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ASSESSING IMPACT OF TEMPERATURE CHANGE ON PHENOLOGY AND GRAIN YIELD OF WHEAT BY USING InfoCrop MODEL

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Since the start of 21st century, the climate change has become a major global issue. This phenomenon is caused by increase in greenhouse gases which include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapors through anthropogenic activities over the last 150 years (Devkota and Phuyal, 2015). Among the variety of reasons, increasing concentration of CO_2 is considered to be the main reason for the climate change (Solomon *et al.,* 2009). According to the latest report from the National Oceanic and Atmospheric Administration, NOAA (2017), the global CO_2 concentrations have risen from 285 ppm during 1850 to 403 ppm during 2016. The CO_2 concentration is likely to become double (735ppm) by the end of the 21st century (Davis, 2017).

The InfoCrop-wheat is an interactive easy web-based model for quantitative examination of the growth and yield of wheat crops (Krishnan *et al.,* 2016) The crop simulation model InfoCrop-wheat estimates the yield components and global warming event (Aggarwal *et al.,* 2006) and due to its dynamic and versatile behavior has many agricultural applications and is used as a decision support system for agro technology transfer (Kumar and Glinni, 2002). Under Punjab conditions, the high yield of wheat can be attained with maximum / minimum temperature within range of 18-22°C / 5-10°C during vegetative stage, 17-20°C / 4-9°C during anthesis stage and 20-25°C / 5-9°C during the grain filling and development stage (Bala and Prabhjyot-Kaur, 2013). You *et al.* (2009) observed significant reduction in yield due to rise in temperature and it was concluded that with 1.8°C rise in temperature caused 3-10% reduction in wheat yields. Canopy temperature depression has an important role in exploring physiological basis of grain yield of wheat (Bahar *et al.,* 2008). A significant change in yield of wheat due to variation in temperature and solar radiation has been observed (Ahmed *et al.,* 2010; Li *et al.,* 2010). Similarly, 0.6 to 8.9% reduction in wheat yield per 1°C rise in temperature has been reported by Lobell and Field (2007). This simulation paper showed the impact of temperature change during three crop scenarios on wheat cultivars under different dates of sowing using Info Crop model for two regions of different weather conditions.

Field experiments at two locations Amritsar and Ludhiana were conducted by sowing two wheat cultivars (HD 3086 and PBW 621) on five dates, i.e., 28 October, 4 November, 11 November, 18 November and 25 November. The wheat crop was raised as per the recommended package of practices prevalent at the Punjab Agricultural University Ludhiana.The data sets generated during *Rabi* were used for calibration and during the following *Rabi* were used for the validation of InfoCrop model. The InfoCrop model was used to study the simulation impact of temperature change on two wheat cultivars i.e. PBW 621 and HD 3086 for five dates of sowing and four scenarios of temperature change ($\pm$1.0 and $\pm$3.0°C from normal) during three scenarios of crop growth, i.e. whole season, vegetative phase and reproductive phase at Amritsar and Ludhiana.This change was done by editing the temperature values in weather file as per different phases.

Daily weather data at least from planting to harvesting date was loaded for each crop growth period separately to run a particular crop file. Weather data were collected from the Agrometeorological observatory. The minimum data set i.e maximum and minimum air temperature (°C), precipitation (mm) and wind speed were collected during the year 2015, 2016 and 2017. The crop management data were recorded throughout the crop growing seasons. The input files such as crop management file, weather file, soil file, and genetic coefficients file were prepared to calibrate and validate the InfoCrop model for both the locations

This section describes the performance of InfoCrop-wheat model in simulating crop growth parameters such as anthesis, physiological maturity and grain yield. The genetic coefficients (Table 1) determined for wheat cultivars ‘HD 3086 and PBW 621’ by the process of calibration were used during validation and the model was run independently for all dates of sowings. The validation of InfoCrop-wheat was performed by comparing the predicted grain yield and

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phenology of wheat crop under five dates of sowing for the year 2016–17. The model performance parameters like R^2, RMSE and d-stat show the correctness of the model. In the InfoCrop model cv. HD 3086 and PBW 621degree days(long duration cultivar) had higher value of degree days for germination to flowering i.e 1200 degree days while in HD 3086 (short duration cultivar) required less heat units i.e 1150. The values of sowing to germination were 1, 1 and 1 for cv HD 3086 and PBW 621, respectively. The values for 50% flowering to physiological maturity were 900 and 500 for HD 3086 and PBW 621, respectively. The InfoCrop-Wheat model was able to simulate phenological events i.e. anthesis (RMSE=2.66-day, d-stat=0.87), maturity date (RMSE=5.00-day, d-stat=0.81) and grain yield (RMSE=403.5 kg/ha day, d-stat=0.80) for wheat cultivars under different sowing dates during the one crop year.

