Journal of Experimental Biology and Agricultural Sciences, October - 2021; Volume – 9(Spl-3-NRMCSSA_2021) page S297 – S305

Journal of Experimental Biology and Agricultural Sciences

http://www.jebas.org

ISSN No. 2320 – 8694

SIMULATING THE IMPACT OF WITHIN SEASON VARIABILITY IN TEMPERATURE ON GRAIN YIELD OF WHEAT

Amarinder Singh Riar[1], Sarabjit Singh[2]*, Prabhjyot-Kaur[3], Gurbax Singh[2]

[1]Department of Agriculture, Guru Nanak Dev University, Amritsar, Punjab, India
[2]P.G. Department of Agriculture, Khalsa College, Amritsar, Punjab, India
[3]Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, Punjab, India

Received – December 15, 2020; Revision – July 13, 2021; Accepted – July 20, 2021
Available Online – October 20, 2021

DOI: http://dx.doi.org/10.18006/2021.9(Spl-3-NRMCSSA_2021).S297.S305

KEYWORDS

Wheat

Temperature

CERES

Infocrop

Model

ABSTRACT

Within season variability in temperature is a major bottleneck in wheat productivity. This simulation study aimed to evaluate the effects of temperature variability on grain yield of two cultivars of wheat (cv PBW 621 and HD 3086) sown under different dates (early, mid and late) using two dynamic crop simulation models (CERES-Wheat and INFOCROP model) for two locations (Amritsar and Ludhiana). The temperature was increased and decreased by 1.0 to 2.0^{o}C for Amritsar and 1.0 to 3.0^{o}C for Ludhiana from normal during three growing periods, i.e., the whole season, vegetative phase, and reproductive phase. In Amritsar the CERES-Wheat and INFOCROP model predicted that with the increase in temperature by 1.0 to 2.0^{o}C from normal during the vegetative phase, the grain yield may decrease by 0.36-15.23 % and 3.61-19.54 % respectively, during the reproductive phase the grain yield may decrease by 0.67–8.64 % and 3.18-26.76 % respectively and during the whole season the grain yield may decrease by 1.52-27.10 % and 1.91-24.10 % respectively. Among the two cultivars of wheat, cv HD 3086 at both locations performed better under thermal stress environments as compared to cvPBW 621. However, the InfoCrop model predicted that cv PBW 621 performed well in comparison to cv HD 3086 at Ludhiana conditions with an increase in temperature up to 3°C. The simulation results showed that mid November sowing of wheat was better able to counteract the negative impacts of an increase in temperature on wheat as compared to early (October) or late (December) sowing dates.

* Corresponding author

E-mail: sarabjitsingh@khalsacollege.edu.in (Sarabjit Singh)

Peer review under responsibility of Journal of Experimental Biology and Agricultural Sciences.

Production and Hosting by Horizon Publisher India [HPI]
(http://www.horizonpublisherindia.in/).

1 Introduction

One of the most widely commence of climate change is global warming. The scientists at NASA's Goddard Institute for Space Studies (GISS) have reported that the earth's average temperature has increased by a little more than 1° C since 1880 and two-thirds of this warming has occurred since 1975 which is estimated @ 0.15 to 0.20 °C per decade (Anonymous, 2020a). The fertilization effect of increasing carbon dioxide concentrations will escalate the net primary productivity of plants, but associated climatic changes and variability in temperature, rainfall, and other parameters may lead to either an increase or decrease in the net productivity of an ecosystem. In many tropical and subtropical regions, potential yields are projected to decrease for most projected increases in temperature (Houghton et al., 2001).

Wheat is one of the important staple cereal food crops of India and accounts for 35% of the food grain production of the country. Its grains are comparatively better source of protein than other cereals. Recently during 2017-18 in Punjab, the area under wheat cultivation was 3.5 million hectares with a production of 17.82 million tons (Anonymous, 2020b). Since wheat is a winter season crop. It is more vulnerable to high-temperature conditions. Hundal & Prabhjyot-Kaur (2007) reported that an increase in temperature by 1°C from normal decreases the wheat yield by 10% under Punjab conditions. The actual and potential yield of wheat may decline by 38 and 50%, respectively with a 5°C increase in temperature (Aggarwal et al., 2006; Aggarwal & Swaroopa Rani, 2009). Rao et al. (2015) reported that during the post-anthesis period in wheat an exposure to continual minimum temperature >12°C for 6 days and maximum temperature >34°C for 7 days are the main thermal constraints in achieving high productivity.

