Int.J.Curr.Microbiol.App.Sci (2018) *7*(10): 2050-2061

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 7 Number 10 (2018)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2018.710.237

Study on Specified Growth Attributes, Thermal Unit Requirement and Its Utilization Efficiency in Barley Cultivars under Varied Microenvironment

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Keywords

Barley, Microclimate, AGDD, Physiological maturity, Crop phenology, Heat use efficiency

Article Info

Accepted:
15 September 2018
Available Online:
10 October 2018

A B S T R A C T

A field experiment was conducted during *rabi* 2016-17 at Research farm of Punjab Agricultural University, Ludhiana involving two barley (*Hordeum vulgare* L.) varieties: V_1 (DWRUB 52, Two-rowed) and V_2 (PL 807, Six-rowed) sown on three sowing dates *viz.* D_1 (25th October), D_2 (10th November), D_3 (25th November) and three irrigation levels *viz.* I_1 (Recommended 4 post sowing irrigation), I_2 (Skip at vegetative stage), I_3 (Skip at anthesis stage) replicated thrice in factorial split plot design to investigate heat summation indices in relation to crop phenology under changed microclimate. Among different sowing windows, V_1 took more number of days (158) along with highest AGDD (2059.45 ^{o}C day) to attain physiological maturity as compared to V_2 (155 days and 1983.75 ^{0}C day) under D_2. Phenological models explained 94 to 99 per cent variation in crop phenology due to heat units under three dates of sowing.V_1 produced more plant height and tiller numbers (89.26 cm and 332 per m^2 respectively) than V_2 whereas D_2 recorded maximum value of these attributes (91.53 cm and 362.06 per m^2 respectively) followed by D_1 and D_3 at harvest and 90 DAS respectively. Heat use efficiency reflected positive linear relationship with different growth components and economic yield of crop.

Introduction

Barley (*Hordeum vulgare* L.), a member of Poaceae family, is now getting significant attention worldwide due to its contribution as food grain, feed and mating purposes. It has covered a noticeable land masses in the agrarian of Punjab. In Punjab, barley occupied around 15 thousand hectares with a production of 39.40 thousand tones and average yield of 35.82 q/ha during 2014-15 (Anonymous, 2016). Barley is a long day plant and due to the thermo and photo sensitive nature of the crop, solar radiation interception and thermal use efficiency have a key role to play during its entire life cycle. Interception of radiation by the plant and conversion of this energy for biomass production ultimately governs different growth attributes (plant height, tiller numbers, dry matter accumulation etc.) and yield of the crop. Discrepancies in optimum temperature both in crop vegetative and maturity stages unfavourably affect the onset and development of different phenophases and grain yield of the crop. Pal *et al.,* (2001) suggested that seedling duration, the rate and duration of growth and productivity of the crop can be determined by temperature, the key component of climate. Hence, quantification of thermal use efficiency or heat use efficiency (the amount of dry matter produced per unit growing degree day) is of utmost importance in recent times for the assessment of crop yield potential under varying environmental conditions.

Now-a-days, temperature is raising day by day putting immense effect on different crop phenophases and huge fluctuations in crop yield have been observed over years. Even, IPCC during its fifth assessment report (2014) mentioned globally averaged combined land and ocean surface warming of 0.85°C during the period from 1880 to 2012. Among different agro-meteorological indices, GDD (Growing Degree Days) is considered to be the most reliable in assessing crop phenology under changing climatic scenarios. All growth and developmental stages of crop estimated more accurately on the basis of GDD (Warthington and Hatchinson, 2005). Terminal heat stress, the main reason behind reduction in grain yield due to increased temperature conditions at crop maturity, is a serious problem in 40 per cent of temperate environments, which approximately covers 36 million ha. High temperatures above 30^{o}C affect final grain yield by reducing the duration of grain filling. Date of sowing is one of the important factors for higher production as it enhances the efficiency of barley by exploiting growth factors in an effective manner. The crop is generally grown as rainfed crop in Punjab, but the state is receiving threats in the form of fast depleting ground water resources due to climatic variability in recent times. Thus, need based irrigation in crucial growth stage is also required to enhance crop productivity.

Keeping the above facts under consideration, the present study was undertaken for investigating variation in specified growth parameters, thermal unit requirements and heat use efficiency of barley under different sowing windows, cultivars and moisture levels in the backdrop of changed climate.

