDK, respectively) followed by late sown crop and similar trends was also found for biomass (Table 1). The loss in grain and biomass yield due to delay in sowing have also been reported by Dubey *et al*., 2008. Delay of wheat sowing reduced wheat yield as a result of high temperature exposure, which reduces growing season length as reported by Ouda *et al*. (2005). Furthermore, the maximum grain yield was obtained with recommended irrigation level (I_1) (BTI : 4353 kg ha^{-1} and FDK : 4237 kg ha^{-1}) followed by I_4 (4103 kg ha^{-1} and 3940 kg ha^{-1}), while least with I_5 (BTI: 1957kg ha^{-1} and FDK : 2093kg ha^{-1}) (Table 1). The decrease in grain and biomass yield with delayed sowing is proportional to degree as well as duration of moisture stress and also might be due to rise in temperature from February onwards that causes crop to mature earlier. Similarly, test weight and grains per spike were also significantly affected by sowing date and irrigation levels and recorded higher with 21st November sowing than 9th December having higher value with I_1 and lowest with I_5 irrigation level (Table 1). The delayed sowing caused poor vegetative growth probably due to low temperature during early vegetative stage, low LAI in association with low photosynthetic rate.

3.3. *Possible mitigation strategies for heat and drought stress on grain yield using CERES-wheat model*

3.3.1. *Selection of sowing window for optimum grain yield*

The effect of different sowing environments from 1st November to the 31st December on wheat grain yield (kg ha^{-1}) as affected by genotypes and irrigation levels is given in Table 2 for Bathinda and Faridkot. Based on the study of both the locations, optimum grain yield was simulated by CERES-wheat model when the sowing was done between 11th to 30th November (Nov) and considered as optimum sowing time. Moreover, maximum grain yield were simulated with 11th November sowing, whereas, with the delay in sowing after 30st November to 30th

TABLE 3

Effect of irrigation amount (mm) on wheat grain yield (kg ha^{-1}) as affected by dates of sowing, genotypes and irrigation levels during *rabi* season 2016-17 at Bathinda (BTI) and Faridkot (FDK)

Sowing dates/ Varieties	Irrigation levels	Simulated grain yield (kg ha^{-1}) at different irrigation amount (mm)											
		Actual yield		20 mm		40 mm		60 mm		80 mm		100 mm	
		BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK
21st Nov (PBW 725)	I_1	4795	4608	4103	4032	4809	4432	4691	4055	4703	4108	4551	4106
	I_2	2807	3073	2559	2426	2499	3170	2509	2548	2490	2590	2574	2556
	I_3	3411	3611	3018	3257	3105	3425	3060	3430	3042	3446	3008	3476
	I_4	4478	4264	3471	3853	4548	4372	4482	4012	4517	4071	4316	4070
	I_5	2151	2251	1827	2355	1965	2608	1941	2499	1926	2512	1892	2495
21st Nov (PBW-658)	I_1	4590	4475	4233	3899	4652	4259	4545	3914	4559	3962	4695	3960
	I_2	2811	2792	2622	2429	2596	3107	2604	2537	2587	2574	2476	2543
	I_3	3417	3517	2972	3179	3062	3322	3000	3335	2995	3351	3069	3378
	I_4	4330	4167	3713	3603	4308	4115	4264	3806	4315	3857	4530	3858
	I_5	1967	2074	1893	2259	1859	2463	1855	2381	1885	2384	1883	2378
9th Dec (PBW-725)	I_1	3864	3664	3191	3181	3602	3469	3565	3181	3512	3859	3469	3411
	I_2	2378	2176	2041	1751	2015	1669	2004	1751	1978	1794	1971	1622
	I_3	2904	2904	2391	2300	2447	2312	2438	2300	2404	2594	2171	2284
	I_4	3659	3686	3113	3165	3358	3325	3332	3165	3288	3746	3245	3239
	I_5	1671	1890	1572	1765	1528	1786	1533	1765	1508	1956	1502	1732
9th Dec (PBW-658)	I_1	4165	4202	3475	3576	3977	3934	3976	3576	3886	3859	3884	3858
	I_2	2673	2373	2264	1927	2255	1839	2219	1927	2193	1794	2186	1792
	I_3	3111	2998	2561	2593	2621	2639	2659	2593	2614	2594	2605	2593
	I_4	3944	3644	3012	3591	3660	3758	3688	3591	3612	3746	3606	3653
	I_5	2038	2158	1760	1991	1754	2008	1730	1991	1701	1956	1694	1960
RMSE		-	-	528.70	438.00	278.23	304.96	289.96	401.74	317.06	324.16	355.29	374.73
%RMSE		-	-	16.23	13.58	8.54	9.45	8.90	12.45	9.73	10.05	10.90	11.61
R^2		-	-	0.95	0.93	0.98	0.89	0.98	0.91	0.97	0.90	0.96	0.91

