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Research Article

Thermal Requirement of Soybean in Two Different Agroclimatic Regions of Punjab

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ABSTRACT

The crop production characteristics are directly related with the temperature and relative humidity of atmosphere during crop growing season. Heat can accelerate soybean maturity because photoperiod and temperature interact to control flowering in soybeans. Growing Degree Days (GDD), also known as heat units, are a concept used in agriculture to quantify the accumulation of heat over time, which is crucial for the growth and development of plants. GDD is particularly important in predicting and managing plant growth, phenology (the study of plant life cycle events), and agricultural practices. The main aim of this study is to calculate thermal requirement (GDD) of soybean for sustainable yield. The field experiments were conducted during *kharif* season 2018 at Research Farm of Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana and Regional Research Station, Faridkot to find out the response of soybean cultivar SL 958 to different sowing dates and treatments. Sixteen treatment combinations were investigated. Treatments comprises four dates of sowing: (D1: May 15, D2: May 30 and D3: June 15 and D4: June 30, 2018) with 2 mulch treatments (M1: straw mulch and M2: no mulch) and two planting methods in subplots (P1: Unidirectional planting (E-W), P2: Bidirectional planting (N-S, E-W)) in Split plot design. The pooled analysis of data revealed that the soybean sown on 15th May 2018 obtained maximum growing degree days value and highest heat use efficiency at different phenological stages. The number of days required to attain different phenological stages decreased with late sowing condition.

Key words: Thermal requirement, Soybean, Unidirectional, Phenological stages

Introduction

Oilseed crops have been the backbone of the country economy from time immemorial. Soybean (*Glycine max* L.) ranks first among oilseed crops in the world and is also known as the wonder crop of the twentieth century. Soybean is one of the short day plants and most of its genotypes respond as quantitative short day plant. It is a unique pulse cum oilseed crop but, mostly grown as an oilseed crop in India. It was introduced in India in 1960s and has a great success. Soybean becomes a major crop in very short period in rainfed area. The variation of photo-period sensitivity among soybean genotypes allows the crop to grow successfully across a wide range of latitudes.

If high temperature and high rainfall coincide with pre harvest phase in delayed sowing, causes decrease in yield, rapid loss of viability and vigour of seed in standing crop. Selection of right time for sowing is primary requirement, as it affects the crop growth and development. Thus, sowing date practice is important for soybean, which has the biggest impact on crop yield. Photoperiod and air

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temperature mainly affect the number of reproductive primordial and development rate of soybean, affect plant height, growing cycle and yield potential of crop (Jiang *et al.*, 2011). There is variability among cultivars regarding photoperiod sensitivity and air temperature. Photoperiod is considered the main factor which, decide the cultivar adaptation (Rodrigues *et al.*, 2001).

Heat can accelerate soybean maturity because photoperiod and temperature interact to control flowering in soybeans, whereas, high temperatures during vegetative stage can result in slowed or stopped photosynthesis due to the plant closing its stomata in an effort to conserve moisture (Rachel, 2020). High temperature during reproductive stage of soybean crop can result into aborted flowers, aborted small pods, aborted seeds in larger pods, and production of smaller seeds. Leaf loss can even occur under severe stress. That is the major reason why temperature is a major environmental factor that determines the rate of plant growth and development. Genotypes behave differently under different environmental conditions. The most common temperature index used to estimate plant development is growing degree days (GDD) or heat unit (HU). GDD is directly related to temperature, and temperature plays a fundamental role in influencing plant development and phenology. Different plant species have specific temperature requirements for various growth stages, such as germination, flowering, fruiting, and maturity. GDD allows farmers and researchers to track how many heat units a region has accumulated, helping them anticipate when specific growth stages will occur. GDD can help in assessing the potential risks associated with climatic variations and fluctuations. If a growing season experiences unusual temperature patterns, the GDD accumulation can indicate whether the current conditions are favorable or unfavorable for crop growth. The accumulation of GDD determines the maturity of crop, yield and yield components. 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 (Kumar *et al.*, 2010). The values of accumulated 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).

