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Research Article

Relationship of Wheat Yield with Agroclimatic Indices under Varying Thermal Regimes, Nitrogen Levels and Stress Management Options

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ABSTRACT

The field experiments were carried out during *Rabi* seasons of 2013-14 and 2014-15 at Research Farm, School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana to study the effect of different temperature regime, nitrogen level and post anthesis management on phenological growth, development and grain yield of wheat. The experiment was laid out in Split-Split plot design having three temperature regime (D_1= October 30, D_2= November 15 and D_3= November 30) in main plot. As subplot, three nitrogen levels were taken into account, namely, N_1=RDF (Recommended dose of N), N_2=125% RDF (25% more than recommended N) and N_3=150% RDF (50% more than recommended N). Four post- anthesis strategies [P_0=Control, P_1= Water sprayed, P_2= Foliar spray of $ZnSO_4.7H_20$ (0.05%), P_3= Thiourea (10 mM) at anthesis and P_4 = 20 days after anthesis] were considered as sub-sub plot during both years. The agrometeorological indices such as Accumulated Growing Degree Days (AGDD), Accumulated Heliothermal units (HTU), Accumulated Photo thermal units (PTU) and Heat use efficiency (HUE) were calculated and their relation with grain yield was also observed. The results showed that number of days required to attain different phenological stages decreased with late sowing condition. Among temperature regimes, the crop sown on October 30 took maximum calendar days, accumulated growing degree days, accumulated photo thermal unit, to attain different phenological stages till maturity which reduced significantly with subsequent delay in sowing time. Among nitrogen levels, the crop with 150% RDF treatment had accumulated more number of days up to maturity as compared to 125% RDF and RDF treatment. Among post anthesis management, spray the crop at or after anthesis at regular intervals with any of stress alleviating chemicals such as $ZnSO_4.7H_2O$ (0.05%), Thiourea (10 mM) or water over control help the crop to overcome the heat stress during this period and crop accumulated more number of days as had higher heat use efficiency than control. It is concluded that timely sown crop with 150% RDF treatment when sprayed with any of stress alleviating chemicals or water exhibit best growth and development which may be due to favorable environmental conditions coincided with heat unit requirement of different phenophases of wheat Along with proper nutrient supply.

Key words: Wheat, Phenology, AGDD, AHTU, APTU, HUE, Grain yield

Introduction

Wheat (*Triticum aestivum* L. emend. Feori & Paul) is an important cereal crop of Indo-Gangetic plains of India in general and Punjab in particular. Wheat is a photo-insensitive and thermo-sensitive long day plant. Wheat requires cool climate during the early part of its growth. Temperature is an important weather factor influencing the growth and development of wheat. It influences the crop phenology and yield of the crop (Bishnoi *et al.,* 1995). Both the start and end of wheat crop

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season are limited by the onset and end of favorable temperature regimes. Phenological development from sowing to maturity is related to accumulation of heat or temperature units above threshold or base temperature (below which no growth occurs). A quantified value of heat or temperature units is required to reach a particular phenophase. Several growth stages are distinguishable for cereals and other crops in which important physiological processes occur (Sikder, 2008). During past few years, wheat sowing often got delayed till December or early January causing substantial loss in grain yield. Drastic reduction in yield of wheat has been recorded with the delay of sowing beyond optimum time. Delay in wheat sowing 20 and 40 days from the normal sowing date (15^{th} November) reduced grain yield by 23 kg ha^{-1} day^{-1} and 30 kg ha^{-1} day^{-1}, respectively (Kaur and Pannu, 2008). The high temperature stress at reproductive phase of crop results in poor yield due to reduced number of grains per spike and shriveled grain with poor quality (Sharma *et al.,* 2007). The optimum sowing time and selection of improved cultivars play a remarkable role in exploiting the yield potential of the crop under particular agro climatic condition.

Air temperature based agromet indices *viz*., growing degree days (GDD), photothermal units (PTU), heliothermal units (HTU), phenothermal index (PTI) have been used to describe changes in phenological behaviour and growth parameters. The wheat crop sown on 20^{th} November consumed more PTU and HTU as compared to 20^{th} December sown crop (Khicher and Niwas 2007). Hence, it becomes imperative to have knowledge of the exact duration of phenological stages in a particular crop-growing environment. Therefore, an experiment was conducted to determine the phenology and heat unit requirement of wheat varieties under different temperature regimes, nitrogen levels and post anthesis strategy.