December (Dec), yield showed decreasing trends consistently. The model also indicated higher grain yield at the I_1 followed by I_4 irrigation level, while, the lowest with I_5 irrigation level. Ggenotype PBW 725 predicted higher yield with normal sowing (1st November to 30th November), while the genotype PBW 658 predicted the higher yield under late sowing. Alternatively, early sowing (*i.e.*, 1st November) indicated lower yield than 11th November, due to decreased crop growth cycle particularly from sowing to anthesis. Delaying the sowing beyond the optimal sowing date reduced the grain yield, due to high temperature prevalence during grain filling which decreases the length of the grain filling period as it was simulated by the CERES-Wheat model. Moreover, higher value of RMSE and % RMSE having lesser R^2 value were also found with delayed sowing over optimum sowing window at both the study locations (Table 2). Pal *et al*. (2012) also showed that crop growth, yield and yield attributing characters were recorded significantly higher under normal sown crop date (20th November) than late sowing. Similarly, Kaur and Dhaliwal (2015) also found that the grain yield was higher with the 1st November sown crop (5132.83 kg ha^{-1}) as compared to 15th and 30th November sown crops.

3.3.2. *Quantification of irrigation amount for best possible grain yield*

The effect of irrigation amount (mm) on wheat grain yield (kg ha^{-1}) as affected by dates of sowing, genotypes

TABLE 4

Effect of deviation in mean temperature (°C) on wheat grain yield (kg ha^{-1}) as affected by dates of sowing, genotypes and irrigation levels during *rabi* season 2016-17 at Bathinda (BTI) and Faridkot (FDK)

Sowing dates/ Varieties	Irrigation Levels	Actual yield (kg ha^{-1})		% departure in grain yield as deviated in mean temperature											
				+1 °C		+2 °C		+3 °C		-1 °C		-2 °C		-3 °C	
		BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK	BTI	FDK
21st Nov (PBW-725)	I_1	4795	4608	4660	3981	4211	3635	3957	3255	5111	4107	5371	4364	6228	4660
	I_2	2807	3073	2525	2530	2237	2206	1950	1775	2751	2476	3343	2561	4425	2525
	I_3	3411	3611	2899	3332	2489	3107	2379	2818	3514	3571	3701	3872	4660	2899
	I_4	4478	4264	4414	3918	3710	3635	3046	3255	4745	4053	4853	4214	5048	4414
	I_5	2151	2251	1803	2422	1528	2026	1353	1746	2097	2450	2196	2527	2276	1803
21st Nov (PBW-658)	I_1	4590	4475	4302	3682	4020	3428	3825	3133	4856	4096	5180	4184	5589	4302
	I_2	2811	2792	2485	2417	2212	2199	2070	1816	2830	2536	3509	2587	4059	2485
	I_3	3417	3517	2633	3050	2421	2909	2243	2673	3337	3560	3659	3711	4264	2633
	I_4	4330	4167	4073	3611	3898	3419	3764	3133	4500	3935	4549	4032	4425	4073
	I_5	1967	2074	1725	2255	1714	2100	1627	1813	2017	2404	2027	2494	2008	1725
9th Dec (PBW-725)	I_1	3864	3664	3712	3787	3380	3649	3395	3432	3979	3819	4038	3786	4784	3712
	I_2	2378	2176	2015	1906	1912	1801	1847	1791	2260	2144	2472	2331	3025	2015
	I_3	2904	2904	2476	2367	2232	2348	2059	2162	2540	2483	2679	2528	3334	2476
	I_4	3659	3686	3437	3551	3067	3386	3082	3182	3751	3614	3864	3649	4540	3437
	I_5	1671	1890	1522	1393	1473	1331	1341	1295	1611	1667	1753	1829	1629	1522
9th Dec (PBW-658)	I_1	4165	4202	3874	4024	3543	3826	3551	3572	4250	4274	4545	4101	4652	3874
	I_2	2673	2373	2095	2015	1962	1859	1925	1853	2449	2303	2656	2457	3005	2095
	I_3	3111	2998	2636	2636	2478	2625	2284	2393	2760	2840	2953	2786	3314	2636
	I_4	3944	3644	3536	3745	3197	3537	3203	3290	3969	4033	4332	3915	4551	3536
	I_5	2038	2158	1676	1533	1606	1454	1453	1421	1846	1862	1832	1973	1995	1676
RMSE		-	-	371.82	422.94	622.52	577.95	784.45	808.79	185.27	282.67	338.55	243.18	801.32	389.75
% RMSE		-	-	11.41	13.11	19.11	17.91	24.08	25.07	5.69	8.76	10.39	7.54	24.59	12.08
R^2		-	-	0.97	0.89	0.96	0.88	0.92	0.84	0.98	0.90	0.96	0.92	0.87	0.94

