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Crop growth analysis of grass pea in relation to thermal condition in new alluvial zone of West Bengal

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Abstract
In order to study the effect of thermal condition on crop growth of grass pea, field experiment was conducted during *Rabi* season of 2016-2017 at the Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya, West Bengal. The experiment was carried out in Randomized Complete Block Design with nine treatments (nine dates of sowing starting from 26th October to 21st December at weekly interval). Crop sown on 16th November produced highest leaf area index at 42 DAS (0.56), 63 DAS (0.89) and at the time of harvest (1.39). During 63 DAS to 84 DAS, crop growth rate was positively correlated with maximum, minimum and average air temperatures (r = 0.70*). Diurnal temperature difference during 63 DAS to 84 DAS showed harmful effect on relative growth rate (r = -0.69*) while during 84 DAS to harvest, diurnal temperature difference showed significant positive effect on NAR (r = 0.67*). The influence of temperature and thermal indices on crop growth parameters varied as growth stages and sowing dates changed.

Keywords: Crop growth, correlation, grass pea, temperature, thermal utilization

Introduction
Yield of crops is actually the results of the effects of various environmental factors (Krishna Murthy and Yogeswara Rao, 2000) [12]. Temperature played an important role in crop growth and biomass production (Hatfield and Prueger, 2015) [9]. Under the context of climate change rising minimum air temperature affects crop growth and yield to a greater extent (Hatfield *et al.*, 2011) [8]. Crop growth attributes such as leaf area index (LAI), leaf area duration (LAD), crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR) are positively correlated with the final yield of the crop. Indirect effect of temperatures on crop growth can be shown by temperature based agrometeorological indices viz. Growing degree day (GDD), Heliothermal unit (HTU) and Photothermal unit (PTU). These thermal indices are used for prediction of growth and yield of various crops (Tzudir *et al.*, 2014) [28]. Influence of delayed sowing and thermal condition on growth and yield of crops can be determined through accumulated heat unit system (Bishnoi *et al.*, 1995) [5]. Crop growth may be analyzed by studying agro-meteorological indices accumulated during crop growing period and their utilizations (Benbi, 1994 and Singh *et al.*, 1996) [3, 26]. Grass pea (*Lathyrus sativus* L.), commonly known as, chickling pea, chickling vetch, Indian pea etc. is an important grain legume cultivated in India during winter season. It is a rich source of protein (28%) andminerals especially calcium, phosphorus and iron (Bhagat *et al.*, 2015) [4]. The present study was carried out to determine the variation in crop growth due to alteration of sowing time.

Materials and methods
Details of the experiment
Field experiment was conducted during the winter season of 2016-2017 at the Instructional Farm (22°58´ N, 88°31´ E and 9.75 m above mean sea level), Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India, with grass pea (cv. 'Prateek'), sown on nine different dates (26th October, 2nd November, 9th November, 16th November, 23rd November, 30th November, 7th December, 14th December and 21st December). Experiment was carried out in Randomized Complete Block Design with three replications with three replications. 40 kg/ ha seed rate was followed and 30 cm of row to row spacing was maintained. All the recommended management practices for this area were followed.

Four distinct stages viz. sowing to 42 DAS (S-1 stage), 42 DAS to 63 DAS (S-2 stage), 63 DAS to 84 DAS (S-3 stage) and 84 DAS to harvest (S-4 stage) were considered for crop growth analysis.

Crop growth parameters

Leaf area index (LAI): It is the ratio of the leaf of the crop to the ground area over a period of interval of time (Sestak *et al*., 1971) [24].

LAI = Leaf area plant^{-1} (cm^2) / Ground area covered by plant (cm^2)

Leaf area duration (LAD): It is the integration of LAI over the growth period (Power *et al*., 1967) [19].

LAD (days) = $[(LAI_1 + LAI_2) / 2] \times (t_2 - t_1)$; Where, LAI_1 and LAI_2 are the LAI at time t_1 and t_2 respectively.