Methodology

A factorial experiment was laid out in Split-Split plot design at the Research farm of School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana having three different dates of sowing (D_1= October 30, D_2= November 15 and D_3= November 30) in main plot so that the crop can get exposed to varied thermal regimes. Three nitrogen level [N_1=RDF (Recommended dose of N), N_2=125% RDF (25% more than recommended N), N_3=150% RDF (50% more than recommended N)] was considered as sub plot and four post- anthesis strategies [P_0=Control, P_1= Water sprayed, P_2= Foliar spray of $ZnSO_4.7H_2O$ (0.05%), P_3= Thiourea (10 mM) at anthesis and P_4 = 20 days after anthesis] was taken as sub-sub plot during both years of experiments. The Accumulated Growing Degree Days (AGDD), Accumulated Heliothermal units (HTU), Accumulated Photo thermal units (PTU) and Heat use efficiency (HUE) were calculated using standard formulae. The phenological stages of crop were recorded through visual observations.

Growing degree days (GDD): GDD values were calculated by simple arithmetic accumulation of daily mean temperature above the base temperature value of 5°C considered for the wheat crop. The different indices for each stage were calculated as suggested by (Nuttonson, 1955)

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

where,

T_{max} = Daily maximum temperature (°C)

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

T_b = Base temperature (5 °C)

Heliothermal units (HTU): The HTU for a day represent the product of GDD and the bright sunshine hours for that day. The accumulated HTU for a particular phenophase was determined by using the following formula:

$$\text{Accumulated HTU (°C-d-hr)} = \sum_{i=1}^{n} \text{GDD} \times \text{Bright sunshine hours}$$

Photothermal units (PTU): The PTU for a day represent the product of GDD and the day length for that day. The accumulated PTU for a particular phenophase was determined by using the following formula:

$$\text{Accumulated PTU (°C-d-hr)} = \sum_{i=1}^{n} \text{GDD} \times \text{Day length}$$

Heat use efficiency (HUE): The heat use efficiency was calculated using the following formula:

$$\text{Heat use efficiency (kg/ha/°C-day)} = \frac{\text{Grain or biological yield (kg ha}^{-1}\text{)}}{\text{AGDD (°C-day)}}$$

Where, AGDD = Accumulated growing degree days (˚C-day)

Results and Discussion

Weather variability during the crop growing season

Meteorological conditions play a pivotal role in influencing the phenological development, growth characteristics and final yield and yield attributes of a crop.. The mean monthly maximum and minimum temperature was recorded to be 24.6 °C and 11.7 °C during crop season 2013-14 and 24.5°C and 12.4°C during crop season 2014-15. The mean monthly morning and evening relative humidity was recorded to be 90.4% and 50.9% during crop season 2013-14 and 90.1% and 56.5% during crop season 2014-15. The mean sunshine hours was recorded to be 6.9 hr during crop season 2013-14 and 6.0 hr during crop season 2014-15. The total amount of rainfall received was 212.4 mm during the crop season 2013-14 and 232.3 mm during the crop season 2014-15 (Fig. 1).

Growing degree days (GDD)

The heat unit or GDD was proposed to explain the relationship between growth duration and temperature. It required for different phenophases varied with date of sowing. The accumulated growing degree days (AGDD) taken from CRI to maturity are given for different temperature regime and nitrogen level and post anthesis strategy (Table 1). AGDD requirement for maturity was 1616.0 °C-day for October 30 sown crop, 1563.4 and 1506.9 °C-day for November 15 and November 30 sown crop for *Rabi* season 2013-14 and for *Rabi* season 2014-15, AGDD requirement for October 30, November 15 and November 30 sown crop for maturity were 1713.3, 1705.3 and 1651.1 °C-day respectively as shown in Table 1. The AGDD was decreased with the successive delay in sowing. The early sown crop had accumulated maximum AGDD at all phenological stages as compared to the rest. This describes clearly the effect of temperature on phenological stage. Every crop needs a specific amount of GDD to enter its reproductive phase from vegetative phase. Early sowing resulted in absorbing sufficient GDD in relatively more time. While late sown crop experienced higher temperature during later stage in less time. The shorter phenophasic duration and lesser consumption of thermal units under late sown crop was because of the fact that later stages of growth coincide with the abrupt rise in air temperature and thereby causing the shortening

