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

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

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

*PAU Regional Research Station, Bathinda, India

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e mail : pksidhu@pau.edu

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 phenological behaviour and heat use efficiency of wheat under abiotic stresses. The wheat variety HD-2967 was evaluated under five thermal environments (D1-20th October, D2-5th November, D3-20th November, D4-5th December and D5-20th December) to expose the crop to different thermal environments and two nitrogen levels (N1 - Recommended dose of N and N2 - 25 per cent less than recommended N) in main plots and two irrigation levels (I1 - Optimal (recommended) irrigation (Irrigation at CRI, Jointing, Flowering and Soft dough stage) and I2 - 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 (*Triticum aestivum* 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 phenological 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 (D1), 5th November (D2), 20th November (D3), 5th December (D4) and 20th December (D5); two nitrogen levels; N1 - Recommended dose of Nitrogen and N2 - 25 per cent less than recommended dose of nitrogen and two irrigation levels in sub-sub plots; I1 - Optimal (recommended) irrigation (Irrigation at CRI, Jointing, Flowering and Soft dough stage) and I2 - 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).

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

where, \( T_{\text{max}} \) = Daily maximum temperature (°C),
\( T_{\text{min}} \) = Daily minimum temperature (°C) and
\( T_b \) = Base temperature (5 °C)

The heliothermal units (HTU) were calculated as;

\[ \text{HTU} = \text{GDD} \times \text{Actual bright sunshine hours (°C days hours)} \]

The photothermal units (PTU) was calculated as;

\[ \text{PTU} = \text{GDD} \times \text{Day length (°C days hours)} \]
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:

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

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
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 20<sup>th</sup> 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 (20<sup>th</sup> 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 <i>et al.</i> (2000) and Singh <i>et al.</i> (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 20<sup>th</sup> October sown crop and decreased with delay in sowing
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, 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 1676.9, 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.
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...
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 photothermal 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), 5th December (2.76 Kg/ha/°C/day) and 20th October (2.66 Kg/ha/°C/day) 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 20th November (3.31 Kg/ha/°C/day) followed by 5th December (2.94 Kg/ha/°C/day) and 20th October (2.84 Kg/ha/°C/day) sown crop and significantly lowest for 20th December (2.53 Kg/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 in grain 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 | R²   |
|----------|--------|---------------------|------|
| 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 led 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.

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