The simulation results (1:1 line graph) for the grain yield predicted by InfoCrop model and actual yield of the wheat cultivars under different sowing dates has been given in the Fig. 1 (Ludhiana) and Fig. 2 (Amritsar) . The coefficient of determination was (R^2) 0.62 and 0.65, Amritsar and Ludhiana, respectively. For Amritsar, d stat value is 0.80 and RMSE of grain yield for the wheat was 403.5 kg/ha. All these statistical indices indicate that the InfoCrop-Wheat model was validated and hence can be used to work out simulation guided management practices for yield maximization of wheat under climate change conditions. The linear regression model between observed and simulated grain yield could account for 62% variation. Out of 10 environments, InfoCrop-Wheat model overestimated for 10 and underestimated for 2 environments for grain yield of wheat. (Ahmad *et al.*, 2014).

InfoCrop model simulated advancement in the anthesis stage of wheat at Amritsar (Table 2) by 6 to 11 days and 6 to 14 days, 7 to 15 days and 6 to 12 days, 7 to 14 days and 7 to 13 days, 6 to 12 days and 4 to 11 days, 6 to 12 days and 7 to 11 days with increase in temperature from 1 to 3°C from normal during whole season; 8 to 12 days and 5 to 14 days, 6 to 11 days and 6 to 10 days, 7 to 13 days and 8to 11 days, 5 to 12 days and 6 to 10 days, 4 to 10 days and 4 to 9 days with increase in temperature from 1 to 3°C from normal during vegetative phase with temperature increase from 1 to 3°C from normal for cv HD 3086 and cv PBW 621 sown on 28 October, 4 November, 11 November, 18 November and 25 November, respectively. Similar simulations performed through model with increase in temperature during reproductive phase favored the advancement in anthesis. As rise in temperature degree leads to the increase in evaporation and transpiration, so it seems that the rise in temperature, evaporation and transpiration, leads to the increase in the growth rate of the plant and in other words the plant efforts to complete the growth process by recognizing the heat stress condition and as a result the period of sowing to anthesis is reduced. Also, Roberts and Summerfield (2007) stated that the rise in temperature during the growth season leads to the fast growth and earlier flowering of the crop.

However, with decrease in temperature -1 to -3°C from normal, the InfoCrop model predicted delay in anthesis by 9 to 19 days and 8 to 18 days, 10 to 16 days and 7 to 18 days, 7 to 15 days and 6 to 12 days, 8 to 16 days and 8 to 15 days, 7 to 14 days and 6 to 13 days during whole season. Similar simulations performed through model with decrease in temperature during vegetative and reproductive phase favored the delay in anthesis

In Ludhiana, the data on the effect of change in temperature from normal during whole season, vegetative phase, grain filling phase on anthesis stage in wheat cultivars with five dates of sowing using InfoCrop-wheat model are given in Table 2. Simulations

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

Cultivar	HD 3086	PBW 621
Sowing to germination	1	1
Germination to 50% flowering	1150	1200
50% flowering to physiological maturity	900	500
Relative growth rate of leaf area (°C/day)	0.008	0.008
Specific leaf area (dm^2/mg)	0.00192	0.0019
Index of greenness of leaves	1	1
Extinction coefficient of leaves at flowering	0.60	0.60
Radiation use efficiency (g/MJ/day)	2.7	2.6
Root growth rate (mm/day)	30	30
Sensitivity of crop to flooding scale	1	1
Index of N fixation	1	1

