Growing degree days and heat use efficiency of wheat as influenced by thermal and moisture regimes

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Wheat development is influenced by several factors such as nutrients, water, photoperiod and temperature. Drought and heat stress are important environmental factors affecting the rate of plant growth and development (Howarth, 2005). Sowing time of wheat is one of the most important factors that governs the crop phenological development and efficient conversion of biomass into economic yield. Normal sowing has longer growth duration, which consequently provides an opportunity to accumulate more biomass as compared to late sowing and henceforth manifested in higher grain yield (Singh and Pal, 2003). Moisture stress has also been found to reduce the number of days required to complete any phenological stage and the crop growth indices (Ihsan et al., 2016).

Because of the very close relation between temperature and plant development, growing degree-days (GDD) are frequently used as an indicator for crop development evaluation. Several authors used degree-days to describe this connection between temperature and crop development (Kingra and Kaur, 2012). GDD also changes with growing stage and permits to estimate the exact time of occurring growth stage in particular location (Mc Master et al., 2012). Heat use efficiency index could be also used in order to predict phenological phases (Rao et al., 1999). Therefore, the objective of this study is to determine the GDD and heat use efficiency of wheat under variable sowing and irrigation regimes and their correlation with grain yield.

A field experiment was conducted during rabi 2014–15 and 2015–16 at Punjab Agricultural University (PAU), Ludhiana, India (30° 54’ N, 75° 48’ E, elevation 247 m above sea level). The soil of the experimental field was alluvial sandy loam (Typic Ustochrept) in texture with 55–59 per cent sand, 23–26 per cent silt and 17–19 per cent clay in different soil layers. The mean bulk density was 1.6 Mg m$^{-3}$ and mean field capacity was 25 per cent (v/v) in the 0–1 m soil profile.

The experiments were conducted in a split plot design consisting of four sowing dates ($D_1$ -25th Oct, $D_2$ -10th Nov, $D_3$ -25th Nov and $D_4$ -10th Dec) in main plots and five irrigation treatments in sub plots, replicated three times. Four drip irrigation treatments based on soil water deficit from field capacity were (1) 15 per cent depletion (2) 25 per cent depletion (3) 35 per cent depletion (4) 45 per cent depletion from field capacity (FC) of the top 0–40 cm layer, and the fifth irrigation treatment was taken as conventional practice (conventional practice here refers to irrigating the crop with 75 mm water after every 4–5 weeks, irrespective of the crop growth stage or soil moisture depletion). The amount of irrigation per application was 15 mm, 25 mm, 35 mm, 45 mm and 75 mm, respectively for the five irrigation treatments. For detailed information on materials and methods, the readers may refer to Dar et al. (2017).

The various heat units viz. growing degree days (GDD), photo thermal unit (PTU) and helio thermal unit (HTU) consumed for attaining phenological stage were calculated taking base temperature of 4.5 °C. The heat use efficiency (HUE), helio thermal use efficiency (HTUE) and photo thermal use efficiency (PTUE) were calculated following Singh and Khushu (2012). Correlation analysis was performed using Proc CORR procedure of SAS version 9.4 (SAS, 2017).

Results revealed that the sowing date strongly influences the GDD requirement for a particular developmental stage (Table 1). The cumulative GDD for attaining different developmental stages were highest in October 25 sown wheat. There was a progressive decrease in GDD as the sowing date was delayed from 25th October to 10th December. The mean maximum GDD accumulation (°C days) of two years for attaining maturity was 1969 in wheat sown on October 25. Higher GDD accumulation by the early
Date of sowing had a strong effect on all of the three heat use efficiencies indices. The maximum HUE (2.80 kg°C⁻¹ day) was under wheat sown on November 10 while maximum HTUE (0.46 kg°C⁻¹ day hour) and PTUE (0.25 kg°C⁻¹ day hour) were found under October 25 sown wheat. The minimum HUE (2.50), HTUE (0.39) and PTUE (0.22) were recorded in late sown (December 10) wheat. The efficiencies were higher in earlier sowing dates due to higher yield as compared to the delayed sowings. Girijesh et al. (2011) reported higher heliothermal use efficiency within optimum sowing window.

Irrigation schedule also influenced the HUE, HTUE and PTUE. All of these efficiencies indices decreased with increase in moisture deficit from FC₁₅ to FC₄₅. The maximum HUE (3.01 kg°C⁻¹), HTUE (0.48 kg°C⁻¹ day hour) and PTUE (0.27 kg°C⁻¹ day hour) were found in FC₁₅. The minimum HUE, HTUE and PTUE were recorded in FC₄₅ (2.26, 0.37 and 0.21, respectively). The reduction in these efficiencies with increase in moisture stress may be attributed to the reduction in yield under water stress conditions.

**Correlation analysis**

All the meteorological parameters at CRI, booting, anthesis and maturity had positive significant effect on grain yield (Table 3). This means that more the GDD, heliothermal units (HTU) and photothermal units (PTU) consumed to reach different phenological stages, higher...
Heat use efficiency of wheat as influenced by thermal and moisture regimes

The maximum correlation with grain yield was found with the helio thermal units (HTU) consumed up to maturity ($r=0.95$) followed by PTU up to maturity ($r=0.89$). The maximum correlation between grain yield and GDD was found at maturity ($r=0.86$) and anthesis ($r=0.85$).

Based on the study, it can be concluded that the growing degree days (GDD), heat use efficiency, helio thermal use efficiency and photo thermal use efficiency were higher in early sowing dates as compared to delayed sowings. Further, GDD, HTUE and PTUE decreased with increase in moisture deficit from FC$_{15}$ to FC$_{45}$. The correlation analysis revealed that more the GDD taken to reach different phenological stages, higher will be the yield.

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