MAUSAM, **72**, 3 (July 2021), 673-680

633.11 : 551.577.38 (540.65)

Improving heat use efficiency of wheat (*Triticumaestivum* L.) under abiotic stresses in semi-arid and arid agroclimatic conditions of Punjab

HARKANWALJOT SINGH, P. K. KINGRA, R. K. PAL* and SOMPAL SINGH

Deptt. of Climate Change & Agricultural Meteorology, Punjab Agricultural University, Ludhiana – 141 004, India

**PAU Regional Research Station, Bathinda, India*

(*Received 23 August 2020, Accepted 5 March 2021*)

e mail : pksidhu@pau.edu

सार – पंजाब के दो कृषि जलवायवी क्षेत्रों (अर्थात लुधियाना अर्ध -शुष्क और बठिंडा शुष्क क्षेत्र का प्रतिनिधित्व करने वाले) में अजैविक प्रतिबल में गेहूँ की फसल उत्पादकता के व्यवहार और ऊष्मा उपयोग दक्षता का अध्ययन करने के लिए एक फील्ड प्रयोग किया गया। गेहूँ की किस्म HD-2967 का मूल्यांकन पाँच तापीय वातावरण (D_1-20 अक्तूबर D_2-05 नवम्बर, D_3-20 नवम्बर D_4-05 दिसम्बर और D5-20 दिसम्बर) के तहत किया गया था ताकि मुख्य भूखंडों में फसल का विभिन्न तापीय वातावरण और दो नाइट्रोजन स्तरों का पता किया जा सके। (N_1 - नाइट्रोजन की अनुशंसित मात्रा और N_2 - अनुशंसित नाइट्रोजन से 25 प्रतिशत कम मात्रा है) और दो सिंचाई स्तरों (I_1 - इष्टतम (अनुशंसित) सिंचाई (CRI पर सिंचाई, जोड़, फूल और गेहूँ के दूध वाले चरण) और I_2 अल्प मात्रा में सिंचित 2017-18 और 2018-19 के लगातार दो रबी मौसमों के दौरान उप-भूखंडों में इष्टतम सिंचाई (अनुशंसित से एक सिंचाई कम) (सीआरआई में सिंचाई, फ्लैग लीफ उभरना और नरम आटा चरण) यह पाया गया कि अर्धशुष्क क्षेत्र यानी लुधियाना में बोई गई गेहूँ की फसल के तैयार होने में अधिक दिन लगे। दोनों ही स्थानों पर देरी से बुआई किए जाने पर फसल तैयार होने के विभिन्न चरणों में आवश्यक दिनों की संख्या में कमी हुई। फसल ने शुष्क क्षेत्र यानी बठिंडा में ऊष्मा का अधिक कुशलता से उपयोग किया। लुधियाना में 2017-18 और 2018-19 के दौरान क्रमशः 20 नवम्बर (3.08 किग्रा / हेक्टेयर / डिग्री सेल्सियस / दिन) और 05 नवम्बर (3.18 किग्रा/हेक्टेयर / डिग्री सेल्सियस / दिन) में बोई गई फसल में उच्चतम HUE देखा गया जबकि बठिंडा में, दोनों वर्षों के दौरान 5 नवम्बर (3.31 और 3.32 किग्रा / हेक्टेयर / डिग्री सेल्सियस/ दिन) को बोई गई फसल में एचयूई सबसे अधिक था। नाइट्रोजन की अनुशंसित मात्रा और इष्टतम सिंचाई ने भी दोनों वर्षों के दौरान दोनों स्थानों पर काफी अधिक HUE का उत्पादन किया।इस अध्ययन से यह निष्कर्ष निकला कि अनुशंसित नाइट्रोजन और इष्टतम सिंचाई से फसल की समय पर बुवाई अर्ध-शुष्क और शुष्क कृषि जलवायवी दोनों स्थितियों में ऊष्मा के उपयोग की दक्षता में काफी सुधार हो सकता है।

ABSTRACT. A field experiment was conducted in two agroclimatic zones of the Punjab (*viz*., Ludhiana representing semi-arid and Bathinda representing arid zone) to study the phenologicalbehaviour and heat use efficiency of wheat under abiotic stresses. The wheat variety HD-2967 was evaluated under five thermal environments (D_1- 20th October, D_2-5th November, D_3- 20th November, D_4- 5th December and D_5- 20th December) to expose the crop to different thermal environments and two nitrogen levels (N_1- Recommended dose of N and N_2- 25 per cent less than recommended N) in main plots and two irrigation levels (I_1 - Optimal (recommended) irrigation (Irrigation at CRI, Jointing, Flowering and Soft dough stage) and I_2 - Sub-optimal irrigation (one irrigation less than recommended) (Irrigation at CRI, Flag leaf emergence and Soft dough stage) in sub-plots during two consecutive *rabi* seasons of 2017-18 and 2018-19. It was found that the wheat crop sown in semi-arid zone *i.e*., Ludhiana took more number of days to reach physiological maturity. The number of days required to attain different phenological stages decreased with delayed sowing at both the locations. The crop utilized heat more efficiently in the arid zone *i.e*., Bathinda. At Ludhiana, highest HUE was observed in the crop sown on 20th November (3.08 kg/ha/°C/day) and 5th November (3.18 kg/ha/°C/day) during 2017-18 and 2018-19, respectively; whereas at Bathinda, HUE was highest in the crop sown on 5th November (3.31 and 3.32 kg/ha/°C/day) during both the years. Recommended dose of nitrogen and optimal irrigation also produced significantly higher HUE at both the locations during both the years. The study concluded that timely sowing of the crop along with recommended nitrogen and optimal irrigation can significantly improve efficiency of heat utilisation both in semi-arid and arid agroclimatic conditions.