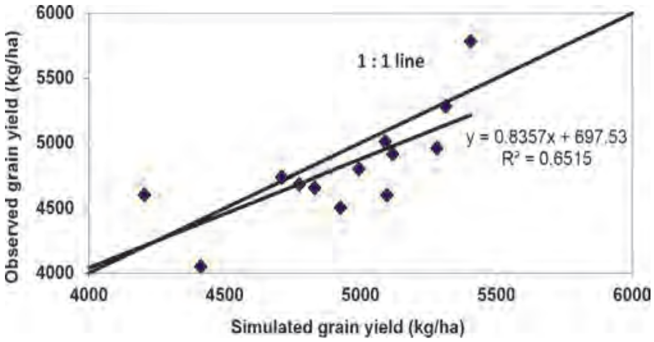

Fig. 1. Comparison of simulated and observed grain yield (kg/ha) for wheat cutivars using InfoCrop under cultivars for Ludhiana

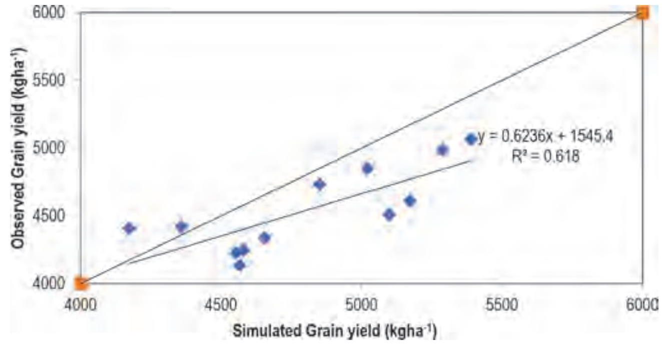

Fig. 2. Comparison of simulated and observed grain yield (kg/ha) for wheat cutivars using InfoCrop under cultivars for Amritsar.

performed for anthesis stage using InfoCrop-Wheat model predicted advancement by 9 to 22 days and 6 to 19 days, 5 to 17 days and 7 to 19 days, 6 to 18 days and 8 to 20 days, 9 to 20 days and 5 to 19 days, 6 to 19 days and 7 to 15 days during whole season, 9 to 22 days and 6 to 19 days, 8 to 20 days and 7 to 19 days, 6 to 17 days and 8 to 20 days, 9 to 20 days and 5 to 19 days, 6 to 19 days and 7 to 15 days during vegetative phase, 8 to 20 days and 5 to 17 days, 6 to 19 days and 5 to 17 days, 7 to 19 days and 8 to 20 days, 8 to 21 days and 5 to 17 days, 6 to 17 days and 5 to 14 days during grain filling phase with temperature increase from 1 to 3°C from normal for cv HD 3086 and cv PBW 621 sown on 28 October, 4 November, 11 November, 18 November and 25 November, respectively. However, with decrease in temperature -1 to -3°C from normal, the InfoCrop model predicted delay in anthesis by 8 to 15 days and 8 to 26 days, 8 to 30 days and 9 to 27 days, 9 to 21 days and 7 to 19 days, 7 to 21 and 9 to 22 days, 7 to 19 and 7 to 19 days during whole season, 8 to 24 and 8 to 26, 8 to 30 and 9 to 27, 9 to 21 and 8 to 19, 7 to 21 and 9 to 21, 7 to 19 and 7 to 19 for vegetative phase. Similar simulations were performed through model with decrease in temperature during reproductive phase which predicted that results favored the delay in anthesis. The results revealed that advancement as well as delay of anthesis stage of both the cultivars HD 3086 and PBW 621 were more in Ludhiana as compared to Amritsar. So, the facts depict that the impact of increase and decrease in temperature 1 to 3°C from normal, was significantly higher in Ludhiana as compared to Amritsar conditions.

For Amritsar (Table 3), InfoCrop model predicted advancement in the physiological maturity of wheat by 6 to 20 days and 7 to15 days, 8 to 18 days and 5 to 18 days, 6 to 17 days and 6 to 19 days, 8 to 22 days and 7 to 20 days, 4 to 22 days and 6 to 21 days with increase in temperature of 1 to 3 °C from normal during whole crop period for cv HD 3086 and cv PBW 621 sown on 28 October, 4 November, 11 November, 18 November and 25 November, respectively. Similarly, simulated advancement in the physiological maturity under similar sets of conditions with increase in temperature from 1 to 3°C during vegetative phase and reproductive phase by using InfoCrop model is illustrated in same Table 3. Rezaei *et al.* (2015) also revealed that high temperature caused two-week advancement in anthesis and physiological maturity. However, with decrease in temperature -1 to -3°C from normal, the InfoCrop model predicted delay in physiological maturity by 6 to 25 days and 8 to 20 days, 7 to 29 days and 10 to 22 days, 6 to 16 days and 5 to 18 days, 8 to 20 days and 10 to 18 days, 6 to 22 days and 7 to 20 days during whole season, 8 to 14 days and 8 to 12 days, 10 to 13 days and 9 to 14 days, 8 to 11 days and 6 to 18 days, 9 to 12 days and 10 to 22 days, 10 to 21 days and 8 to 13 days during vegetative phase, 8 to 15 days and 6 to 13 days, 9 to 12 days and 7 to 11 days, 7 to 11 days and 5 to 18 days, 10 to 24 days and 8 to 16 days, 6 to 18 days and 4 to 22 days for grain filling phase.