In Punjab, the maximum and minimum temperature are projected to increase from the baseline (1960-90) by 2.9 and 4.9 °C, respectively during mid-century (2021-50) and by 5.8 and 7.4 °C, respectively during the end century (2071-2100) under A1B scenario (Prabhjyot-Kaur et al., 2016). In literature, several studies have reported the effect of climate change on crop yields using simulation models. However, a comparative study of CERES-Wheat and InfoCrop-Wheat models has not been done for the Punjab region in India. This study, therefore, focuses on the prediction of wheat yield in Punjab using the CERES-Wheat and InfoCrop-Wheat model.

2 Materials and methods

In the present study two dynamic simulation models, CERES-Wheat and INFOCROP Wheat were used to simulate the effect of change in temperature on two cultivars (PBW 621 and HD 3086) under different dates of sowings comprising early dates of October, normal dates of November, and late dates of December. The models were run under different scenarios of temperature change viz., ±1.0, ±1.5, and ±2.0°C from normal for Amritsar and ±1.0, ±2.0, and ±3.0 °C from normal for Ludhiana during the three scenarios of crop growth, i.e., during the whole period, vegetative phase and reproductive phase.

Daily weather data at least from sowing to harvesting was loaded for each crop growth period separately to run a particular crop file. Weather data were collected from the Agrometeorological observatories of Ludhiana and Amritsar. The input files such as crop management file, weather file, soil file, and genetic coefficients file were prepared to calibrate and validate the CERES-Wheat model and Infocrop model.

The collected field data of two consecutive wheat seasons (2014-15 and 2015-16) has been used for calibration and further validation. The genetic coefficients required for the CERES wheat and Infocrop models for cultivars HD 3086 and PBW 621 were estimated by repeated iterations in the model calculations to get the minimum variation over the actual data. The derived genetic coefficients that have been used for simulating the impact of temperature on the wheat crop are presented in table 1 and table 2.

Table 1 Genetic coefficients of wheat cultivars used for CERES-Wheat model

Cultivar	Vernalization coefficients P1V (°C d)	Day length P1D (°C d)	Grain filling duration coefficient P5 (°C d)	Kernel number coefficient G1	Kernel weight coefficient G2	Tiller weight coefficient G3	Phyllochron interval PHINT
Ludhiana							
HD 3086	30	91	570	20.0	39.0	3.0	69
PBW 621	34	96	550	21.0	34.0	3.2	69
Amritsar							
HD 3086	22	106	570	40.0	44.0	7.0	80
PBW 621	20	100	570	27.0	40.0	3.6	69

Table 2 Genetic coefficients of wheat cultivars used for InfoCrop-Wheat model

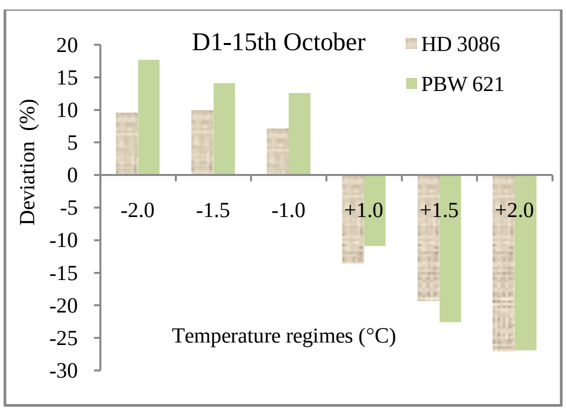
Cultivar	Sowing to germination	Germination to 50% flowering	50% flowering to physiological maturity	Relative growth rate of leaf area (°C/day)	Specific leaf area (dm^2/mg)	Index of greenness of leaves	Extinction coefficient of leaves at flowering	Radiation use efficiency (g/MJ/day)	Root growth rate (mm/day)	Sensitivity of crop to flooding scale	Index of N fixation
Ludhiana											
HD 3086	1	1180	900	0.008	0.00195	1	0.60	2.70	30	1	1
PBW 621	1	1200	500	0.008	0.0019	1	0.60	2.60	30	1	1
Amritsar											
HD 3086	1	1150	900	0.008	0.00192	1	0.60	2.70	30	1	1
PBW 621	1	1200	500	0.008	0.0019	1	0.60	2.60	30	1	1