The crop growth rate (CGR): CGR may be defined as the overall growth rate of the crop plant and it was recorded after the fixed period of time, irrespective of the previous growth rate (Leopold and Kridemann, 1975) [15].

CGR (g $m^{-2}day^{-1}$) = $(W_2 - W_1) / (t_2 - t_1)$; Where, W_2 and W_1 are the dry weight of crops (g m^{-2}) at time t_1 and t_2 respectively.

Relative growth rate (RGR): RGR is the rate of growth per unit dry matter (Leopold and Kridemann, 1975) [15].

RGR (g g^{-1} day^{-1}) = $(LnW_2 - LnW_1)/ (t_2 - t_1)$; Where, LnW_1 and LnW_2 are the natural logarithm of dry weight of plant at the time interval t_1 and t_2.

Net assimilation rate (NAR): NAR indirectly indicates the rate of net photosynthesis. It is expressed as g of dry matter produced per m^2 of leaf area in a day.

NAR (g $m^{-2}day^{-1}$) = $[(W_2 - W_1) (LN\ L_2 - LN\ L_1)] / [(t_2 - t_1) (L_2 - L_1)]$; Where, L_1 and W_1 are leaf area and dry weight of plants at time t_1, and L_2 and W_2 are leaf area and dry weight of plants at time t_2.

Agrometeorological indices and thermal utilization

Growing degree day (GDD) accumulated during different phases were computed (Nuttonson, 1955) [17].

Growing degree day (GDD) = $(T_{mean} - T_b)$

Where, T_{mean} = Daily mean temperature in °C [$(T_{max} + T_{min}) / 2$; where, T_{max} & T_{min} are maximum and minimum air temperatures respectively.]; T_b = Base temperature (5°C)

Heliothermal unit (HTU) and photothermal unit (PTU) were calculated using the formulae adopted by Kingra and Kaur (2012) [11].

Photothermal unit (PTU) = $[(T_{mean} - T_b) \times DL]$

Heliothermal unit (HTU) = $[(T_{mean} - T_b) \times BSH]$

Where, DL = Day length (Possible sunshine hours: from dawn to twilight); BSH = Bright sunshine hours (Hour)

Heat use efficiency (HUE) was obtained by using the formula adopted by Kingra and Kaur (2012) [11].

Heat use efficiency (kg/ha/°C day) = [Yield (kg/ha)] / [Accumulated heat units (°C day)]

Photothermal use efficiencies (PTUE) and heliothermal use efficiencies (HTUE) were calculated by following formulae adopted by Ghosh *et al*. (2018) [7].

Photothermal use efficiency (kg/ha/°C hour) = [Yield (kg/ha)] / [Accumulated photothermal units (°C hour)]

Heliothermal use efficiency (kg/ha/°C hour) = [Yield (kg/ha)] / [Accumulated heliothermal units (°C hour)]

Daily maximum and minimum air temperatures and bright sunshine hours values were collected from the Principal Agrometeorological Observatory which is situated beside the experimental field. Day length for the latitude of the experimental field was calculated following the table values of possible sunshine hours given by Doorenbos and Pruitt (1977) [6].

Statistical analysis

Leaf area index (LAI), leaf area duration (LAD), crop growth rate (CGR), relative growth rate (RGR) and Net assimilation rate (NAR) data from different growth stages were subjected to Fischer's protected least significant difference mean separation test at $p < 0.05$ using OP-STAT online software package. Simple correlation studies were carried out between growth parameters and air temperatures and thermal indices.