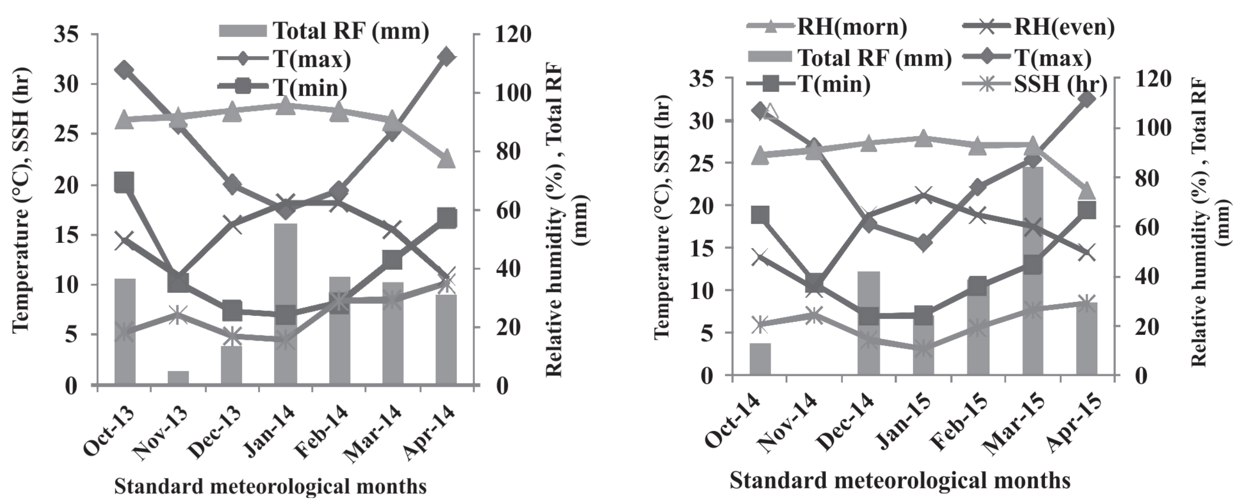

Fig. 1. Mean monthly meteorological data during *rabi* 2013-14 and 2014-15

Table 1. Variation in Accumulated growing degree days, heliothermal units and photothermal units for maturity under different temperature regime, nitrogen level and post anthesis strategy during *rabi* season 2013-14 and 2014-15

Treatment	AGDD (°C-day)		AHTU (°C-day-hours)		APTU (°C-day-hours)		Grain yield (q ha^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Temperature regime								
October 30	1616.0	1713.3	10310.8	10630.4	17773.5	19919.2	47.33	50.12
November 15	1563.4	1705.3	10892.6	10581.7	17518.2	18907.0	43.77	45.55
November 30	1506.9	1651.1	10486.7	11488.8	17257.8	18426.0	39.61	42.39
CD (p=0.05)	25.8	NS	261.9	309.2	324.7	872.4	4.06	4.12
Nitrogen level								
RDF	1527.5	1635.5	10216.9	10494.6	17071.4	18322.4	41.40	43.62
125% RDF	1556.4	1703.1	10498.8	10952.4	17444.3	19270.2	43.58	46.81
150% RDF	1602.5	1731.2	10974.4	11253.9	18033.8	19659.5	45.73	47.63
CD (p=0.05)	43.0	63.9	409.4	817.5	551.3	403.8	2.11	2.69
Post anthesis strategy								
Control	1541.4	1653.2	10325.6	10523.5	17256.2	18589.6	42.12	45.31
Water sprayed	1566.5	1695.1	10591.1	11040.7	17573.2	19312.1	42.25	45.44
$ZnSO_4.7H_2O$ (0.05%)	1570.3	1726.4	10698.6	11150.8	17618.3	19276.4	44.13	47.46
Thiourea (10mM)	1570.3	1684.8	10638.2	10886.1	17618.4	19158.1	43.78	46.77
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

of later growth stages resulting in early maturity of crop. That is why, the thermal units consumed by the crop reduced progressively in case of delay in sowing. Sandhu *et al.* (1999), Paul and Sarker (2000) and Pandey *et al.* (2010) also reported that the requirement of heat units decreased for different phenological stages with delay in sowing.