Key words – Wheat, GDD, HTU, PTU, Heat use efficiency, Abiotic stresses.

1. Introduction

Wheat (*Triticumaestivum* L. emend. Feoriand Paul) is an important cereal crop of Indo-Gangetic plains of India and contributes to a great extent to the national food security providing more than 50 per cent of the calories to the people relying on it (Barkha *et al*., 2017). Wheat was grown in India over an area of about 30.23 million hectares with a production of 97.44 million tonnes during 2017-18 (Anonymous, 2018a). Whereas, in Punjab, it was grown on 35.00 lakh hectares with a production of 176.13 lakh tonnes and productivity of 47.50 quintals per hectare during 2017-18 (Anonymous, 2018b). Wheat is a thermo sensitive long-day crop and requires photoperiod of 14 hours (Pandey and Sinha, 2006).

Temperature is the foremost determinant of development and productivity of wheat. Extremely high temperature at grain filling stage cause the greatest loss for crop production (Balla *et al.*, 2009). The late sowing of wheat in rice-wheat system exposes pre-anthesis stage to elevated temperature that influence grain maturity and eventually the yield (Nagarajan *et al.*, 2008). Phenological development of crops is related to the accumulation of heat units above threshold temperature. A quantified value of heat units is necessary to achieve a particular phenophase. During growth and development of a cereal crops several growth stages are discernible in which important physiological processes occur (Sikder, 2008). Plants have a specific temperature requirement before they reach certain phenological stages. Several research findings noticed that temperature below 10 °C or above 25 °C, the optimum being 12-25 °C alter phenology, growth, development and finally reduce the yield of wheat varieties (Hakim *et al.*, 2012).

Air temperature based agrometeorological indices, *viz*., Growing Degree Days (GDD), Photo-thermal Units (PTU), Helio-thermal Units (HTU) have been used to describe changes in phonological behaviour and growth parameters (Kumar *et al.*, 2010). The accumulated values of GDD, HTU and PTU for each phenophase are relatively constant and independent of sowing date but vary in a crop from variety to variety (Phadnawis and Saini, 1992). As heat use efficiency of crops needs to be improved under global warming scenarios, in view of this, the present study was conducted to evaluate the phenology, heat unit requirement and heat use efficiency of wheat under thermal regimes as well as optimal and sub-optimal irrigation and fertiliser application in semi-arid and arid conditions.

2. Materials and method

2.1. *Study area*

The present study was conducted at two locations representing semi-arid and arid agroclimatic regions of Punjab. Ludhiana, representing semi-arid agroclimatic zone of Punjab, is located at 30°54′ N latitude, 75°54′ E longitude and 247 meter altitude above the mean sea level, whereas, Bathinda, representing arid zone, is located at 30°36′ N latitude, 74°28′ E longitude and 211 meter altitude above mean sea level. Both these locations are characterized by sub-tropical climate with hot summers and severe cold winter. May is the hottest month and January is the coolest month at both the locations. During winter the night time temperature can be as low as 0 °C, whereas during hot summer months, day time temperature can be as high as near 48 °C. The average annual rainfall is 755 and 400 mm for Ludhiana and Bathinda, respectively, about 75 per cent of which is received during south-west monsoon season (June to September). During winter months, the rainfall is received by western disturbances.

2.2. *Experimental details*

A factorial experiment was laid in split plot design at the research farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana and Regional Research Station, Bathinda during two consecutive *rabi* seasons of 2017-18 and 2018-19. The soil of the experimental field was loamy sand with alkaline reaction at Ludhiana and sandy loam at Bathinda. The treatments included five thermal environments as sowing dates in main-plots; 20th October (D_1), 5th November (D_2), 20th November (D_3), 5th December (D_4) and 20th December (D_5); two nitrogen levels**;** N_1 - Recommended dose of Nitrogen and N_2 - 25 per cent less than recommended dose of nitrogen and two irrigation levels in sub-sub plots; I_1 - Optimal (recommended) irrigation (Irrigation at CRI, Jointing, Flowering and Soft dough stage) and I_2- Sub-optimal irrigation (one irrigation less than recommended) (Irrigation at CRI, Flag leaf emergence and Soft dough stage). The phenological stages of crop were recorded by visual observations. Growing degree days were calculated by accumulation of daily mean temperature above the base temperature of 5 °C. The different agroclimatic indices for each stage were calculated as recommended by (Nuttonson, 1955).

$$\text{Growing degree days (°C days)} = \frac{(T_{\max} + T_{\min})}{2} - T_b$$

where, $T_{\max}$ = Daily maximum temperature (°C),

$T_{\min}$ = Daily minimum temperature (°C) and

T_b = Base temperature (5 °C)