Materials and Methods

The present experiment on barley crop was conducted at the research farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana (30°54’N latitude, 75°56’E longitude; altitude of 247 meters above the mean sea level) during *rabi* 2016-17. The experiment was laid out in factorial split plot design with three replications comprising of three sowing environments D_1 (25th October), D_2 (10th November), D_3 (25th November); two varieties V_1 (DWRUB 52) & V_2 (PL 807) and three irrigation levels I_1 (Recommended 4 post sowing irrigations i.e. CRI, tillering, jointing, anthesis), I_2 (Skip at vegetative stage) and I_3 (Skip at anthesis stage). A set of 18 treatment combinations were found by taking sowing dates and varieties in main plot and irrigation levels in sub plot. The study area is characterized by semi-arid, sub-tropical climate with very hot summer during April-June and cold winters during December-January. This region is dominated by NW winds during winter season and the average annual rainfall in Ludhiana is 733mm, 75-80% of which is received during the period from June to September. Soil of the experimental site was loamy sand in texture and neutral in reaction (pH 7.5) having organic matter content 0.28 per cent (0-15 cm surface layer). Using the seed rate @ 35 kg per acre, seeds were sown by ‘Kera’ method of sowing with a row spacing of 22.5 cm. In this study, sequential phasic development of the crop called as crop phenology, starting from the emergence to maturity was monitored throughout the growing season of the crop. Different phenological stages and days taken to complete each stage were recorded. Periodic observations on plant height and tiller numbers were made from 40 days afterwards and continued till maturity. Plant height and total tiller numbers were recorded from the five representative plants tagged at random in the1m row length in each plot.

Thermal heat unit calculation

Cumulative growing degree days were determined by summing the daily mean temperature above base temperature, expressed in day °C. This was calculated by using the following formula:

$$GDD = \sum_{i=1}^{n}\left(\frac{T_{max} + T_{min}}{2}\right) - T_{base} \ (^{o}C \text{ days})$$

Where,

T_{max} = Daily maximum temperature (°C)
T_{min} = Daily minimum temperature (°C)
T_{base} = Minimum threshold/base temperature (For barley T_{base}= 5^{o}C)

Heat Use Efficiency (HUE)

The HUE was computed to compare the relative performance of crop under varying environments with respect to utilization of heat energy using the following formula:

Heat Use Efficiency (g/m^2/^{0}C day) = $\frac{\text{Dry matter yield (g/m}^2)}{\text{AGDD(°C day)}}$

Statistical analysis

The data collected on all the characters in respect of various growth and yield parameters were statistically analyzed by using split plot design as directed by Cheema and Singh (1991) in statistical package CPCS-1. Another statistical software named EDA 1.1 was also used to analyze the data on all parameters to maintain more accuracy. The significance of differences was tested between treatment means and compared using least significant difference or critical difference (LSD or CD) values at 5 per cent level of significance. Regression analysis was also made to associate grain yield with different growth parameters and HUE.

Results and Discussion

Crop phenology

Crop phenology is defined in general as the periodic events occurring in a plant's entire life period and how these are impacted by the surrounding nature of the plants, variations in the seasonal and annual climate and also influenced by habitat factors. In the present exploration, the crop was subjected to different dates of sowing, variations in cultivars and irrigation regimes. In the present study, different phenophases of the two barley varieties under different sowing time have been prescribed in Table 1 to 3. Barley crop overcomes several phenological stages such as emergence, CRI, tillering, jointing, flag leaf, booting, heading, anthesis, milk stage and finally maturity during the entire growth period. Here, the number of days taken by the crop for attaining different growth stages under different dates of sowing was observed and the AGDD (Accumulated Growing Degree Days) value was calculated for various growth period taking into account the climate factor (Temperature).

For first date of sowing, V_1 reached complete emergence at 9 DAS while V_2 at 7 DAS having AGDD values of 180.65 and 145.85 ^{0}C day respectively. V_1 completed CRI and tillering stages at 23 DAS (399.4 ^{0}C day) and 45 DAS (704.5 ^{0}C day) while V_2 at 22 DAS (385.5 ^{0}C day) and 44 DAS (693 ^{0}C day). But both the varieties took 67 days to attain the jointing stage with an AGDD value of 928.25

^{0}C day. The reproductive phase of the crop was started with the emergence of flag leaf about 91 DAS for V_1 and 89 DAS for V_2 with AGDD values of 1118.1 ^{0}C day and 1098.1 ^{0}C day respectively. From flag leaf emergence to maturity, the crop covered booting, heading, anthesis and milking stages at around 99 DAS (1198.8 ^{0}C day), 105 DAS (1261.4 ^{0}C day), 121 DAS (1455.5 ^{0}C day) and 133 DAS (1607.1 ^{0}C day) for V_1 whereas for V_2 at 98 DAS (1188.9 ^{0}C day), 104 DAS (1252.8 ^{0}C day), 119 DAS (1432.7 ^{0}C day) and 133 DAS (1569.1 ^{0}C day) respectively. V_1 took overall 154 days while V_2 required 151 days from sowing to physiological maturity with AGDD values of 1917.7 and 1854.7 ^{0}C day respectively.