Among the nitrogen level, AGDD requirement for RDF from sowing to maturity was 1527.5 °C-day, for 125% RDF, it was 1556.4 and 1602.5 °C-day for 150% RDF for *Rabi* season 2013-14. AGDD requirement for RDF, 125% RDF and 150% RDF from sowing to maturity were 1635.5, 1703.1 and 1731.2 °C-day respectively for second year as shown in Table 1. The crop took more number of days to complete one stage to another in 150% RDF treatment because by applying more fertilizers, vegetative phase of crop got enhanced.

At anthesis or after that crop experienced high temperature stress during this stage which will result in shriveling of grains and reduction in yield of crop. To avoid this heat stress during grain filling by spraying the crop at anthesis and after that at regular intervals with water or any stress alleviating chemicals help the crop to combat with this stress period. Among post-anthesis strategies. The AGDD requirement of various spraying treatment is given in Table 1.

Heliothermal units (HTU)

The accumulated heliothermal units required to attain different phenological stages under different temperature regime, nitrogen level and post anthesis strategy of wheat were presented in (Table 1). For crop maturity, highest helio thermal unit (10892.6 °C-day-hr) were required in case of November 15 sown crop followed by November 30 sown crop (10486.7 °C-day-hr) of 2013-14. This might be due to duration of sunshine hours were more in November 15 sown crop as compared to November 30 and October 30 sown crop. During *rabi* season of 2014-15, the data shows that the highest helio thermal unit (11488.8 °C-day-hr) were required for maturity for November 30 sown crop followed by October 30 (10630.4 °C-day-hr) and November 15 (10581.7 °C-day-hr) sown crop because duration of bright sunshine hours were less for the growth period of November 15 sown crop.

Irrespective of temperature regime and post-anthesis strategies, highest heliothermal unit (10974.4 °C-day-hr) were acquired in 150% RDF treatment followed by 125% RDF (10498.8 °C-day-hr) and RDF (10216.9 °C-day-hr) treatment respectively during the *rabi* season of 2013-14. Similar pattern was observed during 2014-15, though the crops under all DOS's acquired more heat than previous year.

Among post-anthesis strategies, the highest heliothermal unit (10698.6 °C-day-hr) requirement was calculated under ZnSO.7H_2O (0.05%) treatment followed by Thiourea (10 mM) (10638.2 °C-day-hr), water (10591.1 °C-day-hr) for *rabi* season of 2013-14. Next year, $ZnSO_4$.7H_2O (0.05%) treatment acquired highest HTU followed by Thiourea (10 mM) treatment. Crops under controlled situation required less heat to mature for both the experimental years.

Photothermal units (PTU)

The variation of accumulated PTU under different temperature regimes, nitrogen levels and post anthesis strategies were presented in (Table 1). Among temperature regimes, APTU requirement for October 30 sown crops was 17773.5 °C-day-hr for 2013-14 *rabi* season. During next season, APTU requirement for October 30, November 15 and November 30 sown crop for maturity were 19919.2, 18907.0 and 18426.0 °C-day-hr respectively. The higher APTU value in early sown crop may be due to the fact that crops took longer duration to attain maturity.

Among the nitrogen levels, APTU requirement for RDF during 2013-14 was 17071.4 °C day hours, whereas, for 125% RDF, it was 17444.3 °C day hours and 18033.8 °C-day-hr for 150% RDF. Experiments completed during 2014-15 showed exactly similar trend.

During 2013-14, the APTU requirement for $ZnSO_4$.7H_2O (0.05%) (17618.3°C-day-hr) and Thiourea (10 mM) (17618.4°C-day-hr) sprayed crop were at the highest level during maturity followed by water sprayed (17573.2°C-day-hr) crops. For *rabi* season of 2014-15, accrued PTU requirement for $ZnSO_4$.7H_2O (0.05%), water sprayed, Thiourea (10 mM) and control treatments atmaturity were 19276.4, 19312.1, 19158.1 and 18589.6 °C-day-hr respectively as shown in Table1.