Optimum temperature for germination of soybean is approximately 30°C with base temperature of 10°C (Ghadekar, 2001). The growth and development of soybean plants largely influenced directly or indirectly by heat unit requirement. The occurrence of different phenological events during crop growth period in relation to temperature can be estimated by using accumulated heat units or growing degree days. Knowledge of accumulated GDD (growing degree days) can provide an estimate of harvest date as well as crop development stage.

The experiment was conducted to study the effect of heat unit requirement and heat use efficiency of soybean cultivars.

Materials and Methods

A factorial experiment for soybean cultivar SL 958 was laid under split plot design at the Research Farm of Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana and Regional Research Station, Faridkot during the *kharif* season 2018. The treatments included four sowing dates in main-plots (D1: May 15, D2: May 30 and D3: June15 and D4: June 30, 2018) with2 mulch treatments (M1: straw mulch and M2 : no mulch) and two planting methods in subplots (P1: Unidirectional planting (E-W), P2 : Bidirectional planting (N-S, E-W)). The phenological stages of crop were recorded by visual observations.

Growing degree days

Growing degree days were calculated by simple arithmetic accumulation of daily mean temperature above the base temperature value of 10°C considered for the soybean crop. The cumulative growing degree-days were determined by summing the daily growing degree day. Growing degree day can be worked out by using the following formula:

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

Where,

T_{max}=Daily maximum temperature

T_{min}=Daily minimum temperature

T_b= Minimum threshold/Base temperature

Photothermal units (PTU)

The photothermal units (PTU) for a day represented by the product of GDD and the maximum possible sunshine hours (day length) for that day. The accumulated PTU for a particular phenophase was calculated as follows:

Accumulated PTU = Σ(GDD × Day length)

Heliothermal units (HTU)

The helio-thermal units for a day are represented by the product of GDD and the actual bright sunshine hours for that day. The sum of HTU for particular phenophases was determined by using the following formula:

Accumulated HTU = Σ(GDD x Bright sunshine hours)

Heat use efficiency

Heat use efficiency was indicated as the amount of dry matter or grain yield produced per unit of growing degree days or thermal time. It was calculated by using the following formula:

$$\text{Heat use efficiency (kg/ha/°C day)} = \frac{\text{Grain or dry matter yield (kg/ha)}}{\text{Accumulated growing degree day (°C day)}}$$

The radiation use efficiency was calculated by the ratio of dry matter yield to intercepted PAR according to the following formula

$$\text{RUE} = \frac{\text{Dry matter yield (g/m}^2\text{)}}{\text{IPAR (MJ/m}^2\text{/day)}}$$

Where,

RUE = Radiation use efficiency (g/MJ)

Y = Yield (g/m^2)

IPAR = Intercepted photosynthetically active radiation (MJ/ m^2/day)

The PAR values were converted from (μ mol m^{-2} s^{-1}) to the (MJ/m^2/day) using the following formula given by Kumar *et al* (2010)

1MJ/m^2/day= 0.0007826 × PAR (μ mol/m^{-2}/s^{-1}) × BSS

Where,

BSS = Bright sunshine hours.

Results and Discussion

Growing degree days (GDD)

The accumulated heat units were calculated based on phenology for both locations i.e. Ludhiana and Faridkot as presented in the Table 1. Data revealed that crop sown on 15^{th} May required 87 and 109 accumulated growing degree day for the emergence at Ludhiana and Faridkot, respectively. The accumulated growing degree day requirement for the physiological maturity was 3074°C at Ludhiana and 3060°C day at Faridkot. The requirement of accumulated growing degree day for the emergence for the crop sown on 30^{th} May was 121°C day at Ludhiana and 122°C day at Faridkot. The requirement of growing degree day for the maturity was 2872°C day (Ludhiana) and 2834°C day (Faridkot). Crop sown on 15^{th}June required 121 heat units for emergence at Ludhiana and 112°C day

Table 1. Accumulated growing degree day (GDD) (°C day) under different sowing dates at Ludhiana and Faridkot during *kharif* 2018

Phenological stages	15^{th} May		30^{th} May		15^{th} June		30^{th} June	
	Ludhiana	Faridkot	Ludhiana	Faridkot	Ludhiana	Faridkot	Ludhiana	Faridkot
Start Emergence	87	109	121	122	121	112	118	114
Complete Emergence	171	199	216	240	239	218	208	208
Flowering (50%)	1601	1621	1471	1476	1286	1259	1196	1189
pod initiation	1862	1872	1731	1724	1513	1506	1422	1420
End of pod filling stage	2708	2719	2494	2472	2229	2216	2035	2045
Physiological Maturity	3074	3060	2872	2834	2640	2672	2425	2411