In Ludhiana (Table 3), simulations performed for physiological maturity using InfoCrop-Wheat model predicted advancement by 7 to 23 days and 6 to 18 days, 5 to 20 days and 7 to 19 days, 7 to 18 days and 6 to 21 days, 7 to 20 days and 4 to 22 days, 6 to 18 days and 7 to 14 days during whole season, 11 to 25 days and 6 to 21 days, 7 to 23 days and 6 to 18 days, 7 to 18 days and 7 to 19 days, 6 to 20 days and 7 to 22 days, 5 to 21 days and 7 to 14 days during vegetative phase, 9 to 22 days and 5 to 23 days, 6 to 21 days and 5 to 19 days, 8 to 20 days and 5 to 22 days, 8 to 21 days and 3 to 21 days, 7 to 19 days and 6 to 16 days during grain filling phase with temperature increase from 1 to 3°C from normal. However, with decrease in temperature -1 to -3°C from normal, the InfoCrop model predicted delay in physiological maturity by 7 to 27 days, 8 to 24 days, 8 to 32 days and 7 to 23 days, 8 to 18 days and 6 to 21 days, 6 to 17 days and 8 to 23 days, 6 to 21 days and 6 to 21 days during whole season. Similar simulations were performed through model with decrease in temperature during vegetative phase

Table 2. Impact of temperature change on the anthesis stage of wheat cultivars sown on five dates by InfoCrop-wheat model

Sowing date/ Cultivar	Normal	Ludhiana						Amritsar					
		Whole season		Vegetative phase		Grain filling phase		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	-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	113	+8 to +15	-9 to -22	+8 to +24	-9 to -22	+8 to +24	-8 to -20	+9 to +19	-6 to -11	+5 to+12	-8 to -12	+8 to +13	-6 to-12
PBW 621	115	+8 to +26	-6 to -19	+8 to +26	-6 to -19	+8 to +26	-5 to -17	+8 to +18	-6 to -14	+7 to +13	-5 to -14	+7 to+11	-7 to -13
D_2:4 November													
HD 3086	114	+8 to +30	-5 to -17	+8 to +30	-8 to -20	+8 to +30	-6 to -19	+10 to+16	-7 to -15	+5 to +10	-6 to -11	+6 to +12	-9 to -11
PBW 621	116	+9 to +27	-7 to -19	+9 to +27	-7 to -19	+9 to +27	-5 to -17	+7 to +18	-6 to -12	+6 to +15	-6 to -10	+8 to +15	-8 to -12
D_3:11 November													
HD 3086	119	+9 to +21	-6 to -18	+9 to +21	-6 to -17	+9 to +21	-7 to -19	+7 + to 15	-7 to -14	+5 to +11	-7 to -13	+7 to +10	-8 to -13
PBW 621	121	+7 to +19	-8 to -20	+8 to +19	-8 to -20	+8 to +19	-8 to -20	+6 to +12	-7 to -13	+5 to +13	-8 to -11	+9 to +12	-7 to -11
D_4:18 November													
HD 3086	118	+7 to +21	-9 to -20	+7 to +21	-9 to-20	+7 to +21	-8 to -21	+8 to +16	-6 to -12	+4 to +9	-5 to -12	+7 to +8	-6 to -11
PBW 621	118	+9 to +22	-5 to -19	+9 to +21	-5 to -19	+9 to +21	-5 to -17	+8 to +15	-4 to -11	+6 to +10	-6 to -10	+7 to +11	-7 to -12
D_5:25 November													
HD 3086	114	+7 to +19	-6 to -19	+7 to 19	-6 to -19	+7 to+19	-6 to -17	+7 to +14	-6 to -12	+3 to +7	-4 to -10	+6 to +10	-6 to -10
PBW 621	119	+7 to +19	-7 to -15	+7 to +19	-7 to -15	+7 to +19	-5 to -14	+6 to +13	-7 to -11	+4 to +8	-4 to -9	+7 to +9	-5 to -11