Heat use efficiency (HUE)

Heat use efficiency was also computed for grain and biomass yield of wheat and presented in Table 2. Irrespective of Nitrogen, post-anthesis strategies and experimental years, HUE was found to be highest when crops sown early and decreased with delay in sowing. The highest HUE (2.78 kg ha^{-1} $°C^{-1}$ day^{-1} for grain and 7.97 kg ha^{-1} $°C^{-1}$ day^{-1} for biological yield) was recorded under the October 30 sown crop followed by (2.53 kg ha^{-1} $°C^{-1}$ day^{-1} for grain and 7.21 kg ha^{-1} $°C^{-1}$ day^{-1} for biological yield) crops sown on November 15 during 2013-14 *rabi* season. The trend of HUE for biomass yield under different DOS was similar like the trend observed in grain yield for both years. Delay in sowing resulted in decrease in the heat use efficiency. Kumari *et al.* (2009) also reported that timely sown wheat crop exhibited maximum heat use efficiency.

Among the nitrogen levels the highest HUE (2.80 kg ha^{-1} $°C^{-1}$ day^{-1} for grain and 8.05 kg ha^{-1} $°C^{-1}$ day^{-1} for biological yield) was found in 150% RDF treatment followed by 125% RDF (2.55 kg ha^{-1} $°C^{-1}$ day^{-1} for grain and 7.26 kg ha^{-1} $°C^{-1}$ day^{-1} for biological yield) during *rabi* season of 2013-14. Analyzing the data of 2014-15, similar trend was observed. The increase in nitrogen application significantly increases the heat use efficiency of wheat crop. Mandic *et al.* (2015) and Pradhan *et al.* (2014) also reported that higher nitrogen application significantly resulted in higher radiation use efficiency.

Among the post-anthesis strategies, highest heat use efficiency was obtained under $ZnSO_4$.7H_2O (0.05%) (2.77 kg ha^{-1} $°C^{-1}$ day^{-1} for grain and 7.89 kg ha^{-1} $°C^{-1}$ day^{-1} for biological yield) followed by Thiourea (10 mM) (2.62 kg ha^{-1} $°C^{-1}$ day^{-1} for grain and 7.61 kg ha^{-1} $°C^{-1}$ day^{-1} for biological yield) and water (2.53 kg ha^{-1} $°C^{-1}$ day^{-1} for grain and 7.27 kg ha^{-1} $°C^{-1}$ day^{-1} for biological yield) treatments during 2013-14. HUE values under Controlled situation appeared lowest

Table 2. Heat use efficiency (kg ha^{-1} ºC^{-1} day^{-1}) under different thermal regimes, nitrogen levels and post-anthesis strategy

Treatment	Heat use efficiency (kg ha^{-1} ºC^{-1} day^{-1})			
	Grain		Biomass	
	2013-14	2014-15	2013-14	2014-15
Temperature regime				
October 30	2.92	3.45	7.98	8.97
November 15	2.79	3.31	7.72	8.71
November 30	2.62	3.01	7.37	8.05
CD (p=0.05)	0.21	0.25	0.49	0.67
Nitrogen level				
RDF	2.47	3.07	6.91	8.04
125% RDF	2.86	3.28	7.99	8.63
150% RDF	3.01	3.42	8.16	9.05
CD (p=0.05)	0.19	0.20	0.60	0.44
Post- anthesis strategy				
Control	2.45	3.08	7.22	8.37
Water sprayed	2.64	3.26	7.59	8.59
$ZnSO_4.7H_2O$ (0.05%)	3.07	3.38	8.11	8.71
Thiourea (10mM)	2.96	3.32	7.85	8.64
CD (p=0.05)	0.20	0.12	0.44	0.29

for both the grain and biomass during different experimental years. The foliar spray with $ZnSO_4$ @ 0.05% at anthesis and 20 days interval after anthesis significantly increases the heat use efficiency of wheat crop over other treatments.

Grain yield

The grain yield was significantly affected by the temperature regime, nitrogen level and non significant differences was observed under post-anthesis strategies. The maximum grain yield (46.29 q ha^{-1}) was recorded under October 30 sown crops followed by November 15 (42.73 q ha^{-1}) and for November 30 (38.57 q ha^{-1}) sown crops during *rabi* season of 2013-14 (Table 1). During *rabi* season 2014-15, maximum grain yield (49.45 q ha^{-1}) was recorded under October 30 sown crop and the rest pattern is same like previous year.

Among the nitrogen level, maximum grain yield (47.36 q ha^{-1}) was produced under 150% RDF followed by 125% RDF (43.21 q ha^{-1}) and RDF (39.03 q ha^{-1}) during *rabi* season 2013-14.