For second date of sowing, V_1 attained complete emergence at 10 DAS while V_2 at 9 DAS having AGDD values of 165.05 and 149.65 ^{0}C day respectively. V_1 completed CRI and tillering stages at 24 DAS (364.25 ^{0}C day) and 45 DAS (590.7 ^{0}C day) while V_2 at 23 DAS (351.95 ^{0}C day) and 45 DAS (590.7 ^{0}C day). But both the varieties took 66 days to reach the jointing stage with an AGDD value of 771.55 ^{0}C day. The reproductive phase of the crop was started with the initiation of flag leaf about 91 DAS for V_1 and 89 DAS for V_2 with AGDD values of 1002.55 ^{0}C day and 983.65 ^{0}C day respectively.

From flag leaf emergence to maturity, the crop covered booting, heading, anthesis and milking stages at around 102 DAS (1141.35 ^{0}C day), 109 DAS (1225.25 ^{0}C day), 122 DAS (1378.65 ^{0}C day) and 137 DAS (1617.45 ^{0}C day) for V_1 whereas for V_2 at 100 DAS (1108.15 ^{0}C day), 107 DAS (1200.35 ^{0}C day), 121 DAS (1369.45 ^{0}C day) and 136 DAS (1596.35 ^{0}C day) respectively. V_1 required overall 158 days while V_2 took 155 days from sowing to physiological maturity with AGDD values of 2059.45 and 1983.75 ^{0}C day respectively.

For third date of sowing, V_1 attained complete emergence at 12 DAS while V_2 at 11 DAS having AGDD values of 176.7 and 163.8 ^{0}C day respectively. Among the vegetative stages, V_1 completed CRI and tillering at 25 DAS (313 ^{0}C day) and 47 DAS (521.65 ^{0}C day) while V_2 at 24 DAS (302.6 ^{0}C day) and 46 DAS (517.55 ^{0}C day). But both the varieties took 66 days to reach the jointing stage with an AGDD value of 675.1 ^{0}C day. The reproductive phase of the crop was started with the initiation of flag leaf about 89 DAS for V_1 and 86 DAS for V_2 with AGDD values of 939.8 ^{0}C day and 898.9 ^{0}C day respectively. From flag leaf emergence to maturity, the crop covered booting, heading, anthesis and milking stages at around 98 DAS (1052.5 ^{0}C day), 102 DAS (1102.8 ^{0}C day), 111 DAS (1196.5 ^{0}C day) and 123 DAS (1413.4 ^{0}C day) for V_1 whereas for V_2 at 96 DAS (1025.8 ^{0}C day), 101 DAS (1089.4 ^{0}C day), 110 DAS (1184.6 ^{0}C day) and 122 DAS (1390.9 ^{0}C day) respectively. V_1 comprised of 142 days while V_2 took 139 days from sowing to physiological maturity with AGDD values of 1832.9 and 1757.2 ^{0}C day respectively.

The variation in reaching different growth stages at different time is mainly due to the varietal difference as a two-rowed variety was taken against of a six-rowed barley variety and two might hold different growth characteristics pattern. In case of 25th Nov. sown crop AGDD requirement for emergence was increased for both the varieties as compared to 25th Oct. and 10th Nov. sown crops due to increase in the number of days needed as the third date of sowing fell under relatively colder ambience as against of the first two dates of sowing. Complete emergence for both the cultivars took more number of days in case of D_3 rather than D_1 and D_2 may be due to lessen soil temperature during the later half of November. Although the number of days to attain different vegetative phases remained almost similar for all dates of sowing but significant variation has been observed in case of reproductive and ripening stages of the crop due to late planting. The crop sown on 25th Nov. matured much earlier as compared to other sowing dates because of the increased temperature during the later stages of crop growth which hastened the crop maturity although the period of vegetative stages remained almost similar with that of D_1 and D_2. Both V_1 and V_2 recorded highest AGDD during second date of sowing followed by D_1 and D_2. Sharma *et al.,* (2007) recorded lower thermal heat units under late sown conditions. Alam *et al.,* (2005) from Bangladesh reported that first fortnight of November is the optimum time for sowing of the barley. Mani *et al.,* (2007) reported that 10th November sown barley crop consumed more heat unit than other dates of sowing. Regression analysis between number of days taken to attain different development stages and AGDD under three dates of sowing were given in Figure 1.