The heliothermal units (HTU) were calculated as;

HTU = GDD × Actual bright sunshine hours (°C days hours)

The photothermal units (PTU) was calculated as;

PTU = GDD × Day length (°C days hours)

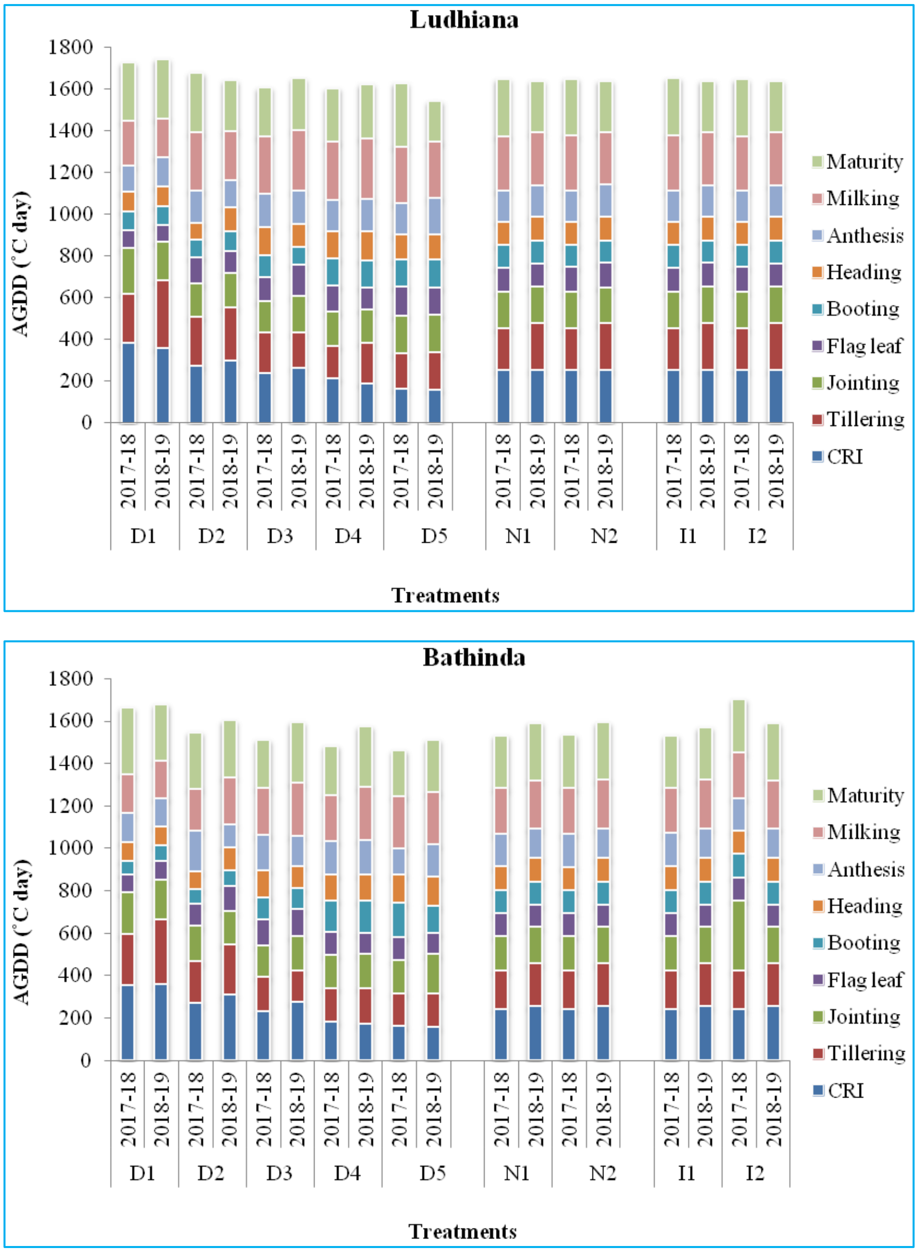


Fig. 1. Accumulated growing degree days of wheat from emergence upto maturity under different dates of sowing, nitrogen and irrigation levels during *rabi* 2017-18 and 2018-19 at Ludhiana and Bathinda

Phenothermal index (PTI): It is the ratio of degree days to the number of days between two phenological stages, and was calculated as:

$$PTI = \frac{\text{GDD consumed between two phenological phases}}{\text{Number of days taken between two phenophases}}$$