Results and discussion

Effect of sowing time on crop growth parameters

Notable variation in crop growth attributes due to change in sowing times was observed (Fig. 1). Results of significance test of growth attributes along with standard error of means and coefficient of variations have been shown (Table 1 and Table 2). Leaf area index (LAI), measured at 42 DAS was the maximum in 16th November sown crop (0.56) which was statistically at par with the crop sown on 9th November (0.45). LAI increased gradually from first sowing date to 4th sowing date and beyond that LAI started to decrease. At 63 DAT, highest and lowest values of LAI were obtained from the 16th November and 21st December sown crops respectively. The crop sown on 30th December resulted in the maximum LAI (2.09) on 84 DAT whereas 26th October sown crop produced the lowest LAI (1.72). For each treatment, LAI increased gradually from 42 DAS to 84 DAS and then it reduced due to senescence. Sowing time significantly influenced LAI of the crop which is in the agreement with the result found by Prasad *et al.*, (2012) [20] who demonstrated the variations in LAI of chickpea due to varying sowing dates. Wajid *et al.* (2004) [29] and Khan (2000) [10] also stated that LAI varied according to the sowing dates. Reduction in LAI during the final stage of crop was due to senescence (Abd El Moneim *et al*., 1990) [1].

The crop sown on 16th November showed highest values of leaf area duration (LAD) (Fig. 1) measured at 42 DAS (11.76 days), 63 DAS (15.26 days) and 84 DAS (29.12 days). Minimum LAD values, calculated at 42 DAS (5.46 days), 63 DAS (7.91 days) and 84 DAS (23.97 days) were observed in case of last sowing date (21st December). Gradual decrease in LAD was found as the sowing dates advanced after third sowing date. Rising trend in LAD with the advancement of growing period was observed irrespective of sowing dates.

CGR in S-1 stage was the highest in the crops sown on 16th November (1.35 g m^{-2} day^{-1}) (Fig. 2). During S-2 stage maximum was obtained from the crop sown on 9th November (1.95 g m^{-2} day^{-1}). In the S-3 stage 30th November sown crop resulted in the highest CGR (6.94 g m^{-2} day^{-1}) which was statistically at par with 23rd November (6.18 g m^{-2} day^{-1}), 7th December (6.11 g m^{-2} day^{-1}) and 21st December (g m^{-2} day^{-1}) sown crops. In case of delayed sowing, CGR was very low during the final growth stage as compare to the earlier stages and the reason behind it was mainly the reduction in LAI and NAR as demonstrated by Mineo and Ujihara (1991) [16]. CGR, RGR and NAR varied greatly according to the sowing dates mainly due to the reason that dry matter production during different stages of crop growth changed as the sowing time differed which was supported by the results of Kumar *et al*. (2016) [13] from an experiment conducted with wheat crop sown on different dates.

The crop sown on 16th November showed the highest relative growth rate (RGR) (0.095 g g^{-1} day^{-1}) while lowest RGR was observed in 21st December sown crop (0.075 g $g^{-1}day^{-1}$) (Fig. 2). RGR was found to increase from 26th October sown crop to 16th November sown crop and then it started to decline. RGR varied significantly during S-3 stage and crops sown on 30th November, 7th December, 14th December and 21st December were statistically at par in terms of RGR.

During S-1 stage net assimilation rate (NAR) was the highest in 14th December sown crop (2.45 g $m^{-2}day^{-1}$) closely followed by the crops sown on 30th November (2.42 g $m^{-2}day^{-1}$), 16th November (2.39 g $m^{-2}day^{-1}$) and 26th October (2.39 g $m^{-2}day^{-1}$) as shown in figure 2. Crops sown on 9th November (2.43 g $m^{-2}day^{-1}$), 21st December (3.54 g $m^{-2}day^{-1}$) and 16th November (5.62 g $m^{-2}day^{-1}$) showed highest NAR during S-2, S-3 and S-4 respectively.

Table 1: Values of critical differences (C.D.), standard error of means (S.E. m) and coefficient of variations (C.V.) for leaf area index and leaf area duration among different sowing dates.

Crop growing stage	Leaf area index			Leaf area duration		
	C.D. ($p < 0.05$)	S.E. m (±)	C.V. (%)	C.D. ($p < 0.05$)	S.E. m (±)	C.V. (%)
42 DAS	0.112	0.037	16.208	2.35	0.777	16.139
63 DAS	0.162	0.054	13.496	2.221	0.735	11.172
84 DAS	0.142	0.047	4.332	1.777	0.588	3.786
Harvest	0.084	0.028	3.729	3.31	1.095	3.618

Table 2: Values of critical differences (C.D.), standard error of means (S.E. m) and coefficient of variations (C.V.) for crop growth rate, relative growth rate and net assimilation rate duration among different sowing dates.