Table 2. Accumulated photo thermal units (PTU) (°C day hour) under different sowing dates at Ludhiana and Faridkot during *kharif* 2018

Phenological stages	15th May		30th May		15th June		30th June	
	Ludhiana	Faridkot	Ludhiana	Faridkot	Ludhiana	Faridkot	Ludhiana	Faridkot
Start Emergence	1164	1473	1688	1705	1706	1570	1656	1606
Complete Emergence	2304	2692	3017	3369	3377	3075	2924	2920
Flowering (50%)	22164	22430	20384	20388	17631	17311	16115	15974
pod initiation	25646	25776	23818	23646	20585	20552	18933	18850
End of pod filling stage	36386	36447	33300	32836	29286	29281	26220	26264
Physiological Maturity	40308	40382	37600	36938	33872	34425	30469	30236

at Faridkot, whereas, consumption of heat units for complete emergence was 239 and 218°C day at Ludhiana and Faridkot, respectively. For the physiological maturity requirement of growing degree day were 2640 and 2672°C day at Ludhiana and Faridkot, respectively.

The requirement of accumulated growing degree for the emergence for the crop sown on 30th June was 118°C day at Ludhiana and 114°C day at Faridkot. Crop sown on 30th June required 1196 and 1189 growing degree day for the flowering at Ludhiana and Faridkot, respectively. The requirement of growing degree day for the maturity was 2425°C day at Ludhiana and 2411°C day at Faridkot.

The requirement of heat unit for 50 per cent flowering and Physiological maturity was reduced with delay in sowing. Singh *et al.* (2007) also found the same results. Ram *et al.* (2010) also recorded decreased in thermal units with delay in sowing.

Photothermal units (PTU)

The accumulated photo thermal units (°C day hour) at the different phenological events were calculated for the both locations i.e. Ludhiana and Faridkot as presented in the Table 2.

The crop sown on 15th May required 1164.4 and 1473.4 °C day hour accumulated photo thermal units for the emergence at Ludhiana and Faridkot, respectively and consumed 2304.6°C day hours PTU for the completion of emergence at Ludhiana and 2692.2°C day hour at Faridkot whereas, the accumulated PTU requirement for the physiological maturity was 40308.5 and 40381.8°C day hours at Ludhiana and Faridkot, respectively. The requirement of accumulated photo thermal units for the emergence under the crop sown on 30th May were 1688°C day at Ludhiana and 1705°C day hours at Faridkot. Crop consumed 3017 and 3369 PTU for the complete emergence at Ludhiana and Faridkot, respectively. The requirement of PTU for the physiological maturity was 37600°C day hour at Ludhiana and 36938°C day hour at Faridkot. Crop sown on 15th June required 1706 photo thermal units for emergence at Ludhiana and 1570°C day hour at Faridkot. For the physiological maturity requirement of photo thermal units were 34425 and 30469°C day hour at Ludhiana and Faridkot, respectively. The requirement of accumulated photo thermal units for the emergence of the crop sown on 30th June were 1656°C day hour at Ludhiana and 1606°C day hour at Faridkot. The requirement of photo thermal for the maturity was 30469°C day hour at Ludhiana and 30236°C day hour at Faridkot. PTU requirement varied with date of sowing and location.

Heliothermal units (HTU)

The accumulated heliothermal units (°C day hour) at the different phenological events was calculated and presented in the Table 3.The requirement of accumulated heliothermal units for the emergence of the crop sown on 15th May was 497°C day hour at Ludhiana and 704°C day hours at Faridkot. Crop required 10924 and 7518 HTU for the 50% flowering at Ludhiana and at Faridkot respectively. The requirement of HTU for the maturity was 20532°C day hour at Ludhiana and 14901°C day hour at Faridkot.