and irrigation levels at Bathinda and Faridkot are given in Table 3. Among the irrigation amount applied using CERES-wheat model, the highest grain yield was simulated with 40 mm amount of irrigation (BTI : 4809 kg ha^{-1} and FDK : 4432 kg ha^{-1}) followed by 60mm irrigation amount (BTI : 4691 kg ha^{-1} and FDK : 4055 kg ha^{-1}), thereafter, grain yield was decreased due to increasing of irrigation amount either of 80 mm (BTI : 4703 kg ha^{-1} and FDK : 4108 kg ha^{-1}) or 100mm (BTI : 4551 kg ha^{-1} and FDK : 4106 kg ha^{-1}) with the crop sown on 21st November with recommended irrigation. Inspite of that, model also showed decline in simulated grain yield while lesser irrigation amount of 20 mm was applied (4103 kg ha^{-1}). Overall, best possible yield was simulated with the application of irrigation amount of 40 mm. On the other hand, lesser value of RMSE and % RMSE was observed with higher R^2 at 40 mm irrigation application than rest (Table 3). Alternatively, the highest grain yield was simulated with I_1 irrigation level, while, lowest with I_5. Similar tendency has also been found for Faridkot, in which maximum simulated grain yield was observed with I_1, whereas, least with I_5 treatments. Bieniek *et al*. (2017) analysed the impact of four irrigation dose (15, 20, 25 and 30 mm) on the winter wheat and they proved that the size of the irrigation dose influences the wheat yield. The grain yield between control field and field with highest irrigation dose increased by twofold.

3.3.3. *Assessment of temperature impact on grain yield*

The effect of deviation in mean temperature (°C) on wheat grain yield (kg ha^{-1}) as affected by dates of sowing, genotypes and irrigation levels is given in Table 4 for Bathinda and Faridkot. Due to applying of incremented temperature by +1 to +3 °C using CERES-wheat model during whole season of the crop, a decreasing trend was found in grain yield. Similarly, simulated grain yield was found to be enhanced, when the mean temperature of the whole season was decreased by -1 to -3 °C for both the locations. Instead of that, the lowest % deviation in grain yield was found with elevation in mean temperature by 1 °C, over normal value of grain yield, while, the highest % deviation or maximum error between observed and simulated grain yield was possessed as the mean temperature was increased by 3 °C. Likewise, simulated grain yield also declined maximum with increase in mean temperature by 3 °C followed by 2 °C, while, lowest deviation was observed with 1 °C and *vice versa*.

The % deviation between was ranged from 0 to 33% and 0 to 44% with incremented temperature, while, ranged from 1 to 77% and 1 to 34% when the mean temperature was decreased by 1 to 3 °C for Bathinda and Faridkot, respectively. Additionally, due to increased unit of temperature, the maximum deviation (6 to 21%) was found with I_3, while, with decreased unit by 1 to 3 °C, the highest deviation (10 to 55%) was recorded with I_2 at Bathinda. While, at Faridkot, highest in grain yield over normal was found with I_5 and I_3 irrigation level with increased and decreased units of temperature, respectively. Overall, the decrease in unit temperature had more significant effect as compared to that of increased temperature having lowest % deviation with I_1 (recommended irrigation). On the other hand, decremented unit of temperature also indicated lesser error in simulated yield over actual having lesser value of RMSE and % RMSE along with higher R^2 followed by incremented, moreover, lesser RMSE with higher R^2 was observed with ±1 °C than ±2 and ±3 °C at both the locations (Table 4). Asseng *et al*. (2011) studied the impact of temperature variability on wheat yields observed that variations in average growing-season temperatures by ±2 ºC may cause reductions in grain yield by 50%. Pal and Murty (2013) also showed decrement in yields by 11 to 34.5% due to increased units of Tmean by 1 to 3 °C.

