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

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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 split plot design with two dates of sowing viz., 21st November and 6th December, two cultivars, i.e., PBW-725 and PBW-658 having 5 irrigation levels as recommended (I1), skipped at Crown Root Initiation-CRI (I2), skipped at flowering (I3) skipped at dough (I4) and skipped at I5. 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 (I1) followed by I2, while least with I5. 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 I1, while, the lowest at I5 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., 21\(^{st}\) November (D\(_1\)) and 9\(^{th}\) 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\(_1\), I\(_2\) and I\(_4\) (I\(_5\)).

The study region of Bathinda comes under South-Western part of the state in 4\(^{th}\) Agro Climatic zone (ACZ), while, Faridkot 5\(^{th}\) 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
sowing environments (i.e., 1\textsuperscript{st}, 11\textsuperscript{th}, 21\textsuperscript{st}, 30\textsuperscript{th} November, 9\textsuperscript{th}, 20\textsuperscript{th} and 30\textsuperscript{th} 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 \degree 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 Agrometeorological 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\textsuperscript{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\textsuperscript{-2} was found significantly more with crop sown on 21\textsuperscript{st} November followed by 9\textsuperscript{th} 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\textsubscript{1}), while, lesser with I\textsubscript{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 9\textsuperscript{th} December sown crop (BTI : 3.82 and FDK : 3.81) (Table 1). Similar results were also reported by Pal \textit{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\textsubscript{1}) (BTI : 4.60 and FDK : 4.53).

### Table 1

| Treatments | Grain yield (kg ha\textsuperscript{-1}) BTI | Biomass yield (kg ha\textsuperscript{-1}) BTI | Test weight (g) BTI | Grains spike\textsuperscript{-1} BTI | Effective tillers m\textsuperscript{-2} BTI | Maximum LAI BTI |
|-----------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| D\textsubscript{1} | 3476 | 3483 | 7854 | 7985 | 37 | 37 | 38 | 37 | 418 | 373 | 4.12 | 4.07 |
| D\textsubscript{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 |
| V\textsubscript{1} | 3212 | 3213 | 7448 | 7576 | 36 | 36 | 37 | 37 | 408 | 377 | 3.94 | 3.98 |
| V\textsubscript{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 | 5.64 | NS | NS |
| Irrigation levels | | | | | | | | | | | |
| I\textsubscript{1} | 4353 | 4237 | 10294 | 10229 | 42 | 42 | 42 | 41 | 496 | 442 | 4.60 | 4.53 |
| I\textsubscript{2} | 2667 | 2604 | 6762 | 6859 | 34 | 33 | 36 | 37 | 350 | 323 | 3.20 | 3.34 |
| I\textsubscript{3} | 3211 | 3257 | 8110 | 8211 | 38 | 38 | 39 | 39 | 466 | 415 | 4.26 | 4.23 |
| I\textsubscript{4} | 4103 | 3940 | 8397 | 8560 | 41 | 41 | 41 | 40 | 459 | 409 | 4.38 | 4.30 |
| I\textsubscript{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 |
and FDK : 4.53), while, least with I3 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 3438kg 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 (I1) (BTI : 4353 kg ha⁻¹ and FDK : 4237 kg ha⁻¹) followed by I2 (4103 kg ha⁻¹ and 3940 kg ha⁻¹), while least with I4 (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 I1 and lowest with I3 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 30th November to 30th

| 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   |
| PBW-725   | I₁                | 4510                            | 3376 | 5289  | 4290          | 4795  | 4608          | 4441  | 4696  | 3864  | 3664  | 3569  | 3488  | 2901  | 2787  |
|           | I₂                | 2606                            | 1793 | 3000  | 2453          | 2807  | 3073          | 2654  | 2848  | 2378  | 2176  | 1302  | 1615  | 1587  | 1823  |
|           | I₃                | 3369                            | 2808 | 4132  | 3396          | 3411  | 3611          | 2945  | 4071  | 2904  | 2904  | 2168  | 1957  | 2274  | 2154  |
|           | I₄                | 4510                            | 3376 | 4844  | 4251          | 4748  | 4264          | 4135  | 4005  | 3659  | 3686  | 2467  | 2877  | 2780  | 2787  |
|           | I₅                | 1648                            | 1163 | 1396  | 1305          | 2151  | 2251          | 2003  | 2208  | 1671  | 1890  | 1077  | 1169  | 1151  | 1442  |
|           |                   |                                 | BTI  | FDK   | BTI           | FDK   | BTI           | FDK   | BTI   | FDK   |
|           | PBW-658           | I₁                | 3152 | 2745  | 3835          | 3184  | 3417          | 3517  | 2788  | 3841  | 3111  | 2998  | 2046  | 2056  | 1966  | 2279  |
|           |                   | I₂                | 4243 | 3412  | 4495          | 3954  | 4330          | 4167  | 3828  | 3680  | 3944  | 3644  | 2501  | 2795  | 2685  | 3003  |
|           |                   | I₃                | 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 | 0.84  |
|           |                   |                   | % RMSE | 8.24 | 27.78       | 13.65 | 14.58       | -     | 10.38 | 7.56   | -     | 33.72 | 25.65 | 33.45 | 25.16 | 0.94  |
|           |                   |                   | R²    | 0.98 | 0.95        | 0.94  | 0.97        | -     | 0.97 | 0.91   | -     | 0.84 | 0.93 | 0.90 | 0.94 |   |

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
Month (Dec), yield showed decreasing trends consistently. The model also indicated higher grain yield at the I1 followed by I2 irrigation level, while, the lowest with I5 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 R² 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...
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

![Table 4](https://example.com/table4.png)

| Sowing dates/ Varieties | Irrigation Levels | Actual yield (kg ha\(^{-1}\)) | % departure in grain yield as deviated in mean temperature |
|------------------------|------------------|-------------------------------|----------------------------------------------------------|
|                        |                  | BTI  | FDK  | BTI  | FDK  | BTI  | FDK  | BTI  | FDK  | BTI  | FDK  | BTI  | FDK  |
| 21st Nov (PBW-725)     | I\(_1\)          | 4795 | 4678 | 4660 | 4389 | 4211 | 4357 | 3597 | 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 |
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 $I_3$ 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 $I_3$ 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 $±2$ °C 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 $T_{mean}$ 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 $I_3$ 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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