The requirement of accumulated heliothermal units for the emergence of the crop sown on 30th May

Table 3. Accumulated heliothermal units HTU (°C day hour)under different sowing dates at Ludhiana and Faridkot during *kharif* 2018

Phenological stages	15th May		30th May		15th June		30th June	
	Ludhiana	Faridkot	Ludhiana	Faridkot	Ludhiana	Faridkot	Ludhiana	Faridkot
Start Emergence	497	704	816	684	623	407	521	498
Complete Emergence	1353	1321	1538	1363	1710	551	1591	801
Flowering (50%)	10924	7518	9450	6027	7545	4812	6773	4961
pod initiation	12579	8661	10602	7177	8767	5911	7940	5647
End of pod filling stage	17747	12618	15617	10997	13924	9489	12965	9766
Physiological Maturity	20532	14901	18993	13313	16954	12117	15475	11143

was 816°C day hour (Ludhiana) and 684°C day hour (Faridkot). The requirement of HTU for the maturity was 18993°C day hour at Ludhiana and 13313°C day hour at Faridkot. The crop sown on 15th June required 623 and 407 accumulated heliothermal units for the emergence at Ludhiana and Faridkot, respectively and the accumulated HTU requirement for the physiological maturity was 16954°C day hour at Ludhiana and 12117°C day hour at Faridkot. The requirement of accumulated HTU for the emergence under the crop sown on 30th June were 521°C day (Ludhiana) and 498°C day hour (Faridkot). HTU required for the maturity was 15475°C day hour at Ludhiana and 11143°C day hour at Faridkot.

The requirement of HTU was highest for 15th May while lowest for 30th June due to variation in temperature, bright sunshine hours and cloudy weather during crop growing period. However, requirement of HTU at Ludhiana was higher during every date of sowing than at Faridkot. The heliothermal unit directly or indirectly affects the yield by delaying flowering and pod formation. Higher HTU was not favourable for better yield (Chavan *et al.,* 2018).

Heat use efficiency (HUE)

The data presented in Table 4 showed that heat use efficiency was influenced by the different sowing

Table 4. Heat use efficiency of soybean under different sowing dates at Ludhiana and Faridkot during *kharif* 2018

Treatments	HUE (grain yield) (kg/ha/°C/day)		HUE (straw yield) (kg/ha/°C/day)	
	Ludhiana	Faridkot	Ludhiana	Faridkot
		Date of Sowing		
15th May	0.34	0.54	1.21	1.24
30th May	0.44	0.64	1.24	1.28
15th June	0.57	0.74	1.19	1.22
30th June	0.38	0.61	0.88	0.80
LSD (p=0.05)	0.06	0.09	0.18	0.28
		Mulch Application		
Straw mulch	0.47	0.67	1.21	1.29
No mulch	0.40	0.59	1.04	0.98
LSD (p=0.05)	0.04	0.06	0.12	0.20
		Planting Methods		
Unidirectional	0.42	0.62	1.06	0.96
Bidirectional	0.45	0.64	1.18	1.31
LSD (p=0.05)	NS	NS	0.09	0.21

dates and locations. The highest grain heat use efficiency was recorded when crop was sown on 15th June followed by crop sown on 30th May at both locations, responsible for the higher yield for 15th June sown crop followed by 30th May sown crop at both locations. Lowest heat use efficiency was recorded in early sown crop (15th May) that contributed to the low yield. Delay in sowing also reduced the heat use efficiency. The heat use efficiency was comparatively higher at Faridkot due to higher grain yield. Heat use efficiency showed reverse trend for the straw yield.

Highest straw heat use efficiency was recorded when crop sown on 30th May, whereas, lowest heat use efficiency was recorded in late sown (30th June) crop, lower straw yield was recorded. Early sown crop produced more dry matter as they consumed more growing degree day. Higher heat use efficiency responsible for the higher grain yield under crop sown on 15th June at Ludhiana and Faridkot and low heat use efficiency responsible for poor grain yield production. Kumar *et al.* (2008) also found similar results. Mulching significantly affected the heat use efficiency. Heat use efficiency was higher under straw mulch than without mulching. Planting methods non significantly affect the heat use efficiency of grain yield but significantly affect the straw yield heat use efficiency. Heat use efficiency was significantly higher under bidirectional planting.

Radiation use efficiency (RUE)

Radiation use efficiency was worked out for soybean under different treatments at Ludhiana as shown in Fig. 1-3.

