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631.15 (540.35)

Thermal indices in relation to crop phenology and seed yield of pigeon pea (*Cajanus cajan* L. Millsp.) grown in the north bank plains zone of Assam

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सार – इस शोध पत्र में 2012-13 से 2013-2014 के दो क्रमिक खरीफ ऋतुओं में बी. एन. कृषि कॉलेज, ए ए यू के AICRPDA अनुसंधान फार्म के बलुई दुमट मिट्टी में अरहर की दो किस्में - BC (local) और ICPL 88039 बोई गईं। दोनों किस्में 3 जून से लेकर 23 जून तक दस दिनों के अंतराल में तीन अलग-अलग तारीखों को बोई गई। विभिन्न ऋतुजैविक घटनाओं अर्थात् आविर्भाव, पहली पुष्प कली का आना और पुष्प दिखना, 50 प्रतिशत पुष्प आना, पहली फली बनना, पहला बीज निरूपण और ऋतुजैविक परिपक्वता को प्राप्त करने के लिए GDD एक्यूमेलेशन तैयार किए गए। ऋतुजैविक परिपक्वता तक संचयी GDD एक्यूमेलेशन BC (local) में अपेक्षाकृत अधिक थे जो 3395.6 से 3593.S °C प्रतिदिन भिन्न थे जबकि ICPL 88039 में भिन्नता बुआई और ऋतुओं में प्रतिदिन 2945.0 से 3296.7 °C तक की भिन्नता थी। दो ऋतुओं में दोनों किस्मों में बुवाई की क्रमिक देरी सहित किसी ऋतुजैविक घटना को प्राप्त करने के लिए संचयी GDD में कमी की प्रवृत्ति देखी गई। फसल की दोनों ऋतुओं में फेनों थर्मल इंडेक्स (PTI) सभी बुवाई की तारीखों में वनस्पति वृद्धि अवधि के दौरान BC (local) में 16.67 से लेकर 18.18 °C दिवस वृद्धि दिवस $^{-1}$ और ICPL 88039 में 18.31 से लेकर 19.11 °C दिवस वृद्धि दिवस $^{-1}$ तक की भिन्नता रही जबकि पुर्नउत्पादित वृद्धि अवस्था में ये अपेक्षाकृत कम थे और BC (local) में 7.96 से लेकर 8.23 °C दिवस वृद्धि दिवस $^{-1}$ तक और ICPL 88039 में 10.28 से लेकर 11.87 °C दिवस वृद्धि दिवस $^{-1}$ रही। दोनों फसल ऋतुओं में अलग-अलग बुवाई के तहत BC (local) में बीज उपज ऊष्मा उपयोग क्षमता (HUE) में 0.207 से 0.296 kg ha^{-1} °C दिवस $^{-1}$ की भिन्नता रही जबकि ICPL 88039 में 8.201 से 0.312 kg ha^{-1} °C दिवस$^{-1}$ की भिन्नता रही। दोनों खेतियों में बीज उपज उष्मा उपयोग क्षमता 2012-13 के बाद 2013-14 में अपेक्षाकृत अधिक थी जिससे यह पता चलता है कि पौधों के लिए उपलब्ध उष्मा के उपयोग में उल्लेखनीय भिन्नता थी।

ABSTRACT. Two varieties of pigeon pea *viz.*, BC (local) and ICPL 88039 were grown on the sandy loam soils of AICRPDA research farm of B. N. College of Agriculture, AAU in two consecutive *kharif* seasons of 2012-13 to 2013-14. Both the cultivars were sown on three different dates at ten days interval starting from 3rd June to 23rd June. GDD accumulation for attaining different phenological events *viz.*, emergence, initiation of 1st flower bud and flower appearance, 50 per cent flowering, 1st pod formation, 1st seed formation and physiological maturity were worked out. The cumulative GDD accumulations up to physiological maturity were relatively higher in BC (local) which varied from 3395.6 to 3593.5 °C day, whereas, in ICPL 88039, it varied from 2945.0 to 3296.7 °C day in different sowings and seasons. A decreasing trend in accumulated GDD for attaining any Phenological event was observed with successive delay in sowings in both the cultivars in the two seasons. In both the crop seasons, Pheno-Thermal Index (PTI) varied from 16.67 to 18.18 °C day growth day^{-1}, in BC (local) and 18.31 to 19.11 °C day growthday^{-1} in ICPL 88039 during the vegetative growth period under all the sowing dates while, in the reproductive growth stage, it was comparatively lower and ranged from 7.96 to 8.23 °C day growthday^{-1} in BC (local) and 10.28 to 11.87 °C day growthday^{-1} in ICPL 88039. Seed yield heat use efficiency (HUE) in BC (local) varied from 0.207 to 0.296 kg ha^{-1} °Cday^{-1}, whereas, in ICPL 88039 it varied from 0.201 to 0.312 kg ha^{-1}°Cday^{-1} under different sowing dates in both crop seasons. Seed yield heat use efficiency was relatively higher in 2013-14 followed by 2012-13 in both the cultivars which indicated the significant differences in using the heat, available to the plants.