Growth parameter and economic yield

Plant height

The data pertaining to the periodic plant height of barley was recorded under different sowing dates, varieties and irrigation levels throughout the *rabi* crop season 2016-17 have been presented in Table 4. In early growth phases (up to 60 days), plant height was relatively shorter but with the passing days toward maturity the height seemed to increase. Plant height was affected by different dates of sowing. The November 10 (D_2) sown crop produced significantly more plant height than the October 25 (D_1) and November 25 (D_3) sown crop under 90, 105, 120 and 135 days after sowing. The maximum plant height (91.53 cm) was observed during harvesting for D_2 followed by D_1 (89.55 cm) and D_3 (85.05 cm). The plant height of D_2 was statistically at par with that of D_1 to some extent although had significantly higher value than D_3. The crop which was sown at proper time accomplished maximum plant height as against of late planting and barley crop prefers relatively cool climate for normal sowing. The plant height at harvest of 16th October sown crop was the highest which was statistically at par with 15th November but significantly higher than 15th December sown crop (Pankaj *et al.,* 2015). Alam *et al.,* (2007) reported significant reduction in plant height due to delay in sowing. Among the two varieties (V_1 and V_2) used in the experiment, V_1 produced significantly more plant height than V_2 during the entire life cycle of the plant.

The maximum plant height (89.26 cm) was recorded at maturity under V_1 than that of V_2 (88.16cm). Although for most of the growing season plant height for V_1 remained significantly better than that of $V_{2,}$ yet the values were statistically non-significant at 60, 75 and 105 days after sowing. Varietal differences for plant height were also reported by Sardana and Zhang (2004). Musavi *et al.,* (2012) found highest plant height and ear length achieved in Binam cultivar but the highest of peduncle length and flag leaf length related to Nosrat cultivar. Irrigation treatments did not show much significant effect on plant height. The variations in plant height under different irrigation treatments were statistically non-significant at 45, 60, 90, 105, 120, 135 days after sowing while the values of plant height were statistically significant at 75 days after sowing and during crop harvest having slightly higher value (89.59 cm) of plant height was observed under I_2 followed by I_1 (88.66 cm) and I_3 (87.88 cm).

Tiller numbers

The data regarding the number of tillers of barley under different sowing time, varieties and various irrigation levels have been presented in Table 4.

Table.1 Crop phenological stages and calculated thermal units (^{0}C day) of the two barley varieties under 25th October sown crop

V_1 (DWRUB 52)			V_2 (PL 807)		
Phenophases	**Days Taken**	**AGDD (^{o}C day)**	**Phenophases**	**Days Taken**	**AGDD (^{o}C day)**
Sowing	0	19.3	Sowing	0	19.3
Emergence	4	93.9	Emergence	4	93.9
Complete Emergence	9	180.65	Complete Emergence	7	145.85
CRI	23	399.4	CRI	22	385.5
Tillering	45	704.5	Tillering	44	693
Jointing	67	928.25	Jointing	67	928.25
Flag leaf emergence	91	1118.1	Flag leaf emergence	89	1098.1
Booting	99	1198.8	Booting	98	1188.9
Heading	105	1261.4	Heading	104	1252.8
Anthesis	121	1455.5	Anthesis	119	1432.7
Milking	133	1607.1	Milking	130	1569.1
Physiological Maturity	**154**	**1917.7**	Physiological Maturity	**151**	**1854.7**

Table.2 Crop phenological stages and calculated thermal units (^{0}C day) of the two barley varieties under 10th November sown crop

V_1 (DWRUB 52)			V_2 (PL 807)		
Phenophases	**Days taken**	**AGDD (^{o}C day)**	**Phenophases**	**Days taken**	**AGDD (^{o}C day)**
Sowing	0	15.8	Sowing	0	15.8
Emergence	6	107.75	Emergence	5	94.35
Complete emergence	10	165.05	Complete emergence	9	149.65
CRI	24	364.25	CRI	23	351.95
Tillering	45	590.7	Tillering	45	590.7
Jointing	66	771.55	Jointing	66	771.55
Flag leaf	91	1002.55	Flag leaf	89	983.65
Booting	102	1141.35	Booting	100	1108.15
Heading	109	1225.25	Heading	107	1200.35
Anthesis	122	1378.65	Anthesis	121	1369.45
Milking	137	1617.45	Milking	136	1596.35
Physiological Maturity	**158**	**2059.45**	Physiological Maturity	**155**	**1983.75**

Table.3 Crop phenological stages and calculated thermal units (^{0}C day) of the two barley varieties under 25th November sown crop