The Fig. 1 showed that straw radiation use efficiency was decreased with delay in sowing. Highest straw radiation use efficiency (0.52 g/MJ) was recorded for the crop sown on 15th May followed 30th May sown crop (0.51 g/MJ). Whereas, lowest straw heat use efficiency was recorded for 30th June (0.34 g/MJ) sown crop. The variation in radiation use efficiency under different sowings was due to the different dry matter production under different environments. Similar results were observed by Sunil (2005). However, highest grain radiation use efficiency was recorded for the crop sown on June 15th (0.23 g/MJ) and it decreased before and after the sowing date of 15th June. Among the mulch application treatment higher radiation use efficiency for grain (0.19 g/MJ) and straw (0.48 g/MJ) was recorded, when crop sown with straw mulch application as compared to the crop sown with no mulch application as presented in the Fig. 2.

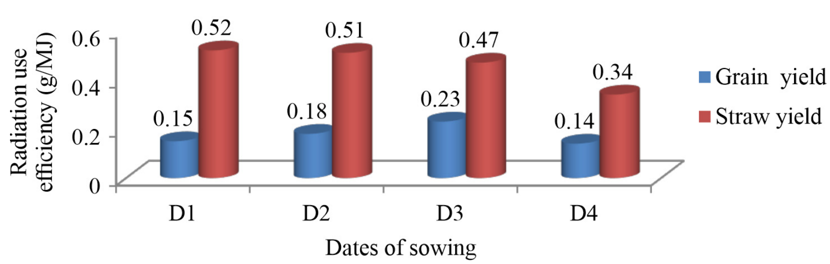

Fig. 1. Radiation use efficiency of grain and straw yield of soybean under different sowing dates at Ludhiana during *kharif* 2018

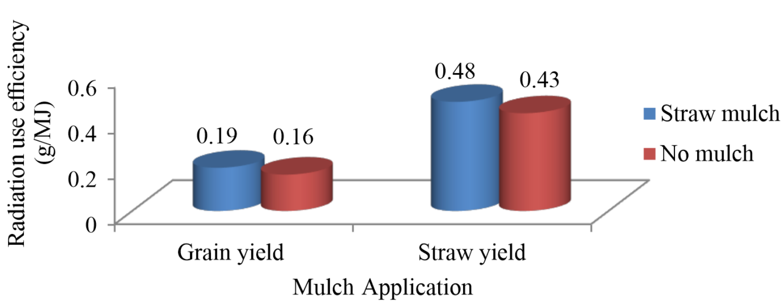

Fig. 2. Radiation use efficiency of grain and straw yield of soybean under mulch application at Ludhiana during *kharif* 2018

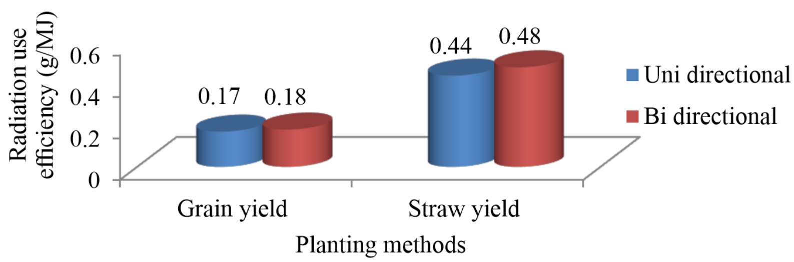

Fig. 3. Radiation use efficiency of grain and straw yield of soybean under planting methods at Ludhiana during *kharif* 2018

Radiation use efficiency under different planting methods was shown in the Fig. 3. Higher radiation use efficiency was recorded under the bi-directional planting for straw (0.48 g/MJ) as well as for grain (0.18 g/MJ). The variation in grain radiation use efficiency under planting methods was less variable. The variation in radiation use efficiency was due to intercepting different amount of radiation because of variation in canopy structure and leaf area index. Radiation use efficiency was basically dependent on three factors i.e. architecture of the canopy, intercepting the radiation, photosynthetic efficiency of the leaves in utilizing the intercepted radiation used in production of dry matter and loss of dry matter due to physiological processes like respiration.