Table 3. Impact of temperature change on the physiological maturity of wheat cultivars sown on five differeent dates by InfoCrop-wheat model

		Ludhiana						Amritsar					
Sowing date/ Cultivar	Normal	Whole season		Vegetative phase		Grain filling phase		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	-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	141	+7 to +27	-7 to -23	+6 to +26	-11 to -25	+6 to +27	-9 to -22	+6 to +25	-6 to -20	+8to +14	-6 to -12	+8 to +15	-7 to -16
PBW 621	143	+8 to +24	-6 to -18	+7 to +23	-6 to -21	+8 to +24	-5 to -23	+8 to +20	-7 to -15	+8 to +12	-5 to -13	+6 to+13	-6 to -12
D_2:4 November													
HD 3086	140	+8 to +32	-5 to -20	+7 to +30	-7 to -23	+8 to +32	-6 to -21	+7 to+29	-8 to-18	+10to+13	-5 to-14	+9 to +12	-9 to -18
PBW 621	141	+7 to +23	-7 to -19	+5 to +20	-6 to -18	+7 to +23	-5 to -19	+10 to+22	-5 to -18	+9 to+14	-6 to -12	+7 to+11	-5 to -13
D_3:11 November													
HD 3086	141	+8 to +18	-7 to -18	+4 to +19	-7 to -18	+9 to +18	-8 to -20	+6 to+16	-6 to-17	+8 to +11	-6 to-14	+7 to +11	-8 to-22
PBW 621	143	+6 to +21	-6 to -21	+5 to +22	-7 to -19	+6 to +21	-5 to -22	+5 to +18	-6 to -19	+6 to +18	-7 to-15	+5 to+18	-5 to-20
D_4:18 November													
HD 3086	141	+6 to +17	-7 to -20	+8 to +18	-6 to -20	+6 to +17	-8 to -21	+8 to+20	-8 to -22	+9 to+12	-4 to -18	+10 to+24	-6 to -18
PBW 621	142	+8 to +23	-4 to -22	+7 to 24	-7 to -22	+8 to +23	-3 to -21	+10 to+18	-7 to-20	+10 to+22	-8 to -22	+8 to +16	-4 to -20
D_5:25 November													
HD 3086	139	+6 to +21	-6 to -18	+7 to +23	-5 to -21	+6 to +21	-7 to -19	+6 to +22	-4 to -22	+10 to+21	-5 to -19	+6 to +18	-8 to-18
PBW 621	140	+6 to 21	-7 to -14	+5 to +24	-7 to -14	+6 to +21	-6 to -16	+7 to+20	-6 to-21	+8 to +13	-6 to -22	+4 to+22	-4 to-23