V_1 (DWRUB 52)			V_2 (PL 807)		
Phenophases	**Days taken**	**AGDD (^{o}C day)**	**Phenophases**	**Days taken**	**AGDD (^{o}C day)**
Sowing	0	14.5	Sowing	0	14.5
Emergence	7	112.6	Emergence	7	112.6
Complete emergence	12	176.7	Complete emergence	11	163.8
CRI	25	313	CRI	24	302.6
Tillering	47	521.65	Tillering	46	517.55
Jointing	66	675.1	Jointing	66	675.1
Flag leaf	89	939.8	Flag leaf	86	898.9
Booting	98	1052.5	Booting	96	1025.8
Heading	102	1102.8	Heading	101	1089.4
Anthesis	111	1196.5	Anthesis	110	1184.6
Milking	123	1413.4	Milking	122	1390.9
Physiological Maturity	**142**	**1832.9**	Physiological Maturity	**139**	**1757.2**

Table.4 Variation in plant height and tiller numbers as influenced by sowing dates, cultivars and irrigation levels

Treatments	40 DAS		60 DAS		90 DAS		120 DAS		At Harvest	
	*Pl. height	*Tiller count	Pl. height	Tiller count	Pl. height	Tiller count	Pl. height	Tiller count	Pl. height	Tiller count
Sowing time										
D_1	34.05	252.83	58.64	280.22	78.48	335.22	85.47	322.56	89.55	313.56
D_2	36.34	269.83	60.71	297.00	82.43	362.06	88.21	352.78	91.53	343.22
D_3	31.61	208.94	56.87	233.78	76.29	281.72	82.13	278.61	85.05	269.50
CD (p=0.05)	**0.70**	**4.64**	**2.00**	**5.08**	**1.31**	**3.94**	**1.28**	**4.61**	**0.93**	**5.23**
Variety										
V_1	34.61	274.07	58.91	274.07	69.97	332.00	85.95	323.41	89.26	313.56
V_2	33.39	266.59	58.58	266.59	69.23	320.67	84.59	312.56	88.16	303.96
CD (p=0.05)	**0.60**	**4.04**	**NS**	**4.15**	**NS**	**3.22**	**1.04**	**3.77**	**0.76**	**4.27**
Irrigation level										
I_1	34.56	242.61	58.71	273.89	68.93	337.33	85.43	328.78	88.66	318.89
I_2	33.47	244.44	58.93	267.89	70.61	319.83	85.84	310.50	89.59	301.72
I_3	33.97	244.56	58.58	269.22	69.26	321.83	84.54	314.67	87.88	305.67
CD (p=0.05)	**NS**	**NS**	**NS**	**3.70**	**1.20**	**3.62**	**NS**	**3.41**	**0.90**	**3.32**

*Pl. height measured in cm & tiller count measured per square meter

Table.5 Variation in heat use efficiency of barley under different sowing windows, cultivars and moisture level

Treatments	Days after sowing (DAS)				*HUE ($g/m^2/^oC$ day)		Grain yield (kg/ha)
Date of Sowing	30	60	90	120	Straw	Grain	
D_1 (25th Oct.)	0.34	0.66	1.71	1.31	0.69	0.26	4249
D_2 (10th Nov.)	0.36	0.73	1.72	1.35	0.64	0.27	4531
D_3 (25th Nov.)	0.32	0.59	1.46	1.16	0.48	0.23	3795
CD (p=0.05)	**0.01**	**0.03**	**0.01**	**0.02**	**0.03**	**0.01**	**102.3**
Variety							
V_1 (DWRUB 52)	0.36	0.69	1.65	1.30	0.63	0.26	4290
V_2(PL 807)	0.32	0.62	1.60	1.25	0.57	0.25	4094
CD (p=0.05)	**0.02**	**0.04**	**0.01**	**0.02**	**0.03**	**0.01**	**78.37**
Irrigation levels							
I_1 (Recommended)	0.34	0.67	1.63	1.27	0.61	0.26	4267
I_2 (Skip at veg. stage)	0.35	0.68	1.67	1.28	0.61	0.25	4110
I_3 (Skip at anthesis stage)	0.33	0.64	1.58	1.26	0.29	0.25	4198
CD (p=0.05)	**NS**	**NS**	**0.02**	**NS**	**NS**	**NS**	**74.09**

* HUE denotes heat use efficiency

Fig.1 Relationship between the number of days taken to attain different crop phonological stages and AGDD for 25th Oct. (a-b), 10th Nov. (c-d), 25th Nov. (e-f) barley varieties