Regression relationship among different parameters

During the crop growth period of soybean crop, the average value of canopy temperature, canopy-air temperature difference, crop water stress index and grain yield under different sowing dates and mulch application during the crop season 2018 at Ludhiana are given in Table 5.

Table 5. Average canopy temperature (°C), average canopy air temperature difference (°C), stress degree day (°C) and crop water stress index under different dates of sowing, mulch application and planting methods at Ludhiana during *kharif* 2018

Dates	Treatments	Grain yield (kg/ha)	Average Tc (°C)	Av Tc-Ta (°C)	SDD (°C)	Average CWSI
D1	M1P1	1859.6	32.6	0.049	1.13	0.53
	M1P2	1824.4	32.8	0.19	4.48	0.69
	M2P1	1551.1	33.3	0.67	13.60	1.02
	M2P2	1400.8	33.4	0.86	19.71	1.2
D2	M1P1	1986.7	32.0	-0.42	-8.73	0.3
	M1P2	1795.3	32.1	-0.28	-5.86	0.4
	M2P1	1617.6	32.5	0.15	3.86	0.5
	M2P2	1813.0	32.6	0.23	4.85	0.5
D3	M1P1	2145.4	32.2	-0.36	-7.56	0.06
	M1P2	2096.2	32.3	-0.29	-6.06	0.09
	M2P1	1721.1	32.5	-0.004	-0.08	0.3
	M2P2	1964.2	32.6	0.01	0.21	0.3
D4	M1P1	1493.4	32.3	-0.32	-6.68	0.3
	M1P2	1559.6	32.5	-0.14	-2.90	0.4
	M2P1	1267.5	33.1	0.41	6.96	0.8
	M2P2	1551.0	33.2	0.49	10.38	0.8

D1: 15th May 2018; D2: 30th May 2018; D3: 15th June 2018; D4: 30th June 2018

M1P1: Straw Mulch Unidirectional Planting; M1P2: Straw Mulch Bidirectional Planting; M2P1: No Mulch Unidirectional Planting; M2P2: No Mulch Bidirectional Planting

D1: May15, D2: May 30, D3: June 15, D4: June 30

Regression relationship between the canopy temperature and grain yield

A negative and binomial regression relationship was observed between canopy temperature and grain yield under different sowing dates and mulch treatment. This showed that grain yield was decreased with increased in the canopy temperature and vice versa (Fig. 4A). The coefficient of determination explained 44 per cent variation in grain yield by canopy temperature.

Regression relationship between the canopy air temperature difference (Tc-Ta) and grain yield

In the present study, a negative binomial regression relationship was observed under different sowing dates, mulch application and planting methods. It was showed that with increase in canopy air temperature difference (Tc-Ta), grain yield decreased and vice versa (Fig. 4B). The coefficient of determination explained 42 per cent variation in yield by canopy temperature.

Regression relationship between the stress degree day and grain yield

A negative and polynomial regression relationship between the grain yield and stress degree day under different sowing dates and mulch application was analyzed, which showed that with increase in canopy temperature, grain yield decreased and vice-versa (Fig. 5A). The coefficient of determination explained 39 per cent variation in grain yield by stress degree day.

Regression relationship between the crop water stress index and grain yield

The crop water stress index is most often used index to quantify crop water stress based on canopy temperature. Polynomial regression relationship was observed between the grain yield and crop water stress under different sowing dates, mulch application and planting methods (Fig. 5B) which showed decreased in grain yield with increase in crop water stress index. The coefficient of determination was explained 56 percent variation in grain yield due to

