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Research Paper

Hydro-thermal conditions and their impact on irradiance and hygro-thermal use efficiency of wheat in central Punjab

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ABSTRACT

The experiments were conducted to develop indices to provide critical insights into crop phenology and yield responses of wheat to thermal and moisture conditions during *rabi* 2021-22 and 2022-23 at PAU, Ludhiana, Punjab. The wheat variety *Unnat* PBW - 550 was sown on three dates (D_1: 27th October, D_2: 17th November, D_3: 8th December) under three irrigation regimes (I_1: irrigations at CRI, Jointing, 50% Flowering, Soft dough stages, I_2: irrigations at CRI, Flag leaf emergence, soft dough stage, I_3: irrigations at Jointing, Soft dough stage). Results revealed that the crop sown on 27th October acquired maximum number of calendar days and various heat indices viz. growing degree days (GDD), solar thermal degree days (STDD) and hygrothermal units (HGTU) for attaining physiological maturity while 8th December sown crop resulted in lowest accumulation. However, late sown crop was observed to accumulate more STDD. Wheat sowing before 17th November resulted in higher grain yield and energy use efficiencies. Four irrigations at critical stages took highest GDD, STDD and HGTU for attaining maturity which was at par with two irrigations. Application of four irrigations resulted in significantly higher yield and energy use efficiencies. Similar performance of three irrigations was observed when irrigation was not skipped at anthesis stage.

Key words: Growing degree days, Hydro-thermal regimes, Hygro-thermal indices, Irradiance, wheat

Wheat is an important cereal crop grown worldwide. In India, the states of Uttar Pradesh, Madhya Pradesh, Punjab, Haryana, and Rajasthan, are known for their extensive wheat cultivation. In Punjab, the rice-wheat cropping system is dominant one which has economically benefitted farmers but it has exerted immense pressure on water resources. Certain phenological stages of crops are more vulnerable to water stress (Memon *et al.,* 2021). So, it becomes imperative to assess the various irrigation scheduling alternatives in wheat crop for understanding when to skip irrigation. Since, wheat is thermo-sensitive long day plant; timely sowing is required to attain proper phenological development and high biomass (Dar *et al.,* 2018). Studies have also revealed solar radiation and atmospheric humidity as key parameters affecting yield (Sivakumar, 2023). Solar radiation often takes precedence because it directly fuels the fundamental process of photosynthesis. Relative humidity acts as a supporting element in determining crop yield by impacting vapour fluxes (Shimoda *et al.,* 2022). Therefore, radiation and relative humidity-based indices viz. solar thermal degree days (STDD) and hygrothermal unit (HGTU) have been introduced along with growing degree days (GDD) in order to determine their impact on phenology and yield of the crop. Investigating the interaction of temperature, solar radiation, and humidity through indices will aid in fine-tuning sowing schedules and irrigation practices, helping to optimize phenological phases, and enhance crop productivity.

MATERIALS AND METHODS

The experiment was conducted for two consecutive wheat growing seasons 2021-22 and 2022-23 for Unnat PBW - 550 in a split plot design keeping three dates of sowing in main plot (D_1= 27thOctober, D_2= 17thNovember D_3= 8th December) and three irrigation regimes based on phenological stages in the sub-plot (I_1= irrigations at CRI, Jointing (JNTG), 50% Flowering (ATH) and Soft dough stages (SD), I_2= irrigations at CRI, Flag leaf emergence (FL) and soft dough stage, I_3= irrigations at Jointing and Soft dough stage) at PAU, Ludhiana, Punjab. Three agrometeorological indices viz. growing degree days (GDD), solar thermal degree days

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(STDD) and hygrothermal units (HGTU) were computed along with their efficiencies. For this, the meteorological data (maximum temperature, minimum temperature, relative humidity and bright sunshine hours) was collected from the agrometeorological observatory of Punjab Agricultural University, Ludhiana.

Solar thermal degree days (STDD)

The STDD metric provides a measure of the combined thermal effect of temperature and solar energy availability on plant growth and development.

STDD (°C day MJ m^{-2}) = GDD Short wave solar radiation (R_s)

The daily solar radiation (R_s) was computed from the Angstrom formula (Allen, 2006).

Hygrothermal unit (HGTU)

The HGTU unit captures the combined effect of temperature and humidity on plant growth and development.

HGTU (°C day %) = GDD Average relative humidity (RH_{mean})

Irradiance use efficiency (IUE)

The IUE is the ratio of grain or biological yield (kg ha^{-1}) to the accumulated solar thermal degree days (ASTDD).