Crop growing stage	Crop growth rate			Relative growth rate			Net assimilation rate		
	C.D. ($p < 0.05$)	S.E. m (±)	C.V. (%)	C.D. ($p < 0.05$)	S.E. m (±)	C.V. (%)	C.D. ($p < 0.05$)	S.E. m (±)	C.V. (%)
Sowing to 42 DAS	0.344	0.114	21.213	0.009	0.003	5.748	0.157	0.052	3.859
42 DAS to 63 DAS	0.373	0.123	15.623	N/A	0.008	51.875	0.416	0.138	11.865
63 DAS to 84 DAS	0.994	0.329	9.78	0.015	0.005	16.754	0.562	0.186	10.459
84 DAS to Harvest	2.85	0.943	31.234	N/A	0.003	24.329	2.159	0.714	30.411

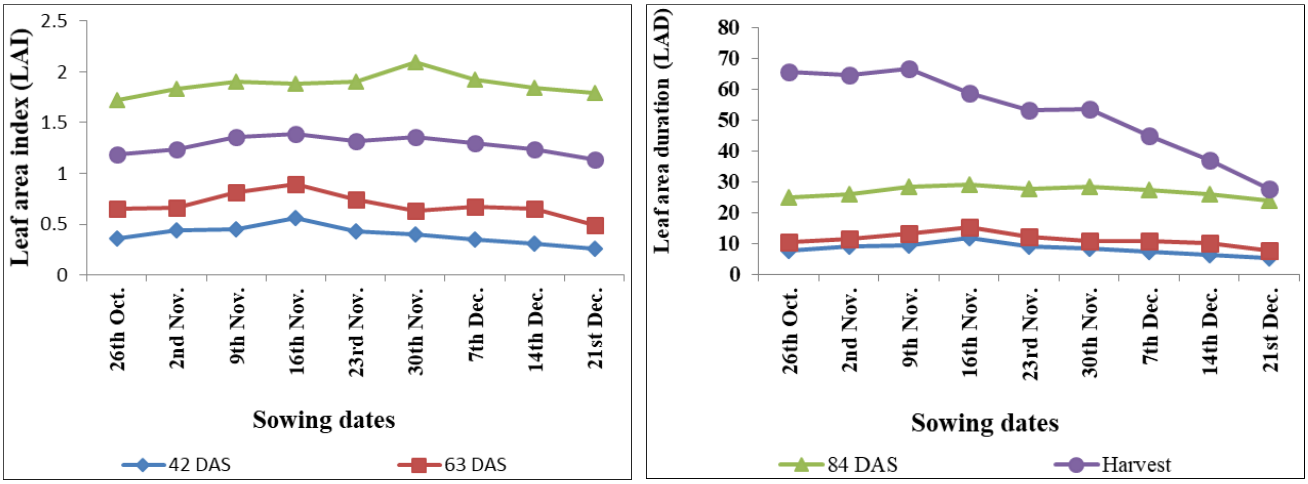
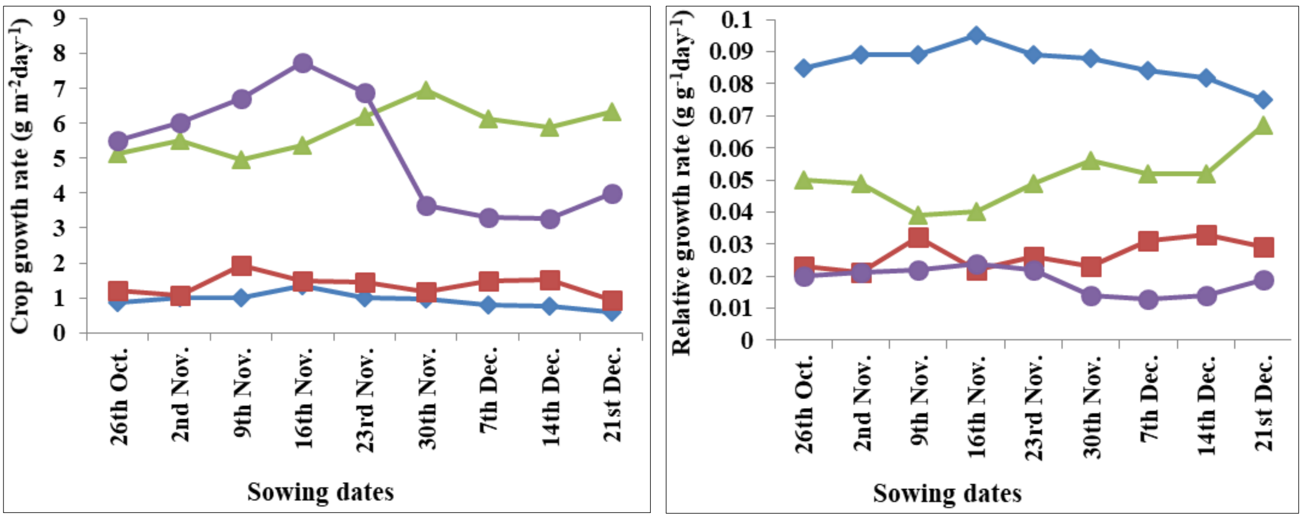