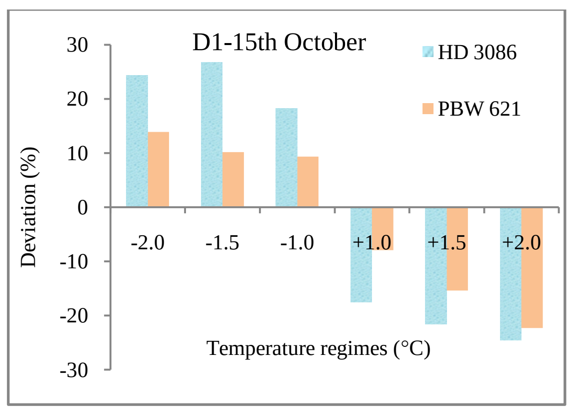
3 Results

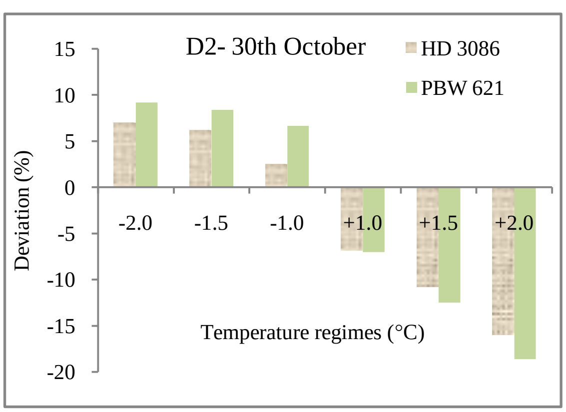
The grain yield is the net photosynthates accumulated as a result of the various plant processes occurring during the crop life cycle, and in wheat crops, this is largely influenced by variations in temperature. Since wheat is a cool season crop so the two simulation models showed an increase/decrease in grain yield with a decrease/increase in temperature from normal.

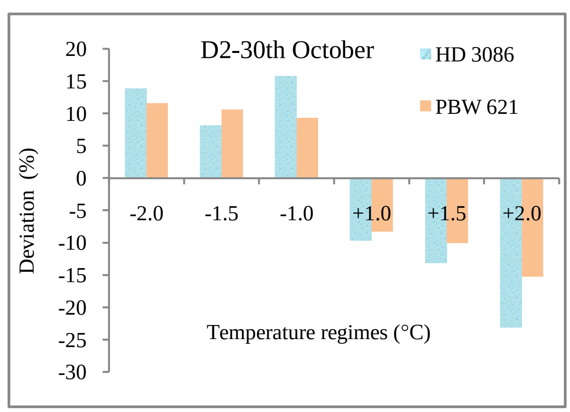
3.1 Amritsar

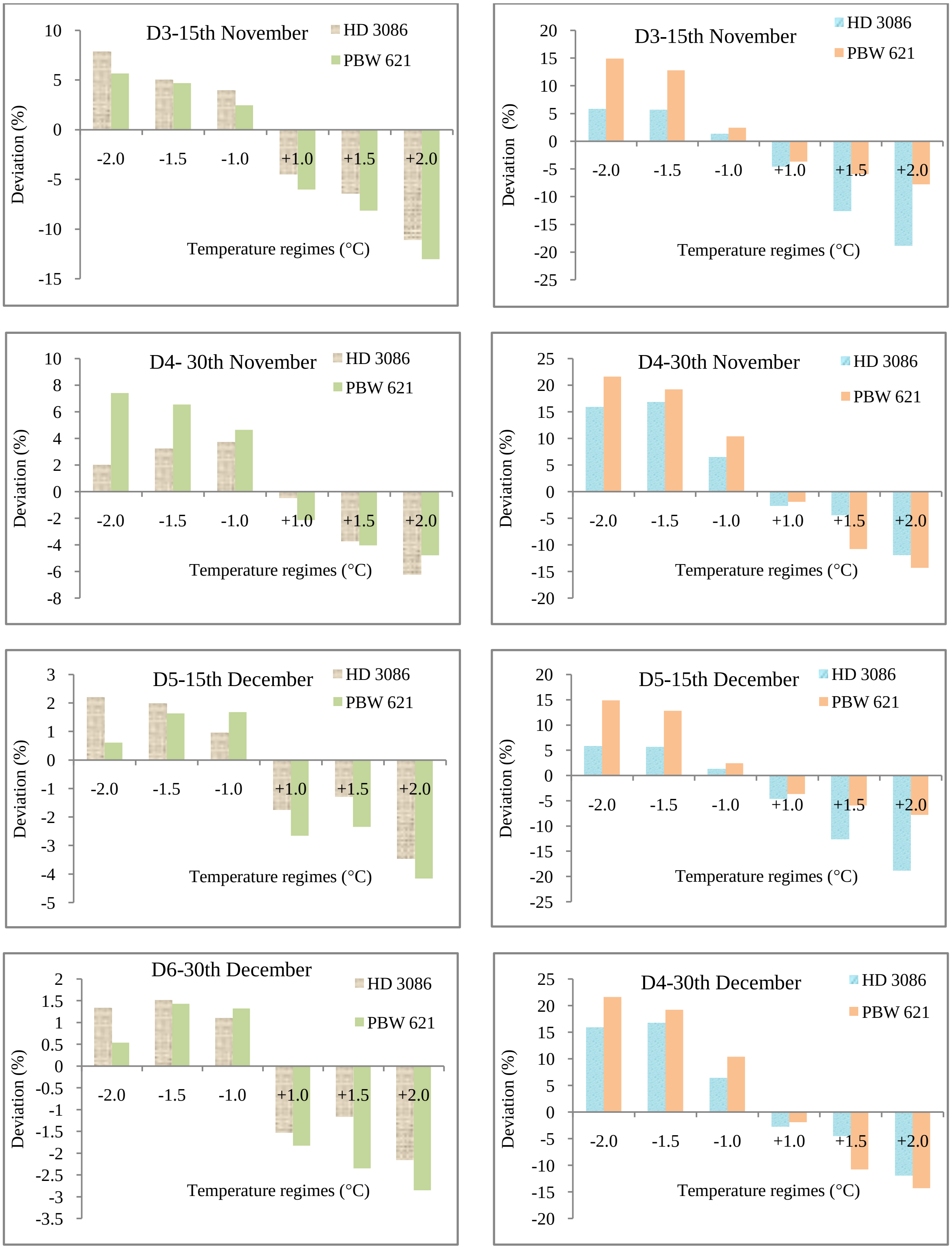
The simulated effect of change in temperature on grain yield of two cultivars, i.e., cv PBW 621 and HD 3086 under different dates of sowing during the whole season, vegetative phase, and reproductive phase are given in figures 1, 2, and 3, respectively.











