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Short Comminucation

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 in to 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° 542 N, 75° 482 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

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Table 1: Effect of date of sowing and irrigation schedule on growing degree days of wheat (mean of 2014-15 and 2015-16)

Treatment	Growing degree days (°C days)							
	CRI	Tillering	Booting	Heading	Anthesis	Milking	Dough	Maturity
Sowing date								
25th Oct.	362	733	972	1068	1212	1496	1743	1969
10th Nov.	332	582	772	901	1057	1310	1543	1768
25th Nov.	272	490	659	821	970	1186	1472	1654
10th Dec.	192	423	611	786	914	1146	1353	1533
Irrigation schedule								
FC_{15}	287	576	781	932	1084	1339	1582	1790
FC_{25}	287	562	760	904	1046	1301	1545	1746
FC_{35}	291	548	742	878	1017	1260	1499	1703
FC_{45}	291	535	721	849	993	1224	1462	1662
CP	291	564	763	908	1051	1300	1550	1753

Table 2: Effect of date of sowing and irrigation schedule on HUE, HTUE and PTUE of wheat

Treatment	HUE (kg/°C days)	HTUE (kg/°C day hour)	PTUE (kg/°C day hour)
Sowing date			
25th Oct.	2.74	0.46	0.25
10th Nov.	2.80	0.45	0.25
25th Nov.	2.68	0.43	0.24
10th Dec.	2.50	0.39	0.22
Irrigation schedule			
FC_{15}	3.01	0.48	0.27
FC_{25}	2.82	0.45	0.26
FC_{35}	2.53	0.41	0.23
FC_{45}	2.26	0.37	0.21
CP	2.79	0.45	0.25

sowing dates was due to higher number of days taken to reach different phenophases, which may be attributed to variation in temperature prevailing under different sowing dates. Ram *et al.,* (2012) also found decrease in GDD accumulation with deferral in sowing time.

Irrigation schedule also produced a pronounced effect on GDD accumulation (Table 1). The GDD accumulation decreased with increase in moisture stress from FC_{15} to FC_{45}. The mean maximum GDD accumulation (°C days) of two years for attaining maturity was 1790 in FC_{15}, and least in FC_{45} (1662 GDD). The reduction in GDD accumulation was due to reduction in number of days taken to attain any phenological stage under water stress conditions, as was also reported by Brar *et al.* (2016).

Date of sowing had a strong effect on all of the three heat use efficiencies indices. The maximum HUE (2.80 kg^{-1} °C days) was under wheat sown on November 10 while maximum HTUE (0.46kg^{-1}°C day hour) and PTUE (0.25 kg^{-1} °C 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 helio thermal 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 FC_{15} to FC_{45}. The maximum HUE (3.01 kg^{-1}°C), HTUE (0.48kg^{-1}°Cday hour) and PTUE (0.27kg^{-1}°C day hour) were found in FC_{15}. The minimum HUE, HTUE and PTUE were recorded in FC_{45} (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

Table 3: Correlation coefficients between heat units (GDD, PTU and HTU) during different stages with grain yield of wheat

Stages	GDD	PTU	HTU
CRI	0.69*	0.71*	0.61*
Boot	0.78**	0.77**	0.77**
Anthesis	0.85**	0.86**	0.88**
Maturity	0.86**	0.89**	0.95**

will be the grain yield. 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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