Fig 1: Variations in leaf area index (LAI) and leaf area duration (LAD) of grass pea at different growth stages due to varying sowing dates



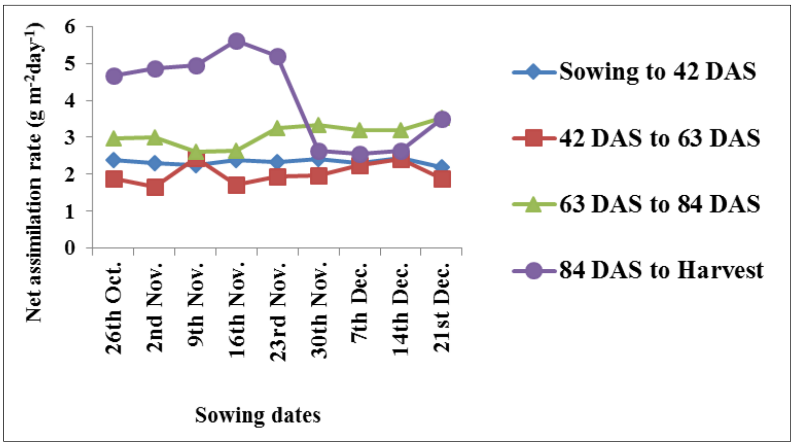


Fig 2: Variations in crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) during different growth stages of grass pea sown on different dates

Effect of sowing time on thermal utilization

Heat unit use efficiency (HUE) was the highest in the crops sown on 16th November during both S-1 stage (0.085 g/ °C day) and S-4 stage (0.404 g/ °C day) while during S-2 and S-3 stages, HUE was the maximum in 9th November sown crop (0.139 g/ °C day) and 2nd November sown crop (0.431 g/ °C day) respectively (Table 3). Heliothermal use efficiency (HTUE) in S-1 stage varied from 0.007 g/ °C hour (26th October sown crop) to 0.015 g/ °C hour (16th November sown crop). During S-2 stage lowest and highest values of HTUE were evaluated in the crops sown on 21st December (0.009 g/ °C hour) and 9th November (0.037 g/ °C hour). During S-1 and S-4 stages, Photothermal use efficiencies (PTUE) started to increase from the first sowing date and reached to its highest values in 16th November sown crop (S-1: 0.008 g/ °C hour; S-4: 0.035 g/ °C hour). During S-2 stage, 9th November sown crop showed maximum PTUE (0.013 g/ °C hour) while 2nd November sown crop resulted in highest PTUE (0.040 g/ °C hour) during S-3 stage. It was clear from the result that as the sowing was delayed; efficiency of the crops to use thermal units was reduced to a greater extent. Variation in thermal use efficiencies as affected by varying sowing time was documented earlier in finger millet (Revathi and Rekha, 2017) [22]. Heat use efficiency was found to be higher for earlier sown crop and it decreased with delay in sowing which was also demonstrated by Kingra and Kaur (2012) [11]. Reduction of HUE in delayed sowing was mentioned by Akhter *et al.* (2015) [2]. HUE increased during the first three stages of crop growth but during the final stage HUE reduced in most cases which are in conformity with the result observed in mustard (Singh *et al.*, 2014) [25]. Thermal utilization was influenced by varying sowing dates and this is in agreement with result found by Rao *et al.* (1999) [21]. Thermal use efficiencies varied as the crop advanced which was confirmed by Tzudir *et al.* (2014) [28].