CERES-Wheat Model INFO CROP Model

Figure 1 Effect of deviations in temperature from normal during whole season on grain yield of wheat using CERES-Wheat Model and INFOCROP Model

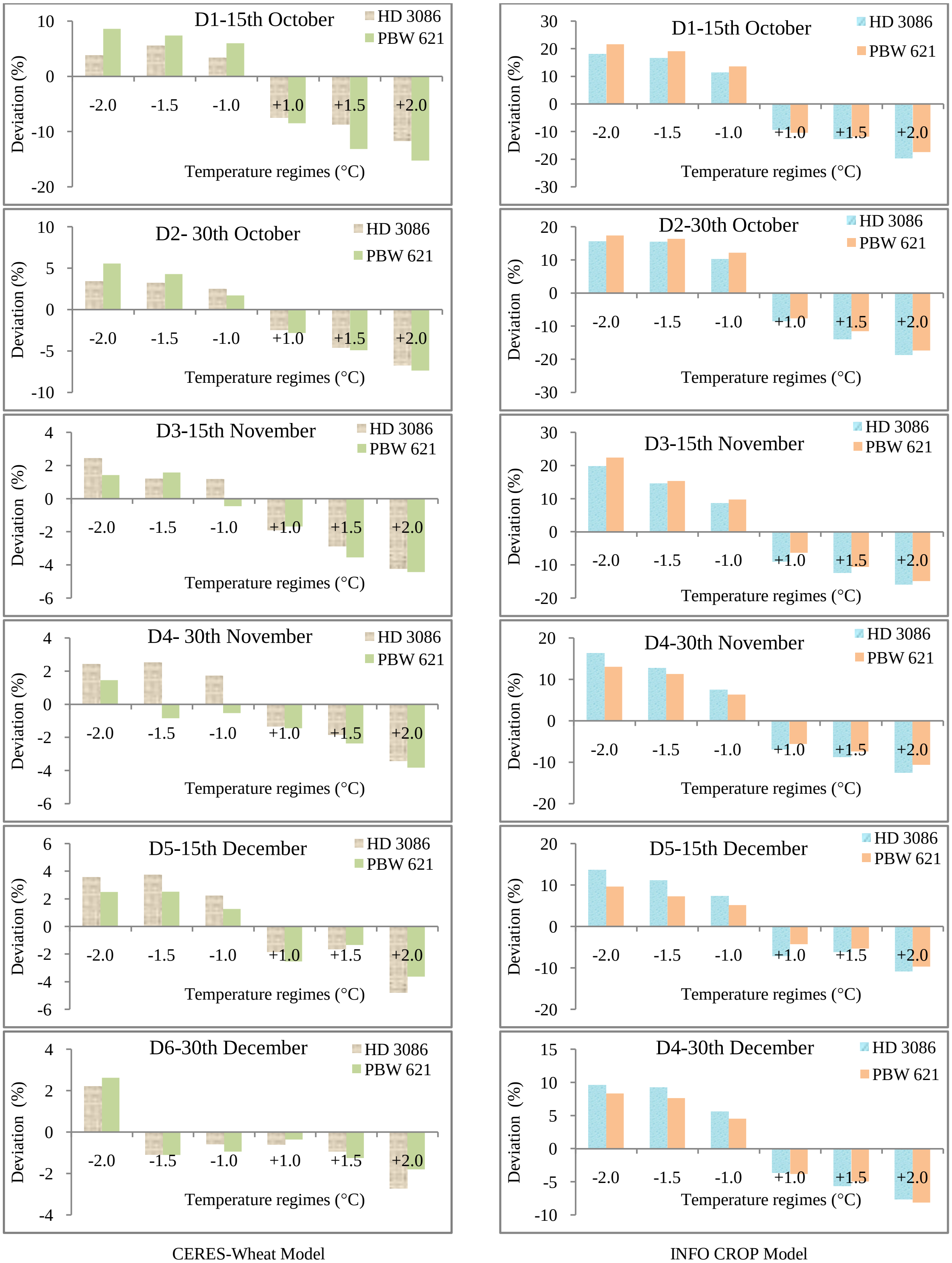
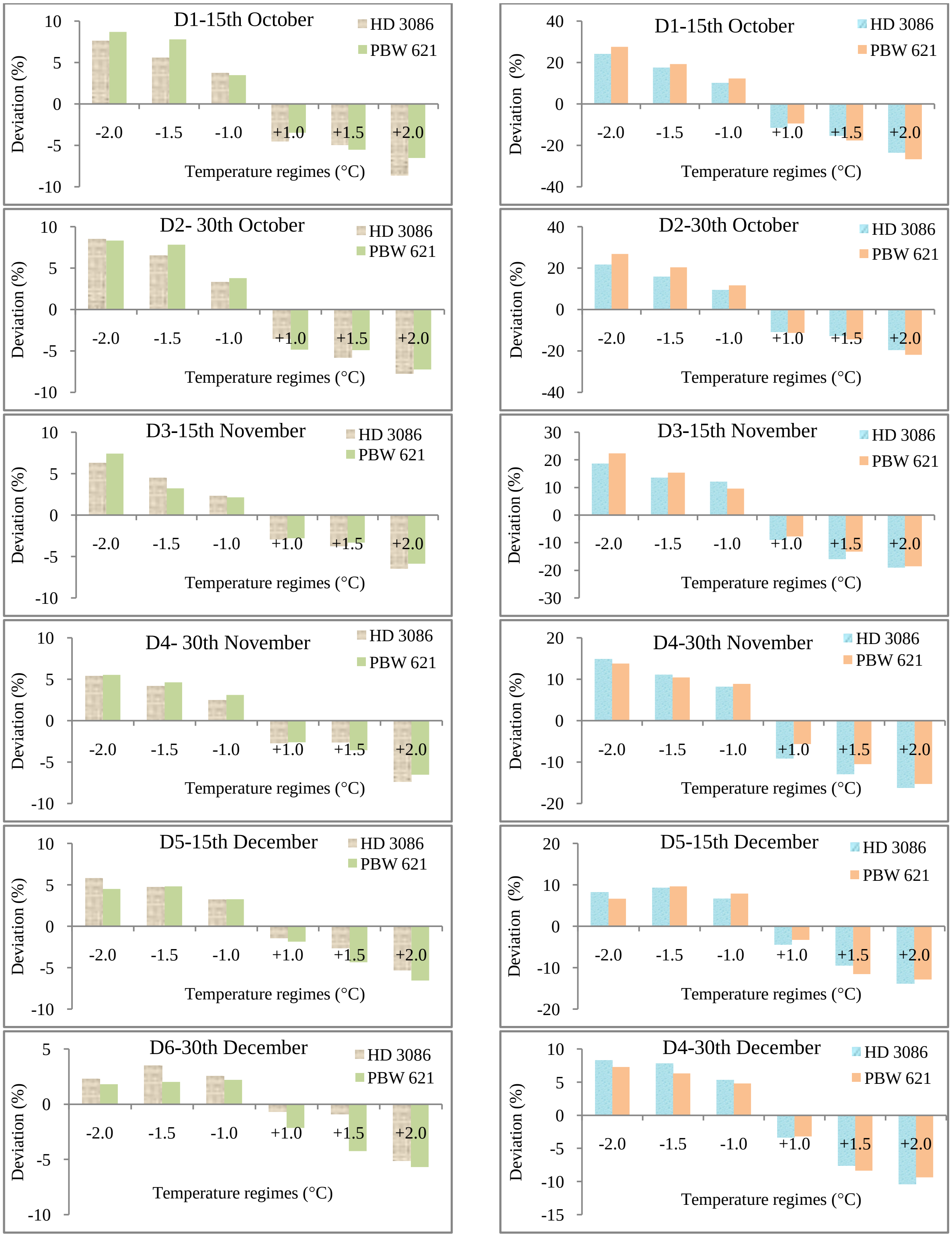