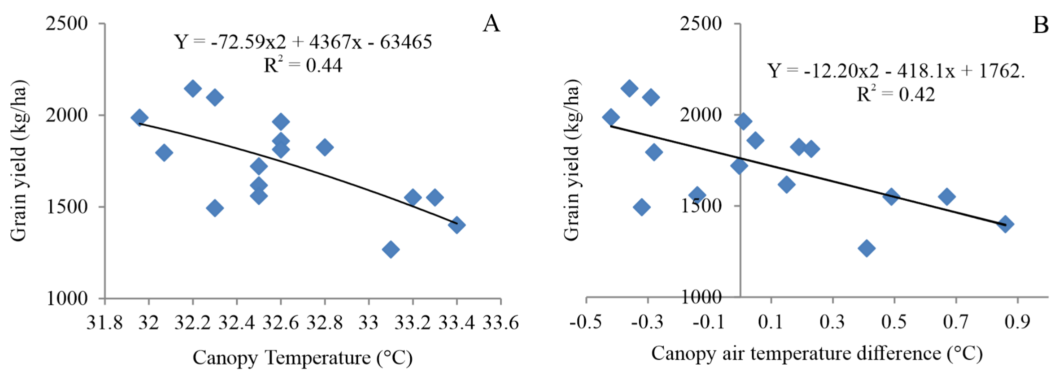

Fig. 4. Regression relationship between the canopy temperature and grain yield (A) and canopy air temperature difference (Tc-Ta) and grain yield (B) at Ludhiana during *kharif* 2018

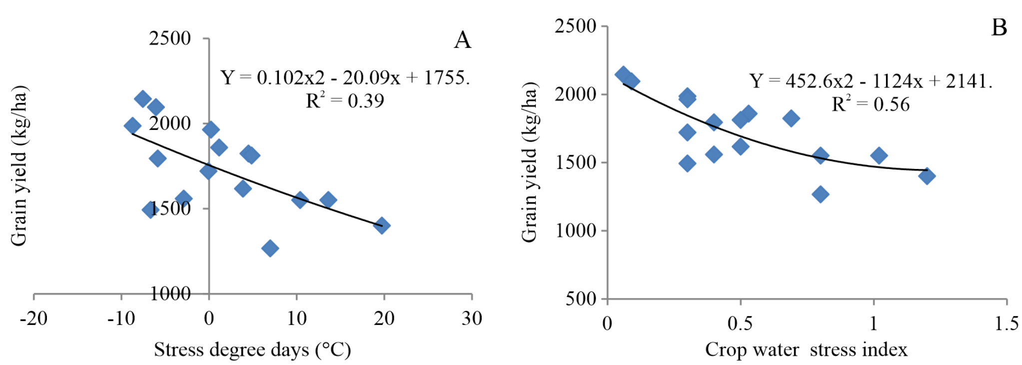

Fig. 5. Regression relationship between stress degree day and grain yield (A) and crop water stress index and grain yield (B) at Ludhiana during *kharif* 2018

canopy water stress index. Cadgon *et al.* (2013) observed inverse relationship between grain yield and crop water stress index.

Regression relationship of total dry matter accumulation with different agrometeorological indices at Ludhiana and Faridkot during kharif 2018

The regression relationship obtained between total dry matter taken as dependent variable and growing degree day, heliothermal units, photothermal units and heat use efficiency as independent variables. Based on data of crop season under different sowing dates the regression relationship were developed.

Regression relationship of total dry matter with growing degree day

A positive linear regression relationship between dry matter and accumulated growing degree day under different dates of sowing at different intervals was recorded which depicted that dry matter was increased with increase in accumulated growing degree day. The coefficient of determination explained as 94 percent variation at Ludhiana (Fig 6A) and 93.2 per cent variation at Faridkot (Fig. 6B).

Regression relationship of total dry matter with photothermal units

Positive logarithmic regression relationship was observed between total dry matter and photo thermal units. It was observed that dry matter increased with increase of photo thermal units at Ludhiana (Fig. 7A) and Faridkot (Fig. 7B). The coefficient of determination explained 88 per cent and 90 per cent variation in dry matter due to photo thermal units at Ludhiana and Faridkot, respectively.

Regression relationship of total dry matter with heliothermal units

A positive logarithmic relationship between dry matter and heliothermal units was observed. The dry matter and accumulated heliothermal units under different dates of sowing at different interval were recorded, which showed increase in heliothermal unit increased the dry matter production at both locations (Fig. 8). The coefficient of determination explained as 90 per cent and 89per cent variation in dry matter