IUE (kg $°C^{-1}$ day^{-1} MJ m^{-2}) = Grain yield accumulated STDD

Hygrothermal use efficiency (HGTUE)

The HGTUE is the ratio of grain or biological yield (kg ha^{-1}) to the accumulated hygrothermal unit (AHGTU).

HGUE (kg $°C^{-1}$ day^{-1} %) = Grain yield accumulated HGTU

RESULTS AND DISCUSSION

Variation in heat unit requirements under different thermal regimes

Growing degree day (GDD)

The sowing date affected the accumulation of GDD significantly ($p<0.05$) in 2021-22 while, in 2022-23 both treatments sowing date and irrigation regimes showed significant impact ($p<0.05$) on accumulated GDD (AGDD). The interaction effect of both the treatments was also observed to be significant in 2022. Amongst the date of sowing, AGDD differed significantly under three sowing dates in both the years (Table 1). In case of irrigation regimes, AGDD were at par in 2021, while in 2022, effect of 4-irrigations and 2-irrigations were at par, whereas, 3-irrigations differed significantly. Brar *et al.,* (2022) have also reported the decline in GDD accumulation by delaying sowing time, as it attains early maturity due to terminal heat stress.

Solar thermal degree day (STDD)

In the year 2021, the sowing date affected STDD accumulation significantly ($p<0.05$), while in 2022 both treatments sowing dates and irrigation regimes and their interaction showed significant effect on accumulated STDD (ASTDD) ($p<0.05$). Results showed that ASTDD of all the dates of sowing were significantly different from each other in both the years (Table 1). The ASTDD under different irrigation regimes were at par in 2021 but in 2022, accumulation was significantly different in 3-irrigations while, in 4-irrigations and 2-irrigations treatments the accumulation was statistically at par. Due to presence of high mean solar irradiance throughout the growth period, late sown crop showed more accumulation despite maturing early.

Hygrothermal unit (HGTU)

The HGTU gives the measure of combined effect of temperature and humidity. In the year 2021, the date of sowing showed significant effect ($p<0.05$) on accumulated HGTU (AHGTU) while in 2022, both the treatments and their interaction affected AHGTU significantly ($p<0.05$) (Table 1). The AHGTU of sowing dates were significantly different in 2021 while under irrigation regimes, accumulation was at par. In 2022, however, the effect of date of sowing differed significantly, irrigation regimes (4-and 3- irrigations treatment) were at par with each other except 2-irrigations which was significantly different. According to Shimoda *et al.,* (2022) high humidity can delay maturation, while low humidity can accelerate it.

Variation in wheat yield and energy use efficiency under different thermal regimes

The yield of different sowing dates as well as irrigation regimes was statistically different from each other in 2021 (Fig. 1). In 2022, result was same as 2021 for different sowing dates but in case of irrigation regimes, 4-irrigations and 3-irrigations were at par whereas 2-irrigations was significantly different. Long duration of crop growth acquired by early sown crop has resulted in higher accumulation of GDD, STDD and HGTU which further supplement higher yield. Adequate moisture availability particularly during vegetative stage, results in higher number of effective tillers hence increasing yield as observed in the case of 4-irrigations and 3-irrigations. Khan *et al.,* (2022) also observed significant impact on growth, physiology and yield due to presence of water stress at pre-anthesis stage.

Energy use efficiency was observed to be significantly affected by both the treatments in 2021, while in 2022; it was affected by their interaction as well (Table 2). In 2021, maximum HUE was observed in case of 17-Nov (D2) sown wheat which was at par with early sown. The 17-Nov sown crop exhibited highest HUE. HUE under different irrigations in both the years was statistically different. The most effective way to achieve high energy use efficiencies was through applying optimum water to the crop at its critical stages as all stages are not sensitive to water. Highest IUE was exhibited by timely and early sown crop in 2021 and their results were statistically at par. Under irrigation regimes 4-irrigations treatment exhibited highest IUE followed by 3-irrigations and 2-irrigations. In 2022, all the three dates of sowing and irrigation regimes exhibited IUE which were significantly different from each other. Early sowing results in higher yield and higher efficiencies as compared to delayed sowing. This can be attributed to the availability of more bright sunshine hours in its vegetative stage.