Figure 2 Effect of deviations in temperature from normal during vegetative phase on grain yield of wheat using CERES-Wheat model and INFOCROP Model



CERES-Wheat Model INFO CROP Model

Figure 3 Effect of deviations in temperature from normal during reproductive phase on grain yield of wheat using CERES-Wheat model and INFOCROP Model

3.1.1 CERES-Wheat model

With an increase in temperature by 1.0 to 2.0°C from normal during the whole crop period, the CERES-Wheat model predicted a decrease in grain yield of cv HD 3086 and PBW 621 for 15 October sowing by 13.6 to 27.1% and 10.9 to 26.9%, respectively; for 30 October sowing by 6.82 to 16.0% and 7.01 to 18.6%, respectively; for 15 November sowing by 4.50 to 11.1%, and 6.01 to 13.02%, respectively, for 30 November sowing by 0.46 to 6.21%, and 2.13 to 4.79%, respectively, for 15 December sowing by 1.74 to 3.46%, and 2.66 to 4.16%, respectively and for 30 December sowing by 1.52 to 2.15%, and 1.83 to 2.85% respectively.

The CERES- wheat with an increase in temperature by 1.0 to 2.0°C from normal predicted the decrease in grain yield for cv HD 3086 and PBW 621 during vegetative phase by 0.59–11.64% and 0.36–15.23% respectively and during reproductive phase by 0.67–8.64% and 1.87–7.23%, respectively.

3.1.2 InfoCrop model

The InfoCrop-Wheat model with an increase in temperature by 1.0 to 2.0°C from normal during the whole crop period predicted a decrease in the grain of cv HD 3086 and PBW 621 for 15 October sowing by 17.6 to 24.1% and 7.93 to 22.3%, respectively; for 30 October sowing by 9.68 to 23.1% and 8.31 to 15.28%, respectively; for 15 November sowing by 4.57 to 18.81%, and 3.66 to 7.77%, respectively, for 30 November sowing by 2.65 to 11.9%, and 1.91 to 14.3%, respectively, for 15 December sowing by 15.06 to 17.6%, and 9.11 to 16.4% respectively and for 30 December sowing by 8.52 to 4.32%, and 6.75 to 14.71%, respectively.

Amongst the two crop models, the InfoCrop model predicted more decrease in the yield of wheat with an increase in temperature as compared to CERES-Wheat model. The InfoCrop wheat with an increase in temperature by 1.0 to 2.0°C from normal predicted the decrease in grain yield for cv HD 3086 and PBW 621 during vegetative phase by 3.61-19.54 % and 3.82-17.46 % respectively and during reproductive phase by 3.36-23.52 % and 26.76 %, respectively.

3.2 Ludhiana

3.2.1 CERES-Wheat model

During the whole season, the CERES-Wheat model predicted that with an increase in temperature by 1.0 ºC to3.0 ºC from normal, the CERES-Wheat model predicted a decrease in grain yield by 2.13 to 42.2%, during the vegetative phase by 0.35 to 42.2% and during grain filling stage by 1.84 to 10.29% for the cv HD 3086 and PBW 621 respectively (Table 3)

Table 3 Effect of temperature change on grain yield of wheat cultivars sown on five dates by CERES-Wheat model

Sowing date/ Cultivar	Normal	Whole season		Vegetative phase		Grain filling phase	
		-1 to -3°C	+1 to +3°C	-1 to -3°C	+1 to +3°C	-1 to -3°C	+1 to +3°C
D_1:28 October							
HD 3086	4432	+17.8 to +45.6	-16.5 to -42.2	+16.6 to +28.1	-16.4 to -42.2	+3.51 to +10.7	-2.95 to -5.46
PBW 621	4973	+12.6 to +20.8	-10.9 to -35.2	+5.44 to +10.4	-8.64 to -30.2	+3.49 to +2.90	-3.37 to -9.41
D_2:4 November							
HD 3086	4997	+10.7 to +29.3	-5.0 to -13.0	+7.50 to +16.1	-9.38 to -30.6	+3.84 to +13.7	-3.66 to -10.1
PBW 621	5187	+6.67 to +13.2	-7.01 to -24.6	-1.67 to +5.55	-3.95 to -18.4	+2.75 to +10.7	-4.54 to -10.29
D_3:11 November							
HD 3086	5516	+9.13 to +13.7	-6.97 to -23.6	+1.64 to +6.12	-3.75 to -13.8	+2.70 to +11.5	-1.84 to -7.94
PBW 621	5451	+2.47 to +9.15	-6.01 to -15.6	-0.69 to +0.93	-2.86 to -5.68	+2.12 to +10.8	-2.18 to -9.53
D_4:18 November							
HD 3086	5371	+3.46 to +10.2	-4.50 to -15.9	-1.63 to +1.95	-1.78 to -11.2	+3.14 to +11.9	-2.71 to -9.19
PBW 621	5155	+4.65 to +7.41	-2.13 to -12.3	-0.69 to +2.17	-1.90 to +4.40	+5.78 to +11.7	-2.69 to -7.41
D_5:25 November							
HD 3086	5368	+1.09 to +8.97	-2.20 to -12.03	-2.10 to +2.66	-0.35 to +1.13	+3.03 to +13.8	-2.44 to -8.68
PBW 621	5173	+0.50 to +4.6	-2.16 to -7.60	-0.83 to -3.96	-1.19 to +1.21	+2.35 to +9.08	-2.47 to -8.67