4. Conclusions

Growth, yield and yield attributing characters were found to be significant among sowing dates and irrigation levels, while non-significant effect between genotypes. About 13-15% reductions in grain yield was recorded with delayed sowing by 20 days. However, approximately 51-55% reduction in grain yield was observed with I_5 irrigation level followed by I_2 irrigation level (38-39% reduction) over recommended irrigation (I_1). Moreover, based on simulated output of both the study locations, best possible grain yield was observed with the crop sown from November 11 to November 30 considered as optimum sowing window. Moreover, reduction in grain yield was found when crop was sown either beyond or prior to the optimum sowing window. Apart from this, highest grain yield was simulated with 40 mm irrigation amount, while, model showed decline in simulated grain yield while lesser as well as higher irrigation amount was applied. It is therefore, sowing of wheat crop between November 11 to November 30 with recommended irrigation and 40 mm irrigation amount is recommended for the study region in order to get best possible yield.

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References

Anonymous, 2018a, "Food and Agriculture Organization of the United Nations, Rome. Italy", http://www.fao.org/faostat/en/?#data/QC. Accessed on July 10, 2020.

Anonymous, 2018b, "Package of practices for *Rabi* crops", Punjab Agricultural University, Ludhiana.

Asseng, S. Foster, I. A. N. and Turner, N. C., 2011, "The impact of temperature variability on wheat yields", *Glob. Change Biol.*, **17**, 997-1012.

Balouchi, H., 2010, "Screening wheat parents of mapping population for heat and drought tolerance, detection of wheat genetic variation", *Int. J. Biol. Life Sci.*, **6**, 56-66.

Bassu, S. Asseng, A. Motzo, R. and Giunta, F., 2009, "Optimizing sowing date of durum wheat in a variable Mediterranean environment", *Field Crops Res*., **111**, 109-118.

Bieniek, J. Mielnicki, M. Romański, L. and Komarnicki, P., 2017, "Impact of the irrigation dose amount on the wheat yield", *Agri. Engg*., **21**, 33-47.

Dubey, A. P. Singh, C. B. Khan, N. Yadav, P. N. and Tiwari, A. N., 2008, "Influence of weather parameters on wheat yield under varying sowing dates", *J. Agrometeorol*., **2**, 457-61.

FAO, 2003, "Strategy of agricultural development in Egypt up to 2017", MOA. May 2003, Cairo, Egypt.

Grover, K. S. and Pal, R. K., 2018, "Simulating the effect of sowing dates and different irrigation levels on wheat cultivars using DSSATCSM-CERES wheat model", *J. Pharmacogn. Phytochem.*, **7**, 5, 1934-1938.

Kaur, S. and Dhaliwal, L. K., 2015, "Yield and yield contributing characteristics of wheat under bed planting method", *Int. J. Farm Sci*., **5**, 1-10.

Ludwig, F. and Asseng, S., 2006, "Climate change impacts on wheat production in a Mediterranean environment in Western Australia", *Agric. Sys.*, **90**, 159-79.

Matthews, R. Stephens, W. Hess, T. Middleton, T. and Graves, A., 2002, "Applications of crop/soil simulation models in tropical agricultural systems", *Advances in Agronomy*, **76**, 31-124. doi: 10.1016/S0065-2113(02)76003-3.

Ortiz-Monasterio, J. I., Dhillon, S. S. and Fischer, R. A., 1994, "Date of sowing effects on grain yield and yield components of irrigated spring wheat cultivars and relationships with radiation and temperature in Ludhiana, India", *Field Crops Res*., **37,** 169-184.

Ouda, S. A., El-Marsafawy, S. M., El-Kholy, M. A. and Gaballah, M. S., 2005, "Simulating the effect of Water Stress and Different Sowing Dates on Wheat Production in South Delta", *J. Appl. Sci. Res.*, **1**, 268-76.

Pal, R. K. and Murty, N. S., 2013, "Temperature effect on growth parameters of wheat (CV. PBW-343) using CERES-wheat model for different sowing dates in foot hills of Western Himalayas", *Indian J. Agric. Res*., **47**, 78-82.

Pal, R. K., Murty, N. S. and Rao, M. M. N., 2012, "Evaluation of yield, dry matter accumulation and leaf area index in wheat (*Triticum aestivum* L.) genotypes as affected by different sowing environments", *Environ. Ecol*., **30**, 1469-73.