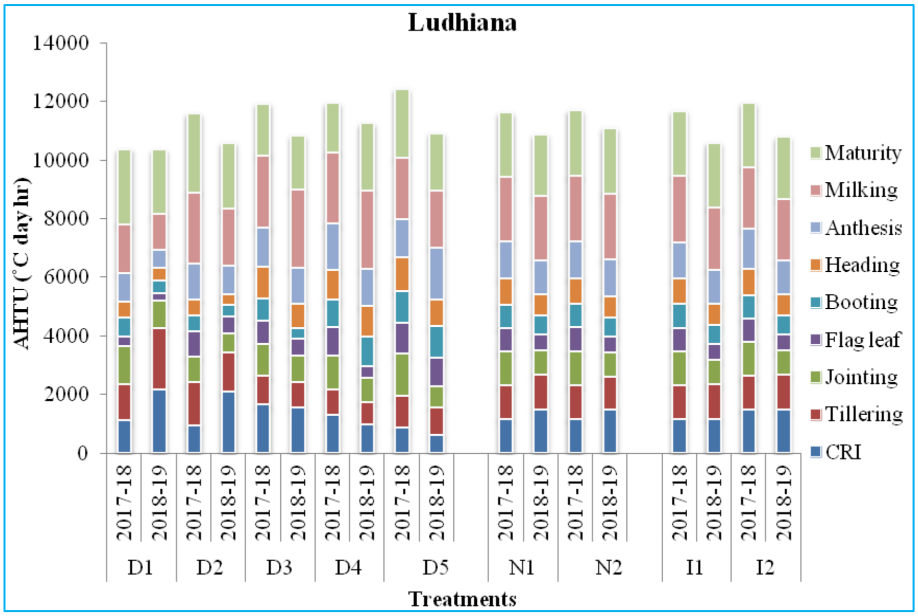
The heat use efficiency was calculated using the following formula:

$$\text{HUE}\left(\text{kg/ha/°C}\right) = \frac{\text{Grain or dry matter yield}\left(\text{kg/ha}\right)}{\text{AGDD}\left(\text{°C day}\right)}$$

3. Results and discussion

3.1. *Crop phenology*

Wheat crop took 20-23 and 21-23 days for crown root initiation at Ludhiana and 21-22 and 21-23 days at



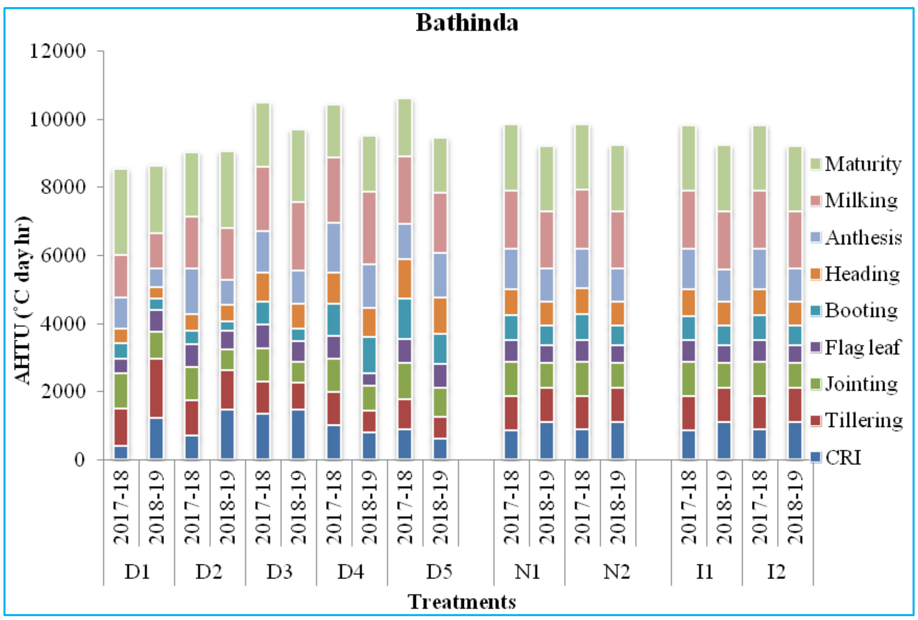


Fig. 2. Accumulated heliothermal units of wheat from emergence upto maturity under different dates of sowing, nitrogen and irrigation levels during *rabi* 2017-18 and 2018-19 at Ludhiana and Bathinda

Bathinda during 2017-18 and 2018-19, respectively, under different dates of sowing. The number of days taken by crop for tillering were more at Ludhiana (41-45 days and 45-50 days) as compared to Bathinda (42-44 days and 43-46 days) during both the years under five sowing dates. The 20th October sown crop acquired more days for reaching the physiological maturity, *i.e.*, 150 and 159 days at Ludhiana and 150 and 155 days at Bathinda as compared to the other sowing dates. Late sown crop (20th December) required lesser days for completion of various phenophases as compared to early sown crop. Such behaviour of late sown wheat might be due to fall in temperature during vegetative phase and abrupt rise during reproductive phases. Such results were also reported by Ghosh *et al.* (2000) and Singh *et al.* (2001). Nitrogen and irrigation levels had no significant influence on days required for initiation and completion of various phenological events.

3.2. *Growing degree days (GDD)*

GDD requirement was observed maximum in 20th October sown crop and decreased with delay in sowing