Whereas with a decrease in temperature by 1.0ºC to 3.0ºC from normal, the CERES-Wheat model predicted an increase in grain yield during the whole season by 0.50 to 45.6%, during the vegetative phase by 0.93 to 28.1% and during the grain filling phase by 2.12 to 13.8% for the cv HD 3086 and PBW 621 respectively sown on 28 October, 4 November,11 November, 18 November and 25 November, respectively.

3.2.2 InfoCrop model

During the whole season, the InfoCrop model predicted that with an increase in temperature by 1.0 ºC to3.0 ºC from normal, the InfoCrop model predicted a decrease in grain yield by 0.31 to 62.4%, during the vegetative phase by 1.01 to 61.3%, and during grain filling stage by 1.05 to 61.3% for the cv HD 3086 and PBW 621, respectively.

Whereas with a decrease in temperature by 1.0ºC to 3.0ºC from normal, the InfoCrop model predicted an increase in grain yield during the whole season by 0.84 to 33.1%, during the vegetative phase by 3.17 to 31.2% and grain filling phase by 5.67 to 30.8% for the cv HD 3086 and PBW 621 respectively sown on under different dates of sowing (Table 4).

4 Discussion and Conclusion

When the temperature was increased from normal during the vegetative and reproductive phase even then both the models predicted a reduction in yield and vice versa. Since a rise in temperature leads to an increase in evaporation and transpiration, so it seems that the plant recognizes the stress signals and accelerates the growth rate to complete its life cycle. Roberts & Summerfield (2007) reported that the rise in temperature during the growing season leads to the fast growth and earlier flowering of the crop which leads to a reduction in grain yield.

Hundal & Prabhjyot-Kaur (2007) also reported that CERES-Wheat model predicted an increase/decrease in temperature by 1.0 to 2.0 ºC, the grain yield was decreased by 9.8 to 18% and with increased by 9.1 to 16.1%. Krishnan et al. (2007), and Krishnan et al. (2016) employed the INFOCROP model and observed that with an increase in temperature by 5 ºC increase the wheat yield can decrease by about 17–23%. Parry et al. (2004) have reported that an increase in temperature accelerates the growth and development of crops. Wheat being a cool-season crop is more affected with an increase as well as a decrease in temperature. The results of this simulation study are in close agreement with an earlier study by Prabhjyot-Kaur & Hundal (2007).

Table 4 Effect of temperature change on the grain yield of wheat cultivars sown on five dates by InfoCrop-wheat model

Sowing date/ Cultivar	Normal	Whole season		Vegetative phase		Grain filling phase	
		-1 to -3°C	+1 to +3°C	-1 to -3°C	+1 to +3°C	-1 to -3°C	+1 to +3°C
D_1:28 October							
HD 3086	3960	+28.2 to +33.1	-28.1 to -62.4	+28.7 to +31.2	-26.2 to -61.3	+29.4 to +30.8	-26.2 to -61.3
PBW 621	4204	+9.36 to +18.3	-7.93 to -33.1	+9.91 to +17.7	-9.31 to -31.1	+11.1 to +18.1	-9.31 to -31.1
D_2:4 November							
HD 3086	4412	+5.80 to +15.9	-16.1 to -51.9	+6.69 to +17.5	-15.7 to -22.3	+9.65 to +17.3	-15.7 to -22.3
PBW 621	4831	+9.31 to +15.1	-0.31 to -8.27	+9.01 to +17.1	-1.01 to -9.22	+9.01 to +19.1	-1.05 to -9.22
D_3:11 November							
HD 3086	4774	+0.84 to +14.4	-0.92 to -18.2	-1.26 to +7.44	-2.12 to -18.7	-2.86 to +8.14	-2.12 to -18.7
PBW 621	5405	+2.45 to +19.3	-3.66 to -11.2	+3.17 to +21.3	-4.22 to -12.2	+5.67 to +19.7	-4.22 to -12.2
D_4:18 November							
HD 3086	5118	-4.79 to +16.7	-12.7 to -21.3	-6.21 to +11.1	-15.9 to -20.9	-8.29 to +9.08	-15.9 to -20.9
PBW 621	4926	+15.4 to +26.7	-1.91 to -17.1	+8.42 to +33.1	-8.61 to -19.1	+7.51 to +35.9	-8.61 to -19.1
D_5:25 November							
HD 3086	5281	+14.1 to +28.7	-3.61 to +0.26	-12.7 to +17.2	-4.62 to +0.17	-11.9 to +19.1	+0.17 to -17.4
PBW 621	4994	+7.24 to +13.9	-9.11 to-18.5	+8.11 to +16.7	-9.75 to -20.1	+8.11 to +18.3	-9.75 to -20.1