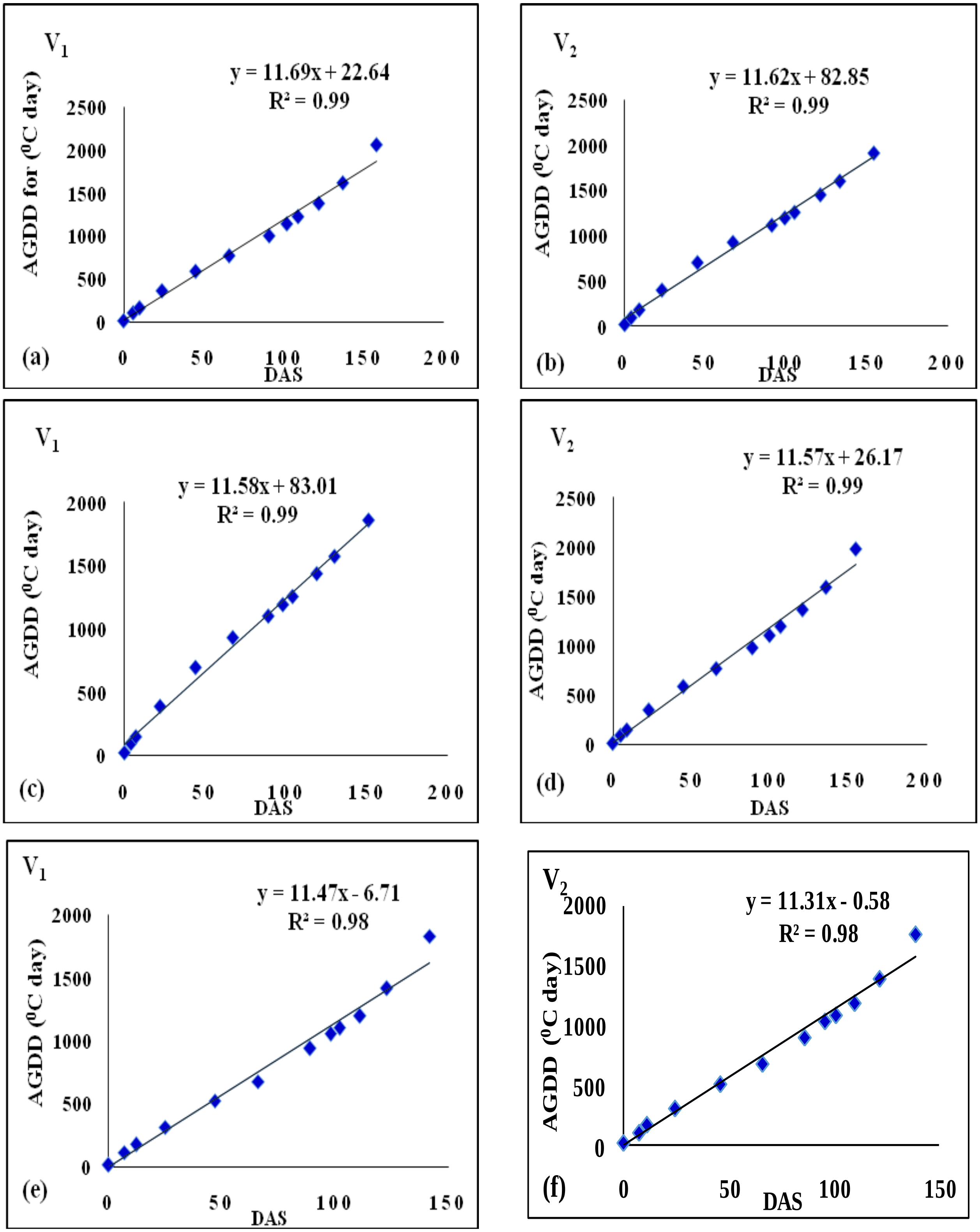
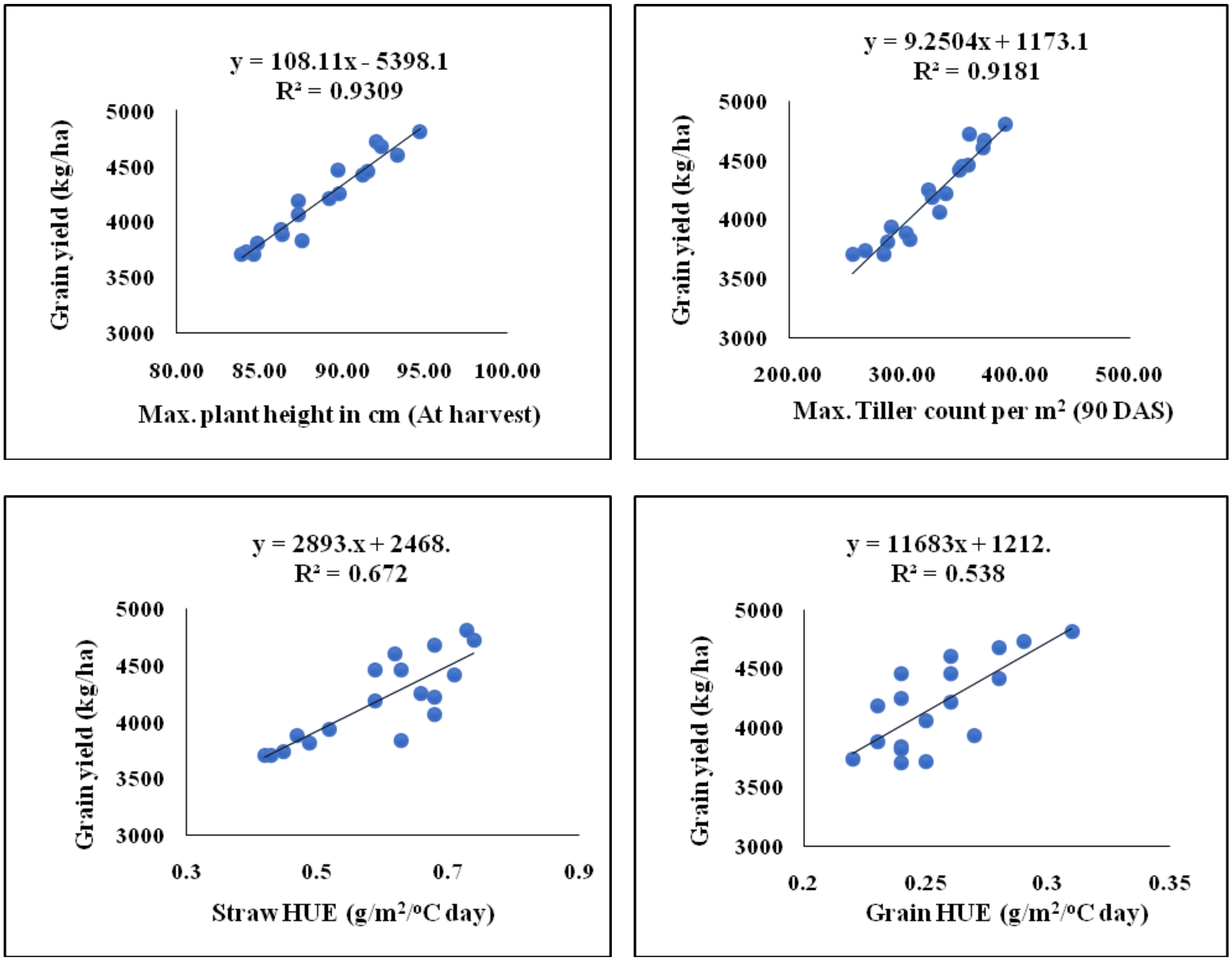