Relationship of grain yield with Agromet indices

Wheat crop is exposed to a variety of weather conditions during its different phenophases of growth, resulting in large variations in growth rate and yield. Air temperature based agromet indices *viz*., GDD, HUE have been used to describe changes in phenological behaviour and growth parameters. The growing degree days concept provides a reliable index for the progress of the crop that can be used to predict the yield of any crop (Fig. 2).

The relation between grain yield and accumulated growing degree days were calculated for *rabi* seasons of 2013-14 and 2014-15 as shown in Figure 2. There was positive and linear relationship exists between them during the *rabi* season of 2013-14, which explained 64.8% variability and during 2014-15 season, their relationship showed 71.1% variability. The number of days taken by the crop to complete its phenological stages had a positive effect on the grain yield.

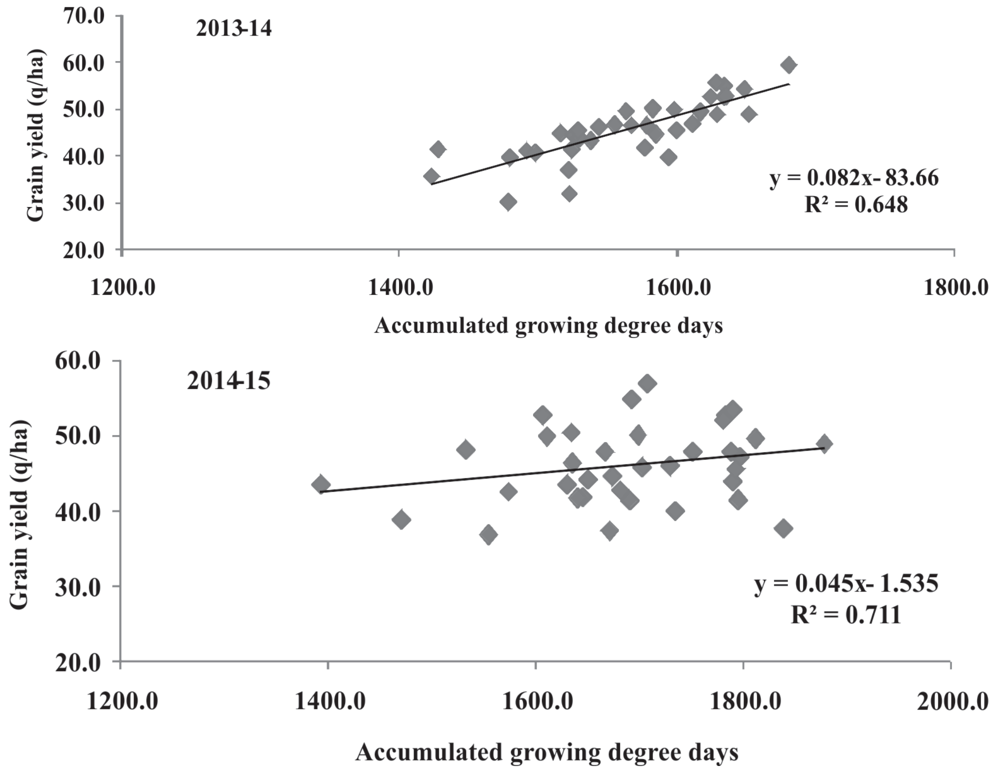

Fig. 2. Relationship between grain yield and accumulated growing degree days during *rabi* seasons 2013-14 and 2014-15