Key words – Pigeon pea, BC (local), ICPL 88039, GDD, Heat use efficiency, Phenothermal index.

1. Introduction

Pigeon pea (*Cajanus cajan* L. Millsp.) is one of the most important tropical legumes in the world. It is a crop of vital importance in tropical countries, especially in India, where it is used as major source of protein in human diets. India alone accounts for about 81 per cent of total world's production and 90 per cent of total world's consumption. Pigeonpea, as other legumes, helps in restoring and maintaining soil fertility through fixing atmospheric nitrogen through the Rhizobium bacteria present in the root nodules. It is also cultivated in Australia, USA, Africa, Indonesia and some countries in South America because of its nutritional qualities and drought tolerance (Faris, 1983). *Cajanus cajan* is very heat-tolerant, deep rooted and most drought tolerant legume crops, with a wide range of rainfall tolerance, but prefers more than 625 mm, because of its longer duration of growth. The optimum range of temperature for proper growth and development of pigeon pea is 18 - 38 °C (Van der Maesen, 1989). Whereas, in the controlled environmental studies, Pigeonpea showed that warm (>28 °C) and cool (<20 °C) temperatures delay flower initiation and that the optimal temperature for flowering for early maturing type is close to 24 °C (Turnbull *et al.*, 1981). The duration of particular stage of growth is directly related to temperature and this duration for particular species could be predicted using the mean sum of daily air temperatures. Phenology is the study of timing of occurrence of biological events of growth, especially in relation to climatic conditions and is an essential component of crop growth modelling, which can be used to specify the most appropriate rate and time of occurrence of specific developmental processes. To forecast the phenology and crop production attributes for large areas, there is need to develop crop models using information derived from variety specific characteristics (Doraiswamy and Thompson, 1982). The heat unit system was adopted for determining the occurrence of Phenological stages and maturity dates of different crops. Influence of temperature on phenology and yield of crop plants can be studied under field condition through accumulated heat units system, the Growing Degree Days (Chakrabarty and Sastry, 1983 and Bishnoi *et al.*, 1995). In present investigation an attempt has been made to study how the thermal parameters are related variedly, to growth and development in respect of two varieties of Pigeon pea (*Cajanus cajan)* grown in the North Bank Plain Zone of Assam.

2. Data and methodology

The experiment was conducted in two *Kharif* seasons (2012-13 and 2013-14) on the sandy loam soils of AICRP for Dryland Agriculture research farm of B. N. College of Agriculture, Assam Agricultural University, Biswanath Chariali, Assam, represented by latitude, longitude and altitude of 26°42′ N, 93°15′ E and 104 m AMSL respectively. Two cultivars of pigeon pea *viz.*, BC (local) and ICPL 88039 having long and medium duration respectively were sown on three different dates at an interval of ten days starting from 3rd June to 23rd June to enable the crop to get exposed to different thermal conditions during its various phenological stages. The crop was grown under *rainfed* condition in both the seasons and recommended agronomic practices were followed for both the cultivars. The experiment was laid out in a randomized block design with three replications. Based on visual observations, different phenological events *viz.* (a) emergence, (b) initiation of 1st flower bud and flower appearance, (c) 50 per cent flowering, (d) 1st pod formation, (e) 1st seed formation and (f) physiological maturity were identified following Gowda *et al*. (2013). Daily data on meteorological parameters were collected from agrometeorological observatory, B. N. College of Agriculture (AAU) located near the experimental field. The thermal time or GDD requirement was computed by taking a base temperature of 10 °C (Nihalani, 1989). The total sum of degree days for each phenophase was obtained by using the following formula:

$$\text{Accumulated GDD} = \Sigma[(T_{max} + T_{min})/2] - T_b$$

where, T_{max} = daily maximum temperature (°C)

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

T_b = base temperature = 10 °C

Phenothermal index (PTI) expressed as degree days per growth days for vegetative stage (sowing to flower bud initiation) and reproductive stage (flower bud initiation to physiological maturity) of the crop were calculated following Neog and Chakravarty (2005b) as follows:

$$\text{PTI} = \frac{\text{Accumulated GDD for attain the physiological stage } (°\text{C})}{\text{Number of days taken (days)}}$$