Table 1: Accumulation of GDD (°C day), STDD (°C day MJm^{-2}), HGTU (°C day %) under different treatments (same superscript letters are statistically at par with each other according to LSD)

Treatments	AGDD		ASTDD		AHGTU	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Sowing dates						
D_1(27-October)	1879^a	1888^d	26914^a	25444^e	125969^a	127030^d
D_2 (17-November)	1647^b	1651^e	24825^c	24574^f	111012^b	112206^e
D_3 (8-December)	1599^c	1601^f	26568^b	26586^d	102364^c	106050^f
Irrigation regimes						
I1 (4-irrigations)	1706^a	1716^d	26057^a	25584^d	113034^a	115248^d
I2 (3-irrigations)	1706^a	1706^e	26057^a	25378^e	113034^a	114603^e
I3 (2-irrigations)	1712^a	1719^d	26194^a	25642^d	113276^a	115435^d

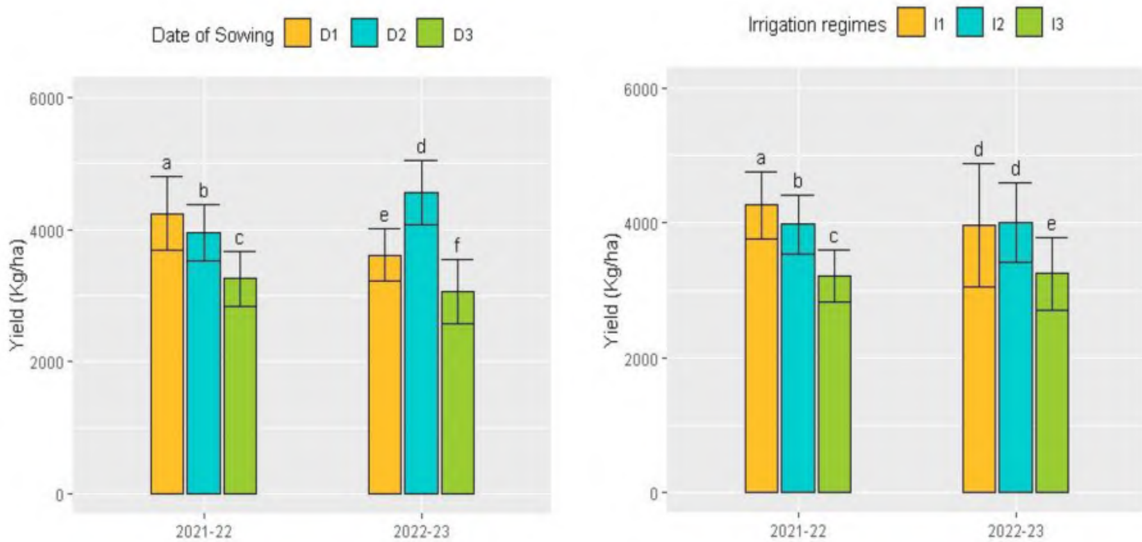

Fig. 1: Yield (kg ha^{-1}) under different dates of sowing and irrigation regimes (bars with same letters are statistically at par with each other according to LSD)

Table 2: Energy efficiencies HUE (kg °C^{-1} day^{-1}), IUE (kg °C^{-1} day^{-1} MJ m^{-2}), HGTUE (kg °C^{-1} day^{-1} %) under different treatments in 2021-22 and 2022-23 (Same superscript alphabets are statistically at par with each other according to LSD)

Treatment	HUE		IUE		HGTUE	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Sowing dates						
D1(27-October)	2.2551^a	1.9154^e	0.1575^a	0.1422^e	0.0336^b	0.0285^e
D2 (17-November)	2.2614^a	2.7622^d	0.1595^a	0.1855^d	0.0356^a	0.0406^d
D3 (8-December)	2.0366^b	1.9110^e	0.0356^b	0.1151^f	0.0318^c	0.0289^e
Irrigation regimes						
I1 (4-irrigations)	2.4566^a	2.3144^e	0.1310^a	0.1563^b	0.0376^a	0.0344^e
I2 (3-irrigations)	2.2821^b	2.3729^d	0.1224^b	0.1588^a	0.0351^b	0.0353^d
I3 (2-irrigations)	1.8142^c	1.9014^f	0.0991^c	0.1276^c	0.0283^c	0.0283^f

Delayed sown encounters low temperature and shorter days during vegetative phase, thus resulting into lower energy use efficiencies (Khichar *et al.,* 2019). Memon *et al.,* (2021) also observed highest reduction in yield and yield attributing characters due to moisture stress at vegetative and reproductive stages.

The computed indices have quantified the cumulative effects of temperature, solar radiation, and humidity on crop development, which can be extended to other cereal or horticultural crops to assess their growth under varying environmental conditions. Incorporating these indices allows for a refined understanding of crop-specific requirements and can inform irrigation scheduling, planting dates, and climate-resilient strategies, improving yield stability and resource use efficiency across diverse agroecosystems.

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