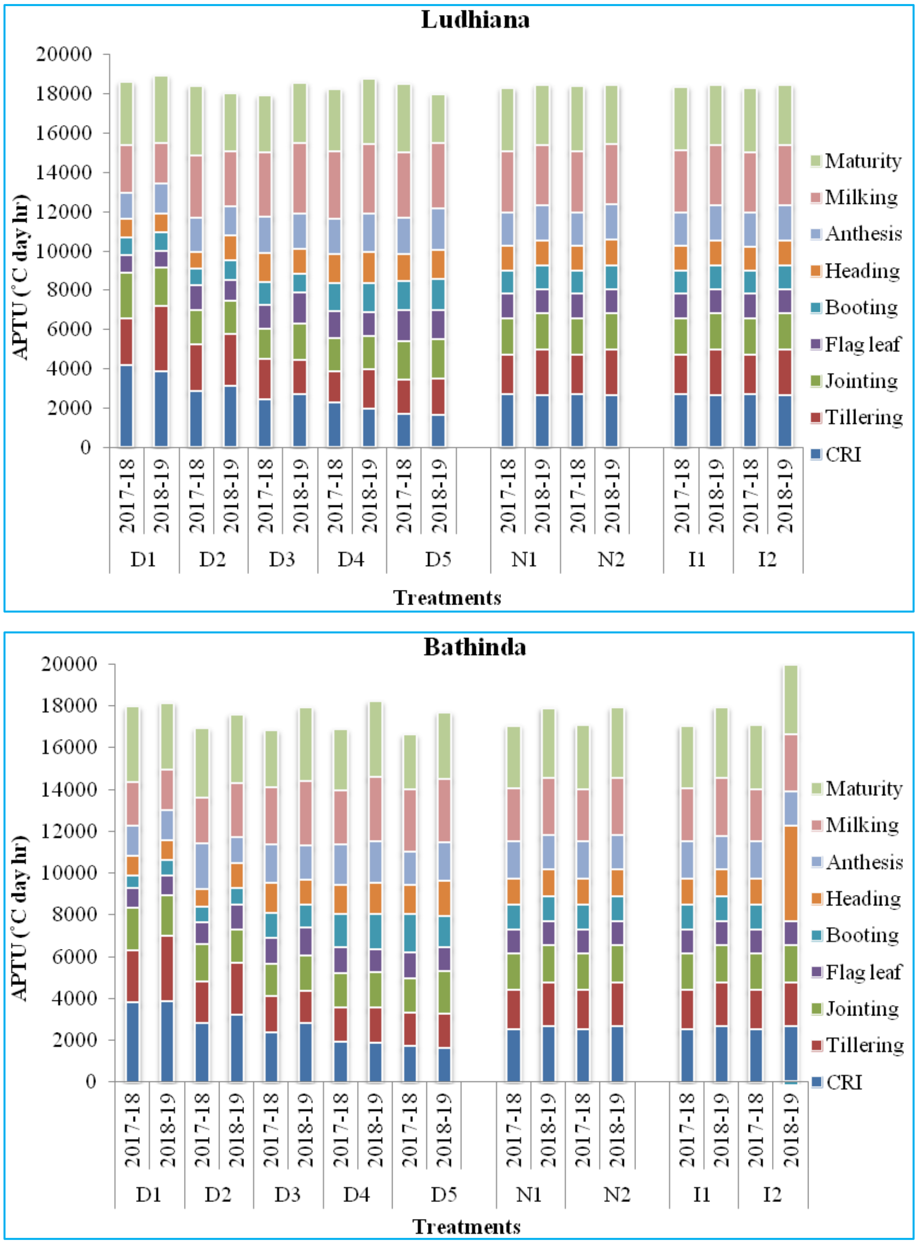
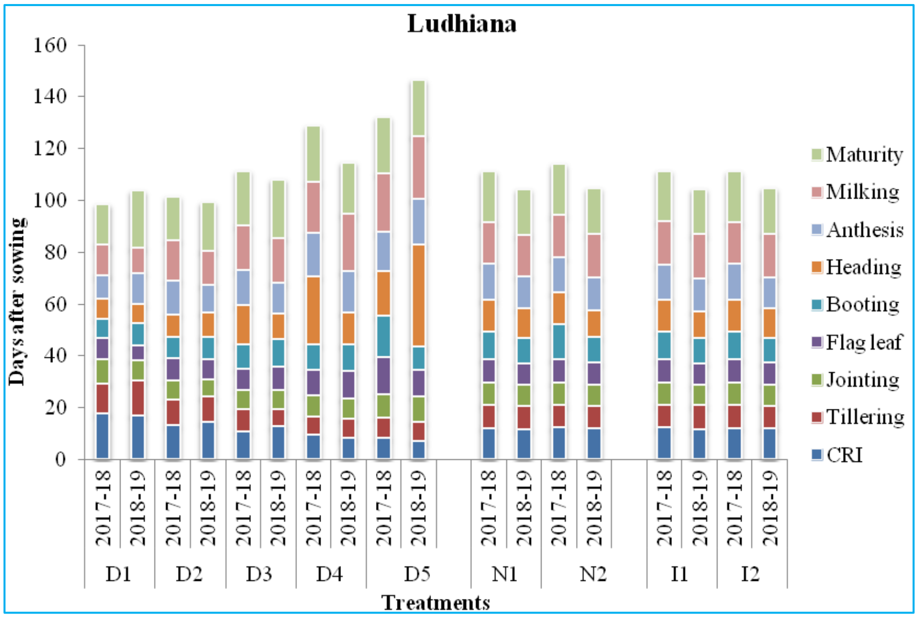