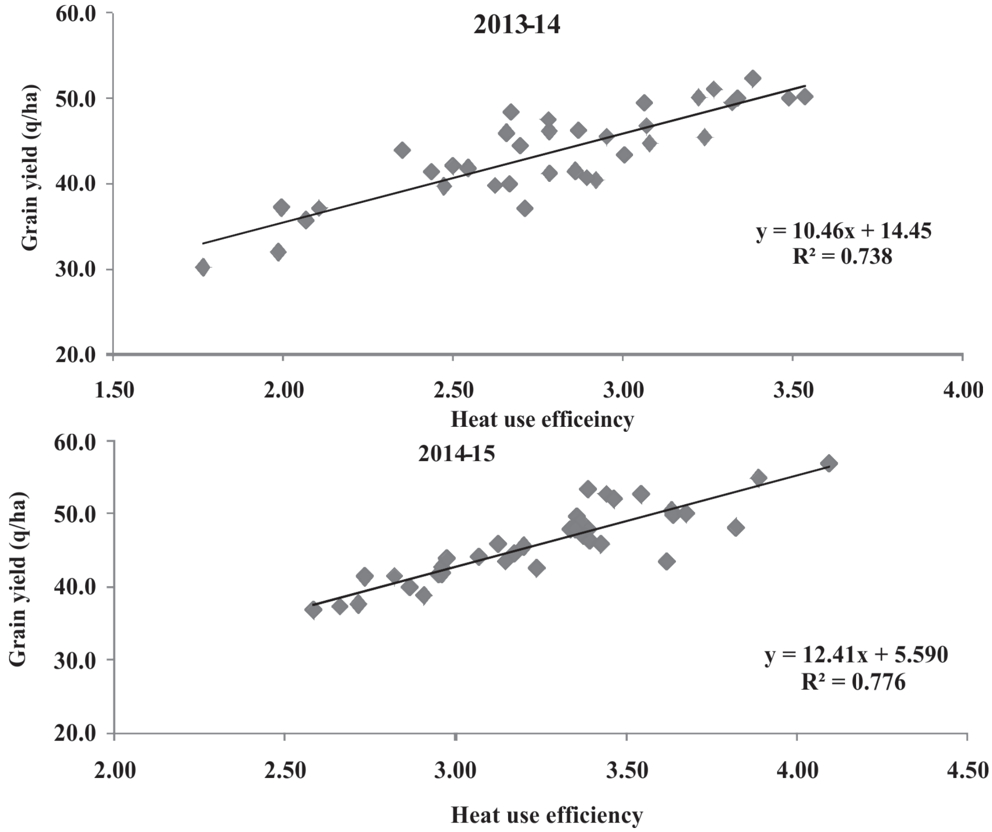

Fig. 3. Relationship between grain yield and heat use efficiency during *rabi* seasons 2013-14 and 2014-15

The relation between grain yield and heat use efficiency for grains was calculated for *rabi* seasons of 2013-14 and 2014-15 and presented in Figure 3. The graph shows linear and positive relationship between grain yield and heat use efficiency with 73.8% variability during 2013-14 and 77.6% variability during 2014-15.

Conclusion

The crop sown at the end of October took more days to mature and thus acquired more heat throughout its growing period. But delay in sowing reduced the GDD, HTU and PTU values as the crops matured early. The timely sown wheat crop performed better in terms of accumulation and utilization of heat units and hence had higher heat use efficiency.

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References

Bishnoi, O.P., Singh, S. and Niwas, R. 1995. Effect of temperature on phenological development of wheat (*Triticum aestivum* L.) crop in different row orientations. *Indian Journal of Agricultural Sciences* **65**: 211-214.

Kaur, A. and Pannu, R.K. 2008. Effect of sowing time and nitrogen schedules on phenology, yield and thermal-use efficiency of wheat (*Triticum aestivum*). *Indian Journal of Agricultural Sciences* **78**: 366-369.

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.

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.

Mandic, V., Krnjajai, V., Tomic, Z., Bijelici, Z., Simic, A., Muslic, D.R. and Gogic, M. 2015. Nitrogen fertilizer influence on wheat yield and use efficiency under different environmental conditions. *Chilean Journal of Agricultural Research* **75**: 92-97.

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

Pandey, I.B. Pandey, R.K. Dwivedi, D.K. and Singh, R.S. 2010. Phenology, heat unit requirement and yield of wheat varieties under different crop growing environment. *Indian Journal of Agricultural Sciences* **80**: 136-140.

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.

Pradhan, S., Sehgal, V.K., Sahoo, R.N., Bandyopadhyay, K.K. and Singh, R. 2014. Yield, water, radiation and nitrogen use efficiencies of wheat *(Triticum aestivum*) as influenced by nitrogen levels in a semi-arid environment. *Indian Journal of Agronomy* **59**: 267-275.

Sandhu, I.S. Sharma, A.R. and Sur, H.S. 1999. Yield performance and heat unit requirement of wheat varieties as affected by sowing dates under rainfed conditions. *Indian Journal of Agricultural Sciences* **69**: 175-179.

Sharma, K.D. Pannu, R.K. and Behl, R.K. 2007. *Effect of early and terminal heat stress on biomass partitioning, chlorophyll stability and yield of different wheat genotypes.* Proc: The international conference on sustainable crop production in stress environment: Management and genetic options. pp 187-94.Agrobios (International), Jodhpur.

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

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