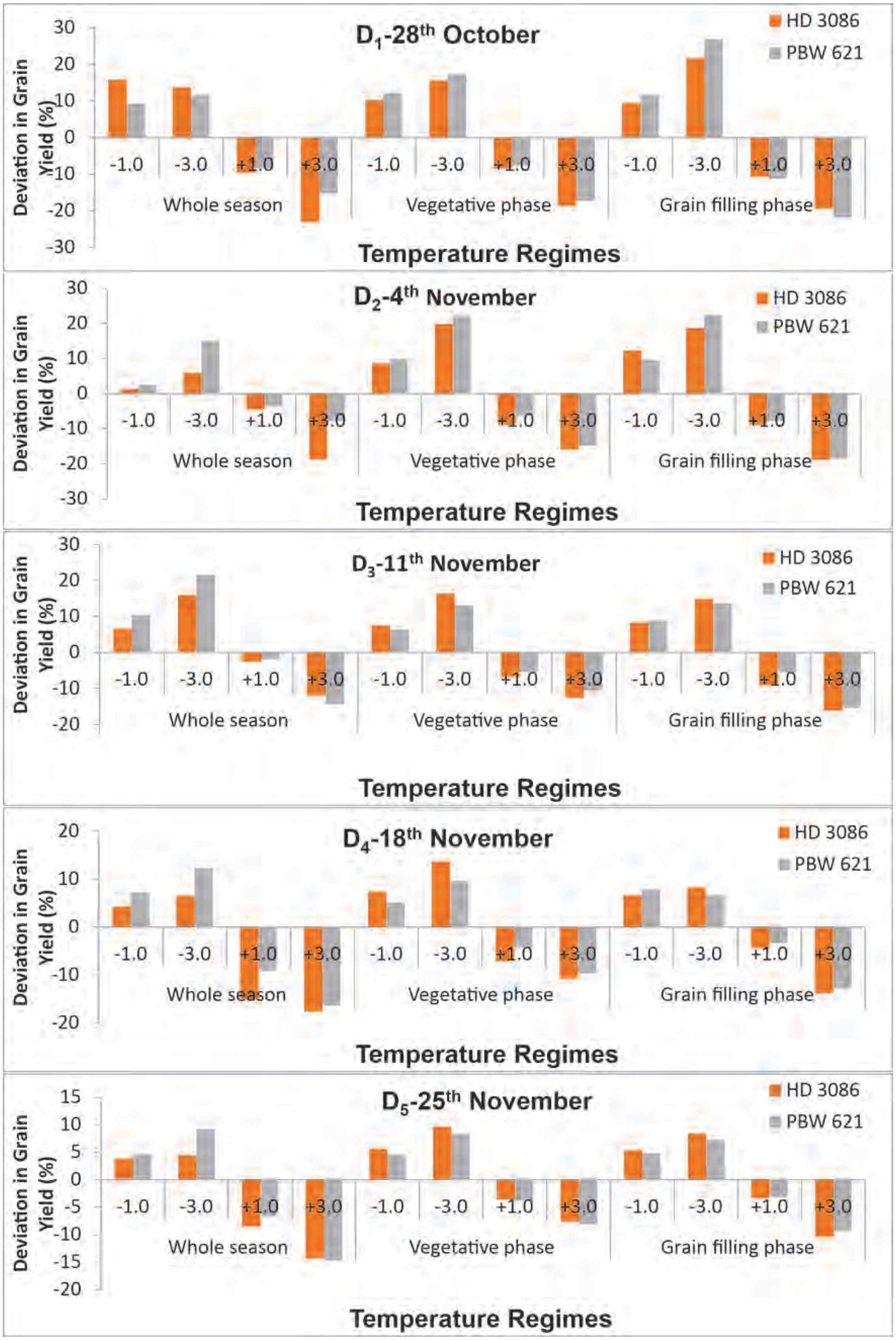

Fig. 3. Effect of temperature change on the yield of wheat cultivars sown on five dates by InfoCrop-wheat model for Ludhiana