Fig. 3. Accumulated photothermal units of wheat from emergence upto maturity under different dates of sowing, nitrogen and irrigation levels during *rabi* 2017-18 and 2018-19 at Ludhiana and Bathinda

followed by 5th November, 20th November, 5th December and was minimum under 20th December sown crop at both the locations. The accumulated GDD taken by wheat crop to attain maturity under 20th October, 5th November, 20th November, 5th December and 20th December sowing were 1728.7, 1679.6, 1608.1, 1605.8 and 1630.6 (°C day) during 2017-18 and 1745.7, 1642.8, 1652.6, 1625.8 and 1542.8 (°C day) during 2018-19 at Ludhiana whereas for Bathinda, they were 1660.5, 1545.7, 1509.0, 1482.7 and 1460.2 (°C day) during 2017-18 and 16769, 1600.9, 1593.4, 1573.2 and 1509.4 (°C day) during 2018-19 (Fig. 1). The GDD requirement was observed to be higher for early sown than late sown crop due to longer period for all the phenological stages in the early sown crop which might be due to prevailing low temperature during vegetative phases and high temperature during reproductive phases of development in late sown crop. Our results were alike to those of (Khicharand Niwas, 2007). Paul and Sarker (2000) also observed that the requirement of heat units decreased with delay in sowing. Nitrogen and irrigation levels had no significant influence on accumulated growing degree days (AGDD) required for initiation and completion of various phenophases.



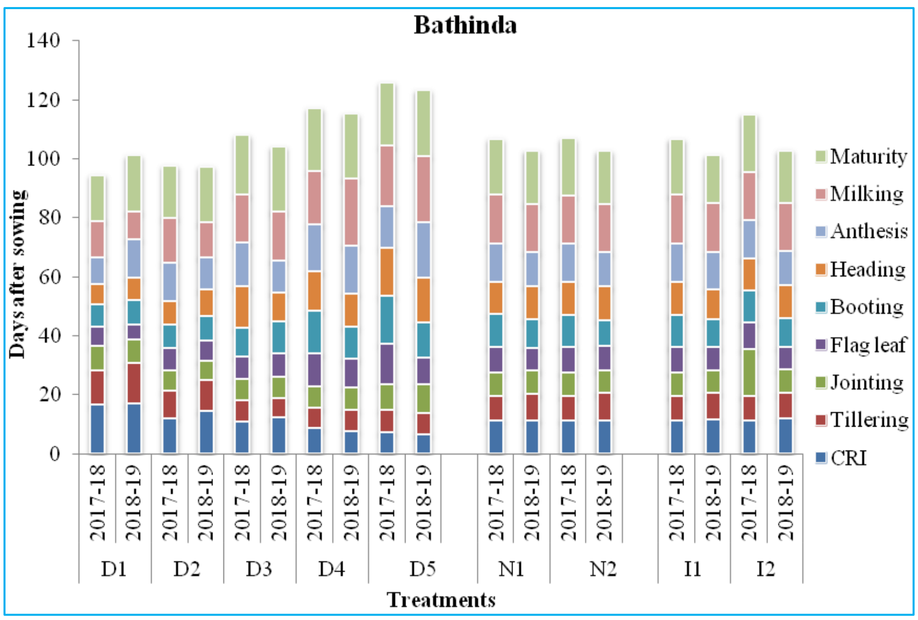


Fig.4. Phenothermal index of wheat from emergence upto maturity under different dates of sowing, nitrogen and irrigation levels during *rabi* 2017-18 and 2018-19 at Ludhiana and Bathinda

3.3. *Helio-thermal units (HTU)*

At Ludhiana, highest helio-thermal units were consumed by the crop sown on 20th October (12418.9 °C day hr) during 2017-18 and 5th December (11240.8 °C day hr) during 2018-19, whereas at Bathinda accumulated HTU were observed highest in the crop sown on 20th December (10625.2 °C day hr) during 2017-18 and 20th November (9700.5 °C day hr) during 2018-19 (Fig. 2) whereas lowest HTU were observed under 20th October sown crop during both years at both the locations. Similar results were also reported by Ram *et al.* (2012). Nitrogen and irrigation levels had no significant influence on the accumulated helio-thermal units (AHTU) required for completion of various phenophases of wheat.

3.4. *Photo-thermal units (PTU)*

The accumulated PTU were observed to be maximum in the crop sown on 20th October and decreased with delay in sowing being lowest for 20th December sown crop. The accumulated PTU under 20th October, 5th November, 20th

TABLE 1

Accumulated growing degree days, grain yield and heat use efficiency (Kg/ha/°C/day) of wheat under different sowing dates, nitrogen and irrigation levels during *rabi* 2017-18 and 2018-19 at Ludhiana and Bathinda