Table 3: Effect of sowing times on the thermal utilization of grass pea during different growth stages

Sowing dates	Sowing to 42 DAS	42DAS to 63 DAS	63 DAS to 84 DAS	84 DAS to harvest
Heat unit use efficiency (g/ °C day)				
26th October	0.046	0.085	0.394	0.327
2nd November	0.057	0.077	0.431	0.337
9th November	0.061	0.139	0.371	0.361
16th November	0.085	0.117	0.367	0.404
23rd November	0.066	0.114	0.390	0.346
30th November	0.067	0.089	0.401	0.179
7th December	0.059	0.102	0.330	0.154
14th December	0.056	0.097	0.295	0.147
21st December	0.042	0.053	0.321	0.169
Heliothermal use efficiency (g/ °C hour)				
26th October	0.007	0.017	0.070	0.047
2nd November	0.008	0.020	0.062	0.050
9th November	0.009	0.037	0.052	0.055
16th November	0.015	0.021	0.051	0.061
23rd November	0.013	0.016	0.058	0.050
30th November	0.012	0.012	0.070	0.023
7th December	0.011	0.014	0.052	0.021
14th December	0.011	0.014	0.043	0.020
21st December	0.008	0.009	0.044	0.021
Photothermal use efficiency (g/ °C hour)				
26th October	0.004	0.008	0.037	0.029
2nd November	0.005	0.007	0.040	0.030
9th November	0.006	0.013	0.034	0.032
16th November	0.008	0.011	0.034	0.035
23rd November	0.006	0.011	0.035	0.030
30th November	0.006	0.008	0.036	0.015
7th December	0.006	0.009	0.029	0.013
14th December	0.005	0.009	0.026	0.012
21st December	0.004	0.005	0.028	0.014

Effect of thermal indices and temperature on crop growth

Heat units (AGDD) accumulated during S-1 stage positively affected each and every growth parameters as shown by the values of correlation coefficients (r) (Table 4). CGR, RGR and NAR during S-3 stage were positively correlated by AGDD (CGR: 0.70*; RGR: 0.68* and NAR: 0.74*). LAI was adversely affected by APTU during S-2 stage. LAD was negatively correlated with AHTU and APTU during S-2 (AHTU: -0.20; APTU: -0.80**), S-3 (AHTU: -0.95**; APTU: -0.27) stages and positively correlated during S-4 (AHTU: 0.96**; APTU: 0.99**) stages. AHTU during S-2 and S-4 stages had positive impact on CGR (0.74*) and NAR (0.75*). On the other hand APTU showed significant positive association with CGR (0.70*), RGR (0.70*) and NAR (0.74*) during S-3 stage.

Maximum and average temperatures during S-2 stage exhibited significant negative correlations (T_{max}: -0.78*; T_{mean}: -0.73*) with LAI. Very high significant negative correlations were observed between LAD and maximum, minimum and average temperatures during S-4 stage (Tmax: -0.96**; Tmin: -0.97**; Tmean: -0.97**). During S-3 stage, air temperatures had positive effects on CGR (Tmax: 0.70*; Tmin: 0.70*; Tmean: 0.70*), RGR (Tmax: 0.62; Tmin: 0.73*; Tmean: 0.68*) and NAR (Tmax: 0.69*; Tmin: 0.77*; Tmean: 0.74*). During the first stage of growth (S-1) diurnal temperature difference adversely affect all the growth parameters. LAI was positively correlated with maximum and minimum temperature during early growth stage (Kumar *et al.*, 2015) [14]. With the delay in planting date, the higher mean temperature was experienced during flowering which led to accelerate the decrease of LAI (Poureisa *et al.*, 2007 and Tripathi *et al.*, 2005) [18, 27].