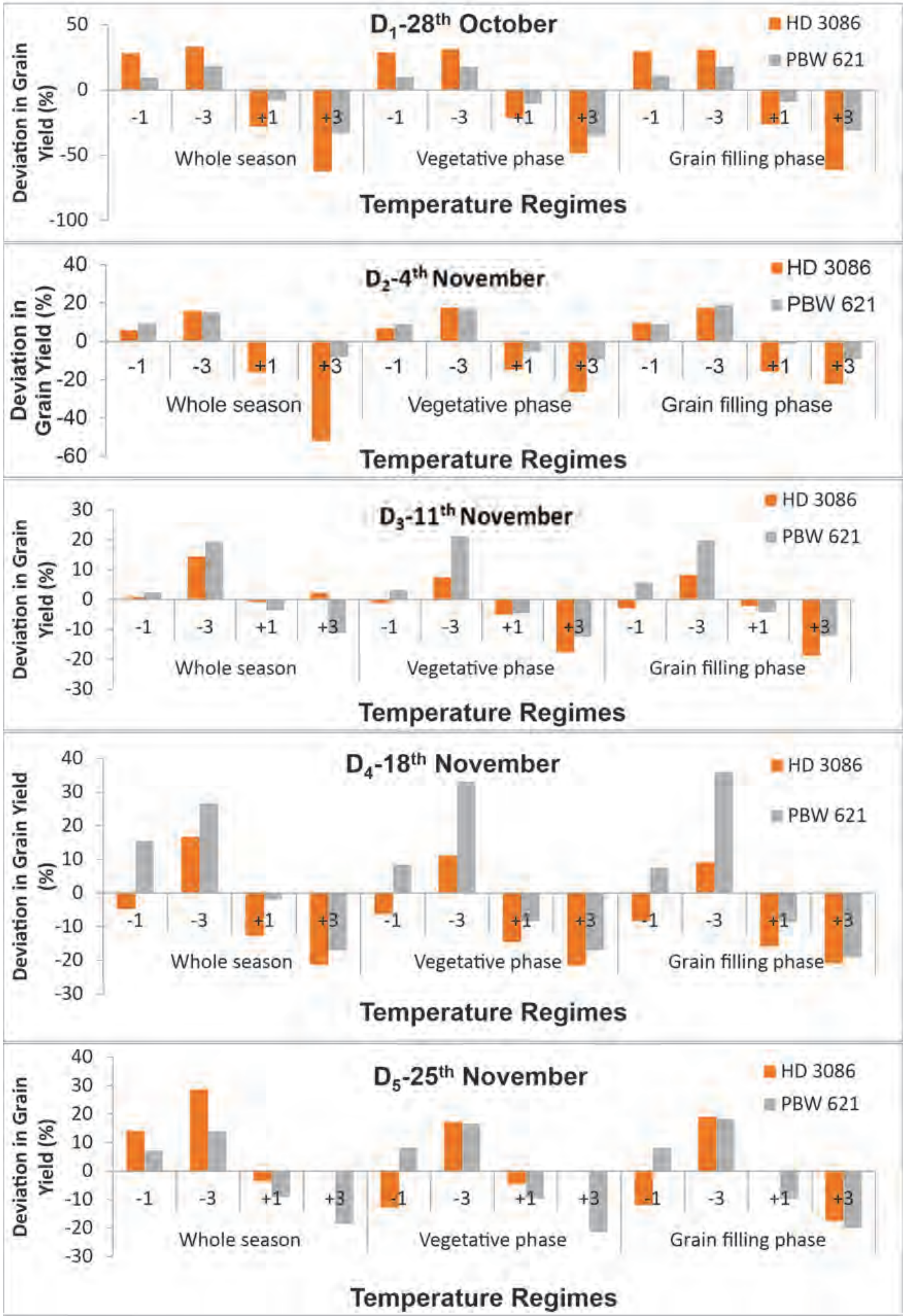

Fig. 4. Effect of temperature change on the yield of wheat cultivars sown on five dates by using InfoCrop-wheat model for Amritsar

and reproductive phase which predicted the delay in physiological maturity for cv HD 3086 and cv PBW 621 sown on 28 October, 4 November, 11 November, 18 November and 25 November, respectively.

In Ludhiana, the data on the effect of change in temperature from normal during whole season, vegetative phase, grain filling phase on grain yield in wheat cultivars with five dates of sowing using InfoCrop-wheat model are given in Fig. 3. Similar trend of reduction in yield with increase in temperature of 1.0°C to 3.0°C from normal during reproductive and vegetative phase was observed for both the locations. However, InfoCrop model predicted decrease in grain yield with increase in temperature by 0.5 to 3.0 ºC which is in accordance with the results presented by Aggarwal and Rani (2009).

In Amritsar, the data on the effect of change in temperature from normal during whole season, vegetative phase, grain filling phase on grain yield of wheat cultivars under five dates of sowing using InfoCrop-wheat model are given in Fig. 4. InfoCrop model simulated increase in grain yield with decrease in temperature from 1 to 3°C. InfoCrop model predicted decreased grain yield with increase in temperature by 1.0 to 3.0 ºC which is in accordance with the results presented by Krishnan *et al.* (2016) who have reported that about 17–23% decrease in wheat yield could occur with a 5ºC increase in temperature. Further, the simulation results for the InfoCrop favoured the decrease in grain yield with increase in temperature on all dates of sowing.

Under the anticipated change in temperature, the simulation results showed that impact of increase in temperature from normal during growth and development of cv. HD 3086 was significantly lower and this cultivar may be recommended for cultivation at both locations due to its tolerant traits towards maintaining its yield which is the most important determinant of high productivity. The mid November sowing of wheat would be optimum as compared to early or late sowing.

Authors' contribution

Conceptualization of research work and designing of experiments(PK, ASR, SS); Execution of field/ lab experiments and data collection(ASR, SS); Data analysis and interpretation of results(PK, ASR, SS, GS); Preparation of manuscript(ASR, SS).

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