Treatment	Ludhiana						Bathinda					
	AGDD		Yield		HUE		AGDD		Yield		HUE	
	2017-18	2018-19	2017-18	2017-18	2018-19	2017-18	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Dates of Sowing												
October 20	1728.7	1745.7	46.04	49.08	2.66	2.82	1660.5	1676.9	47.17	50.00	2.84	2.98
November 5	1679.6	1642.8	50.87	52.25	3.03	3.18	1545.7	1600.9	51.33	52.92	3.32	3.31
November 20	1608.1	1652.6	49.59	50.58	3.08	3.06	1509.0	1593.4	50.00	51.33	3.31	3.22
December 5	1605.8	1625.8	44.29	46.67	2.76	2.87	1482.7	1573.2	43.58	45.58	2.94	2.90
December 20	1630.6	1542.8	38.28	40.92	2.35	2.65	1460.2	1509.4	37.00	38.50	2.53	2.55
CD (p=0.05)	6.64	8.29	0.70	1.87	0.04	0.09	6.61	7.43	1.23	1.34	0.07	0.09
Nitrogen levels												
Recommended (125 kg/ha)	1649.2	1641.4	46.46	48.43	2.82	2.95	1530.8	1590.2	46.37	48.27	3.02	3.03
25% less than recommended	1651.9	1642.4	45.17	47.37	2.74	2.88	1532.3	1591.3	45.27	47.07	2.95	2.95
CD (p=0.05)	NS	NS	0.38	0.87	0.02	0.06	NS	NS	0.86	0.81	0.05	0.06
Irrigation levels												
Optimal irrigation	1652.7	1642.1	47.05	49.10	2.85	2.99	1530.1	1593.3	46.93	48.73	3.06	3.06
Sub-optimal irrigation	1648.4	1641.7	44.58	46.70	2.70	2.84	1533.0	1588.1	44.70	46.60	2.91	2.92
CD (p=0.05)	NS	NS	0.38	0.87	0.02	0.06	NS	NS	0.86	0.81	0.05	0.04

November, 5th December and 20th December sowings were 18617.2, 18406.0, 17913.5, 18239.5 and 18544.1 (°C day hour)during 2017-18 and 18928.2, 18048.7, 18585.7, 18771.7 and 18013.6 (°C day hour)during 2018-19 at Ludhiana and 17940.9, 16905.4, 16804.6, 16848.4 and 16741.0 (°C day hour)during 2017-18 and for 2018-19, it was 18130.9, 17568.2, 17896.3, 18187.7 and 17662.7 (°C day hour)at Bathinda (Fig. 3). Nitrogen and irrigation levels had no significant influence on accumulated photo-thermal units (APTU) required for initiation and completion of various phenological stages of wheat.

3.5. *Phenothermal index*

Phenothermal index (PTI) from sowing till maturity was influenced by the different sowing dates, nitrogen and irrigation levels (Fig. 4). Late sown crop showed higher PTI compared to timely sown crop. Under five sowing dates (20th October, 5th November, 20th November, 5th December and 20th December), highest value of PTI was observed under 20th October, 5th November and 20th November sown crop in their early growth stages and thereafter decreased in the later stages of the crop growth during both years at both the study locations; whereas under 5th December and 20th December sown crop, lowest value of PTI was observed in early growth stages and in the later stages of the crop growth, its value increased.

3.6. *Heat use efficiency (HUE)*

The heat use efficiency of wheat under different sowing dates, nitrogen and irrigation levels for both the years has been given in Table 1. The crop sown on 20th November had significantly highest heat use efficiency (HUE) (3.08 Kg/ha/°C/day) followed by 5th November (3.03 Kg/ha/°C/day), 5thDecember (2.76 Kg/ha/°C/day) and 20th October (2.66 Kg/håC/da y) sown crop and significantly lowest heat use efficiency was observed under 20th December (2.35 Kg/ha/°C/day) sown crop at Ludhiana during 2017-18. During 2018-19, it was significantly highest for 5th November (3.18 Kg/ha/°C/day) sown crop followed by 20th November (3.06 Kg/ha/°C/day), 5th December (2.87 Kg/ha/°C/day) and 20th October (2.82 Kg/ha/°C/day) sown crop and significantly lowest heat use efficiency was observed under 20th December (2.65 Kg/ha/°C/day) sown crop. Heat use efficiency during 2017-18 at Bathinda was significantly highest for 5th November sown crop (3.32 Kg/ha/°C/day) which was statistically at par with the crop sown on 20thNovember (3.31 Kg/ha/°C/day) followed by 5th December (2.94 Kg/ha/°C/day) and 20thOctober (2.84 Kg/ha/°C/day) sown crop and significantly lowest for 20th December (2.53Kg/ha/°C/day) sown crop. During 2018-19 also, it was also significantly highest for 5th November sown crop (3.31 Kg/ha/°C/day) which was statistically at par with the crop sown on 20th November (3.22 Kg/ha/°C/day) followed by 20th October (2.98 Kg/ha/°C/ day) and 5th December (2.90 Kg/ha/°C/day) and significantly lowest in 20th December (2.55 Kg/ha/°C/day) sown crop. Kumari *et al.* (2009) also reported that timely sown wheat crop exhibited maximum heat use efficiency. Similar results were reported by Hague (2000) and Paul and Sarker (2000). The timely sown crop produced higher grain yield by using accumulated heat units efficiently. As the temperature was favourable throughout the growing period in case of timely sown conditions, it utilized heat more efficiently and increased physiological activities resulting in higher grain yield. During both years, nitrogen and irrigation levels had significant effect on heat use efficiency at both the stations. HUE was observed to be significantly higher under optimal irrigation during both years at both the locations. Kingra *et al.* (2011) also reported higher heat use efficiency of wheat under optimal irrigation.