Fig.2 Relationship of grain yield with specified growth parameters and heat use efficiencies of barley



Tillering is very important as it enables the plant to produce multiple stems leading to the formation of dense fruits and numerous seed heads. Periodic observations of tiller count at 45, 60, 90, 120 DAS and during harvesting were taken from the field under different treatments. The November 10 (D_2) sown crop produced significantly more number of tillers than October 25 (D_1) and November 25 (D_3) sown crop throughout the crop season. D_2 recorded maximum tiller count (362.06 per m^2) at 90 DAS followed by D_1 (335.22 per m^2) and D_3 (281.72 per m^2). It was also observed that the tiller numbers of D_2 was statistically at par with D_1 but having significantly higher value than D_3. D_1 also had much higher tiller count as compared to D_3. Singh *et al.,* (1997) recorded significantly higher plant height (91.6 cm) and number of tillers/meter row length (132.5) in oats sown on 6th November compared to plant heights of 87.5 and 81.2 cm and tillers per meter row length (129.1 and 118.2) when sown on 22^{nd} October and 21st November, respectively.

Significant differences in tiller count were observed among the two varieties during the entire crop growing period. V_1 produced maximum number of tillers (332.00 per m^2) as against of V_2 (320.67 per m^2) at 90 days after sowing and thereafter slight decrease in the tiller numbers were noticed as both the cultivars progresses towards maturity. On the contrary, Rashid *et al.,* (2010) reported that number of tillers per plant was found non-significant with sowing date.