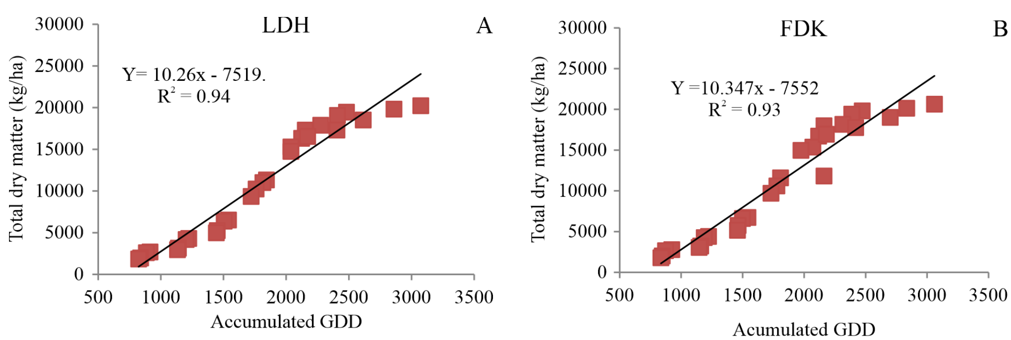

Fig. 6. Regression relationship of total dry matter with growing degree day (GDD) at Ludhiana (A) and Faridkot (B) during *kharif* 2018

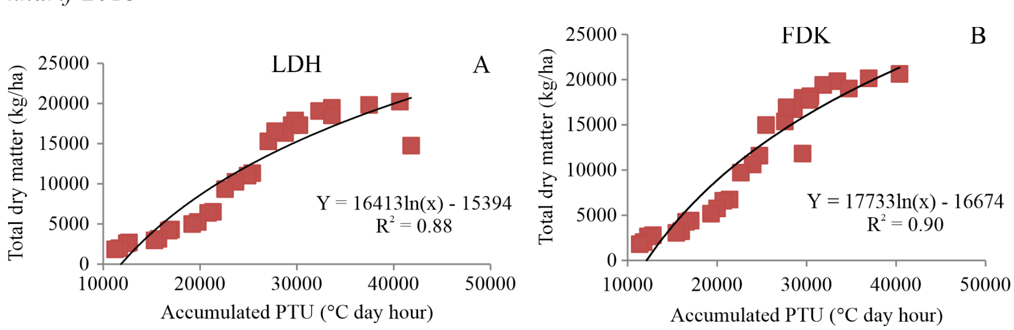

Fig. 7. Regression relationship of total dry matter with photothernal units at Ludhiana (A) and Faridkot (B) during *kharif* 2018

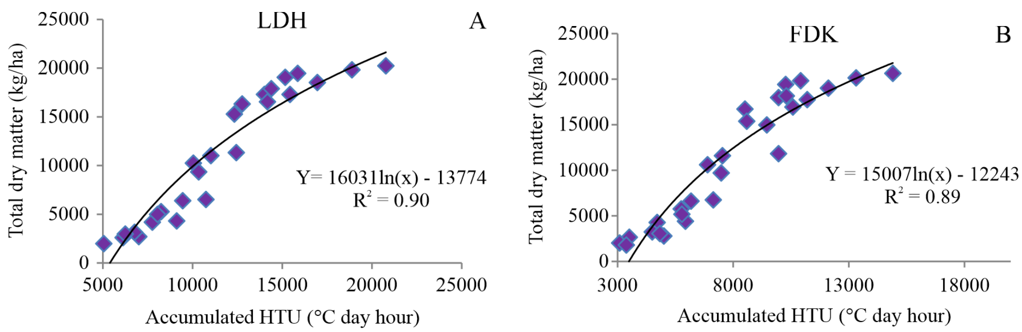

Fig. 8. Regression relationship of total dry matter with heliothermal units at Ludhiana (A) and Faridkot (B) during *kharif* 2018

at Ludhiana (Fig. 8A) and Faridkot (Fig. 8B), respectively.

Conclusions

The above study indicated that thermal units requirement was highest for the early sowing (15th May) and decreased with delay in sowing due to shortening of growing period. Heat use efficiency was highest when crop sown on 15th May. This might be due to high air temperature throughout the life cycle of D_1 (15th May) sowing, whereas, lowest thermal units were required in D_4 (30th June) sowing, due to delay in sowing the crop duration decreased. Highest accumulated photo thermal units was recorded in D_1 (15th May) sown crop and lowest PTU was recorded in D_4 (30th June) at both locations. The higher PTU in D_1 may be due to the fact that crop took longer duration to reach maturity. Photo thermal unit requirement was reduced with delay in sowing.

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