Table 4: Correlation coefficients (r) between accumulated agrometeorological indices and temperatures and the growth parameters of grass pea during different stages

Stages of growth	Leaf rea index (LAI)	Leaf rea duration (LAD)	Crop growth rate (CGR)	Relative growth rate (RGR)	Net assimilation rate (NAR)
Accumulated growing degree days (°C day)					
Sowing to 42 DAS	0.42	0.42	0.4	0.44	0.04
42DAS to 63 DAS	-0.73*	-0.79*	-0.35	0.54	0.25
63 DAS to 84 DAS	0.2	-0.25	0.70*	0.68*	0.74*
84 DAS to harvest	0.4	0.99**	0.67*	0.52	0.65
Accumulated heliothermal units (°C hour)					
Sowing to 42 DAS	0.28	0.34	0.06	-0.46	-0.3
42DAS to 63 DAS	0.22	-0.2	0.74*	0.65	0.75*
63 DAS to 84 DAS	-0.27	-0.95**	-0.51	-0.38	-0.52
84 DAS to harvest	0.35	0.96**	0.47	0.31	0.45
Accumulated photothermal units (°C hour)					
Sowing to 42 DAS	0.39	0.39	0.37	0.4	0.04
42DAS to 63 DAS	-0.74*	-0.80**	-0.36	0.56	0.26
63 DAS to 84 DAS	0.18	-0.27	0.70*	0.70*	0.74*
84 DAS to harvest	0.45	0.99**	0.66	0.49	0.63
Maximum temperature (°C)					
Sowing to 42 DAS	0.44	0.44	0.41	0.44	-0.01
42DAS to 63 DAS	-0.78*	-0.86**	-0.37	0.58	0.31
63 DAS to 84 DAS	0.25	-0.16	0.70*	0.62	0.69*
84 DAS to harvest	-0.22	-0.96**	-0.63	-0.52	-0.65
Minimum temperature (°C)					
Sowing to 42 DAS	0.4	0.4	0.38	0.43	0.08
42DAS to 63 DAS	-0.55	-0.59	-0.27	0.4	0.15
63 DAS to 84 DAS	0.14	-0.32	0.70*	0.73*	0.77*
84 DAS to harvest	-0.28	-0.97**	-0.66	-0.54	-0.67*
Average temperature (°C)					
Sowing to 42 DAS	0.42	0.42	0.4	0.44	0.04
42DAS to 63 DAS	-0.73*	-0.79*	-0.35	0.54	0.25
63 DAS to 84 DAS	0.2	-0.25	0.70*	0.68*	0.74*
84 DAS to harvest	-0.26	-0.97**	-0.65	-0.53	-0.67*
Diurnal temperature difference (°C)					
Sowing to 42 DAS	-0.28	-0.28	-0.29	-0.37	-0.24
42DAS to 63 DAS	-0.36	-0.4	-0.17	0.28	0.22
63 DAS to 84 DAS	0.4	0.76*	-0.24	-0.69*	-0.6
84 DAS to harvest	0.34	0.96**	0.67*	0.54	0.67*

* = Significance of r ≥ 0.67 at 5% and ** = Significance of r ≥ 0.80 at 1%

Conclusions

Crop growth was observed to be greatly affected by sowing time. Air temperatures and accumulated thermal units during different growth stages played vital role in crop growth. It was further clear from the results that temperature and thermal unit differently influence crop growth parameters in different stages of growth. Thermal use efficiency of the crop varied as the sowing time changed. Considerable variations were also noticed in thermal use efficiencies as the crop growing stages differed. From the present study, it may be concluded that growth of grass pea greatly depends on the growing season temperature and thermal conditions.

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