Irrigation treatments seemed to influence the crop tiller count significantly during maximum growth period except from sowing to 45 DAS. Of the three irrigation levels, I_1 attained higher tiller count as compared to I_2 and I_3; I_2 remained statistically almost at par with I_3 during the crop life period.

Grain yield

The data pertaining to the grain yield impacted by the different sowing dates, varieties and irrigation treatments have been demonstrated in Table 5. The highest grain yield (4531 kg/ha) was observed under second date of sowing (D_2) followed by D_1 (4249 kg/ha) and D_3 (3795 kg/ha). It was also seen that D_2 produced grain yield almost at par with D_1 but significantly much higher than that of D_3. Significant difference in the value of grain yield was also recorded between D_1 and D_3; D_1 had much higher grain yield than D_3. D_2 showed maximum grain yield may be due to higher dry matter production, highest number of effective tiller, ear length, more 1000 seed weight and none the less prolonged phenophases as compared to late planting. Mani *et al.,* (2006) recommended that late planting of barley beyond 10^{th} November outcome a significant reduction in grain yield. Similar results were obtained by Hari Ram *et al.,* (2010).

Of the two varieties, V_1 recorded maximum grain yield of 4290 kg/ha as compared to V_2 which was found as 4094 kg/ha. The data designated that V_1 was significantly better than V_2 in reference to grain yield. Irrigation seemed to have significant effect on grain yield under all 3 irrigation levels (I_1, I_2, I_3). I_1 produced average higher grain yield than I_2 and I_3 which were statistically at par eventually. Musavi *et al.,* (2012) reported that cultivar had significant influence on peduncle length, ear length, lodging percentage and seed yield.

Heat use efficiency

Heat use efficiency (HUE) is important factor in crop development. The heat use efficiency is influenced by dry matter production. In the present study, measurement of heat use efficiency (HUE) started from 30 days after sowing and thereby continued at monthly interval up to crop harvesting as showed in Table 5. Heat use efficiency gradually increased till 90 DAS (milk stage) and thereby decreased toward physiological maturity under all three sowing dates. Grain HUE of barley was found higher in case of second date of sowing; D_2 (0.27 g/m^2/^{o}C day) as compared to D_1 and $D_{3.}$ But for straw HUE, maximum value was found under D_1 (0.69 g/m^2/^{o}C day) followed by D_2 and D_3. This was mainly due to accumulation of more amount of dry matter and thermal time in case of D_2 followed by D_1 and D_3. The delayed sowing significantly reduces the heat unit consumption and thermal use efficiency of the crop as suggested by Kaur and Pannu (2008). Kumari *et al.,* (2009) also mentioned that timely sowing of wheat crop seems to be essential for harnessing heat use efficiently under changing environmental conditions. Heat use efficiencies for both the varieties were found significantly different throughout the crop period and V_1 recorded both straw and grain HUE maximum (0.63 & 0.26 g/m^2/^{o}C day) as compared to $V_{2.}$ The value of heat use efficiency was more for V_1 than that of V_2 because of higher amount dry matter production under V_1. Irrigation treatments did not put any significant influence on the heat use efficiency of the crop. However, I_1 recorded relatively higher grain heat use efficiency value followed by I_2 and I_3 which were similar among themselves might be due to more availability of water in case of I_1 than other irrigation treatments.

Yield response of barley to growth parameters and HUE

Regression analysis was done by fitting linear response function between grain yield and different growth parameters (Maximum plant height at harvest and maximum tiller count at 90 DAS) and straw and grain heat use efficiency (Fig. 2). Both max. Tiller count and plant height linear regression equation with grain yield showed positive correlation which explained 91.81 per cent and 93.09 per cent variability under different sowing dates, cultivars and moisture regimes. Heat use efficiency with respect to both straw and grain showed positive association having 67.28 per cent and 53.81 per cent variation with grain yield under modified microenvironment.

Acknowledgements

The authors are highly thankful to Indian Council of Agricultural Research, New Delhi, Govt. of India, for providing grant in the form of Junior Research Fellowship to conduct this study at the research farm of Department of Climate Change and Agriculture Meteorology, PAU, Ludhiana.

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How to cite this article:

Sanu Kumar Saha, Som Pal Singh and Kingra, P.K. 2018. Study on Specified Growth Attributes, Thermal Unit Requirement and Its Utilization Efficiency in Barley Cultivars under Varied Microenvironment. *Int.J.Curr.Microbiol.App.Sci.* 7(10): 2050-2061.
doi: https://doi.org/10.20546/ijcmas.2018.710.237