3.7. *Relationship between grain yield and heat use efficiency*

Regression analysis showed a positive correlation between heat use efficiency and grain yield. Linear regression relationship has been observed between heat use efficiency and grain yield. The linear regression equations explained 92.2 and 83.2 per cent variation ingrain yield with heat use efficiency for Ludhiana and 86.2 and 94.2 per cent variation for Bathinda; under different dates of sowing, nitrogen and irrigation levels during both the years as following:

Location	Year	Regression equation	R^2
Ludhiana	2017-18	GY = 16.062 × HUE + 1.3211	0.92
	2018-19	GY = 18.657 × HUE – 6.4859	0.83
Bathinda	2017-18	GY = 15.874 × HUE – 1.6408	0.86
	2018-19	GY = 18.676 × HUE – 8.1989	0.94

4. Conclusions

The crop sown on 20th October took maximum calendar days and accumulated highest growing degree days and photo-thermal units, which got reduced significantly with subsequent delay in sowing time and recorded lowest value on 20th December sown crop. There was decline in yield at both the locations with delay in sowing. The timely sown wheat crop performed better in terms of accumulation and utilization of heat units at central zone as well as south-western zone of the state. The study concluded that timely sowing of wheat (5th November) along with optimal irrigation schedule lead to more efficient heat utilisation. Thus, appropriate sowing time and irrigation scheduling can be used as effective strategy for improving heat use efficiency of wheat under global warming scenarios.

Disclaimer : The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

References

Anonymous, 2018a, Website: http://www.indiastat.com.

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

Balla, K., Bencze, S., Janda, T. and Veisz, O., 2009, "Analysis of heat stress tolerance in winter wheat", *Acta Agronomica Hungarica*, **57**, 437-444.

Barkha, Bhanvadia, A. S. and Dholiya, S. N., 2017, "Yield, water use efficiency and economics of wheat (*Triticumaestivum* L.) as influenced by drip irrigation scheduling and nitrogen levels", *Journal of Pharmacognosy and Phytochemistry*, **6**, 314-316.

Ghosh, D. C., Nandi, P. and De, B., 2000, "Phenological development and productivity of wheat (*Triticumaestivum*L.) at different dates of sowing", *Indian Journal of Agricultural Sciences*, **70**, 390-395.

Hague, M. M., 2000, "Physiological analysis of yield of wheat (*Triticumaestivum* L.) in relation to sowing date", Ph. D. thesis, University of Rajshahi, Bangladesh.

Hakim, M. A., Hossain, A., Teixeira da Silva, J. A., Zvolinsky, V. P. and Khan, M. M., 2012, "Yield, protein and starch content of 20 wheat (*Triticumaestivum*L.) genotypes exposed to high temperature under late sowing conditions", *Journal of Scientific Research*, **4**, 477-489.

Khichar, M. L. and Niwas, R., 2007, "Thermal effect on growth and yield of wheat under different sowing environments and planting systems", *Indian Journal of Agricultural Research*, **41**, 92-96.

Kingra, P.K., Mahey, R.K., Gill, K.K. and Singh, S.P., 2011, "Thermal requirements and heat use efficiency of wheat under different irrigation levels", *Indian Journal of Ecology*, **38**, 228-233.

Kumar, R., Ramesh, K., Singh, R. D. and Prasad, R., 2010, "Modulation of wild marigold (*Tagetesminuta*L.)phenophases towards the varying temperature regimes - A field study", *Journal of Agrometeorology*, **12**, 234-240.

Kumari, P., Wadood, A., Singh, R. S. and Kumar, R., 2009, "Response of wheat crop to different hydrothermal regimes under the agroclimatic conditions of Jharkhand", *Journal of Agrometeorology*, **11**, 85-88.

Nagarajan, S., Anand, A. and Chaudhary, H. B., 2008, "Response of spring wheat (*Triticumaestivum*L.)genotypes under changing environment during grain filling period", *Indian Journal of Agricultural Sciences*,**78**, 177-179.

Nuttonson, M. Y., 1955, "Wheat climatic relationship and use of phenology in ascertaining the thermal and photothermal requirements of wheat", *Am. Inst. Crop Ecol.*, Washington D.C.

Pandey, S. N. and Sinha, B. K., 2006, "Plant physiology", 4th Edition,Vikas Publishing House Pvt. Ltd, New Delhi, 485-487.

Paul, N. K. and Sarker, D. K., 2000, "Accumulated heat units and phenology relationships in wheat as influenced by sowing dates", *Bangladesh Journal of Botany*, **29**, 49-54.

Phadnawis, B. N. and Saini, A. D., 1992, "Photothermal effects on tiller survival of wheat", *Annals of Plant Physiology*, **6**, 262-267.

Ram, H., Singh, G., Mavi, G. S. and Sohu, V. S., 2012, "Accumulated heat unit requirement and yield of irrigated wheat (*Triticumaestivum* L.) varieties under different crop growing environment in central Punjab", *Journal of Agrometeorology*, **14**, 147-153.

Sikder, S., 2008, "Accumulated heat unit and phenology of wheat cultivars as influenced by late sowing heat stress condition", *Agricultural and Rural Development*, **7**, 57-64.

Singh, A. K., Mishra, S. R. and Tripathi, P., 2001, "Phenology, growing degree days and phasic development model of wheat (*Triticumaestivum* L.) under rice (*Oryza sativa* L.) wheat cropping system", *Indian Journal of Agricultural Sciences*, **71**, 363-366.