Climate variability, i.e., sudden increase or decrease in a weather variable especially temperature are a major determinant of wheat yield. Under different sowing dates for wheat extending from October to December, the lower percentage change in simulated yield was observed in late-sown and early sown wheat which may be due to lower and higher temperatures prevalent during these sowing of wheat. The normal sown wheat is better able to counter the rise and fall in temperature conditions as compared to early and late sowings. Farooq et al. (2011) also reported that elevated temperature between anthesis to maturity affects grain yield of wheat due to shortening of grain filling period to accumulate current or reserve photo-assimilates as compared to normal conditions. According to InfoCrop results, it may be concluded that mid-November sowing is most suitable under elevated temperature environments.

Under the anticipated increase in temperature in Punjab, the simulation results showed that mid-November sowing of wheat would be optimum as compared to early or late sowing. The cv. HD 3086 may be recommended for cultivation instead of PBW 621 due to its tolerant characters towards maintaining its growth and productivity under thermal stress environments. With the imposition of decrease temperature from normal conditions, it may be concluded that early Octobers owing is most suitable under decreased temperature environments (Ritchie & Otter, 1985).

Conflict of Interest

There is no conflict of interest among the authors.

References

Aggarwal PK, Kalra N, Chander (2006) INFOCROP: A dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. I. Model description. Journal of Agriculture System 89: 1-25

Aggarwal PK, Swaroopa Rani DN (2009) Assessment of climate change impacts on wheat production in India. In Global Climate Changeand Indian Agriculture-case studies from ICAR Network Project, New Delhi: 5-12

Anonymous (2020a) Package and Practices for crops of Punjab, *Rabi* 2019-20. Punjab Agricultural University, Ludhiana.

Anonymous (2020b) NASA report available at https://earthobservatory.nasa.gov/world-of change/decadaltemp.php access on 29th April 2020.

Farooq MH, Bramley JA, Siddique KHM (2011) Heat stress in wheat during reproductive and grain-filling phases. Plant Science 30: 491-507.

Houghton JT, Ding Y, Griggs DJ, Noguer M, Van der Linden PJ, Dai X, Maskell K, Johnson CA (2001) Climate change 2001: The scientific basis. Contribution of Working Group I to TAR of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, UK.

Hundal SS, Prabhjyot-Kaur (2007) Climatic variability and its impact on cereal productivity in Indian Punjab. Current Science 92(4): 506-512.

Krishnan P, Sharma RK, Das A, Kukreja A, Srivastava R, Singhal RJ, Bandyopadhyay KK, Khajanchi L, Manjaiah KM, Chhokar RS, Gill SC (2016) Web-based crop model: Web INFOCROP – Wheat to simulate the growth and yield of wheat. Computer and Electronic Agriculture. 127: 324–335.

Krishnan P, Swain DK, Baskar C, Nayak SK, Dash RN (2007) Simulation studies on the effects of elevated CO_2 and temperature on rice yield in Eastern India. Agriculture Ecosystem and Environment 122: 233–242.

Parry M, Rosenzweig C, Inglesias A, Livermore M, Gischer G (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environment Change 14: 53–67.

Prabhjyot-Kaur, Hundal SS (2007) Effect of temperature rise on growth and yield of wheat. Journal of Research (PAU) 44: 6-8.

Prabhjyot-Kaur, Kaur N, Singh H (2016) Near- and long-term projected changes in extreme weather events in Ludhiana district of Indian Punjab. Agricultural Research 53: 360-366.

Rao BB, Chowdary PS, Sandeep VM, Pramod VP, Rao VUM (2015) Spatial analysis of the sensitivity of wheat yields to temperature in India. Agriculture Forest Meteorology 200: 192-202.

Ritchie JT, Otter S (1985) Description and performance of CERES-Wheat, A user oriented wheat yield model USDA-ARS 38: 159-75.

Roberts EH, Summerfield R (2007) Measurement and prediction of flowering in annual crops. In: Atherton JG (Ed.), Manipulation of Flowering. Butterworths, London, Pp. 17-50.