Heat use efficiency (HUE) defined as the biomass accumulated during the given period per degree-day (Kar and Chakravarty, 1999; Neog and Chakravarty, 2005b) was also computed to compare the relative performance of Pigeon pea varieties under various treatments using the formula (Sastry *et al*., 1985; Saha and Ghosh 2012):

$$\text{HUE} = \frac{\text{Seed or total dry matter yield (kg/ha)}}{\text{Growing degree days taken } (°\text{C days})}$$

Five plants from each treatment were selected and tagged for periodic phonological observations. Whenever more than three plants from each treatment attained a particular stage, the date was considered as the one for attainment of that stage. The phenophase stages identified by Nihalani (1989) were adopted.

TABLE 1

Number of days taken to attain different phenological events of cultivars BC (Local) and ICPL 88039 during *Kharif 2012*-13 and 2013-14

Phenological events	Year	Sowing dates D_1	Sowing dates D_2	Sowing dates D_3	Mean
BC (Local)					
Sowing to emergence	2012-13	8	8	7	8
	2013-14	7	6	5	6
Sowing to flower bud initiation	2012-13	163	161	157	160
	2013-14	156	148	152	152
Flower bud initiation to 1st pod initiation	2012-13	24	26	27	26
	2013-14	22	23	25	23
Flower bud initiation to 50% flowering	2012-13	21	24	23	23
	2013-14	18	19	21	19
1st pod initiation to 1st seed formation	2012-13	4	4	4	4
	2013-14	3	3	3	3
Flower bud initiation to physiological maturity	2012-13	87	90	95	91
	2013-14	92	95	98	95
Sowing to physiological maturity	2012-13	250	251	252	251
	2013-14	248	249	250	249
ICPL 88039					
Sowing to emergence	2012-13	5	6	5	5
	2013-14	4	5	4	4
Sowing to flower bud initiation	2012-13	120	114	112	115
	2013-14	116	110	109	112
Flower bud initiation to 1st pod initiation	2012-13	23	26	25	25
	2013-14	21	22	24	22
Flower bud initiation to 50% flowering	2012-13	20	24	23	22
	2013-14	17	18	21	19
1st pod initiation to 1st seed formation	2012-13	4	4	4	4
	2013-14	3	3	3	3
Flower bud initiation to physiological maturity	2012-13	94	94	87	92
	2013-14	91	91	87	90
Sowing to physiological maturity	2012-13	214	208	199	207
	2013-14	207	201	196	201

3. Results and discussion

3.1. *Weather variables*

The second crop season (2013-14) was relatively warmer and dry. The ranges of daily maximum temperature in both the crop seasons were 20.0 to 36.5 °C and 17.4 to 36.5 °C respectively. The daily minimum temperature was higher in the first crop season (5.7 to 28.5 °C) as compared to the second season (5.4 to 28.0 °C). During the first crop season total rainfall was 1520.7 mm, whereas, in the second crop season it was 1202.6 mm. Days to attain maturity in general were shortened as the sowing was delayed in both the cultivars and seasons, which might be due to exposure of the reproductive stages of late sown crops to increasing ambient temperature and decreasing moisture availability. These results were supported by the findings of Singh *et al*., 2004 and Khushu *et al*., 2008.

3.2. *Thermal time and crop phenology*

It was observed that number of days taken to attain any phenological event varied with cultivars, sowing dates

TABLE 2

Accumulated GDD (°C day) in cultivars BC (Local) and ICPL 88039 under different sowings during *Kharif* 2012-13 and 2013-14

Phenological events	Year	Sowing dates			Mean
		D_1	D_2	D_3	
BC (Local)					
Sowing to emergence	2012-13	139.1	141.9	114.4	131.8
	2013-14	129.6	118.9	95.1	114.5
Sowing to flower bud initiation	2012-13	2817.2	2727.0	2617.5	2720.6
	2013-14	2836.3	2730.5	2606.9	2724.6
Flower bud initiation to 1st pod initiation	2012-13	248.0	253.3	233.4	244.9
	2013-14	219.2	228.4	243.8	230.5
Flower bud initiation to 50% flowering	2012-13	218.4	238.2	205.4	220.7
	2013-14	182.0	187.5	213.0	194.2
1st pod initiation to 1st seed formation	2012-13	41.0	29.8	24.5	31.8
	2013-14	33.8	29.9	14.4	26.0
Flower bud initiation to physiological maturity	2012-13	692.9	722.4	780.8	732.0
	2013-14	757.2	759.2	788.7	768.4
Sowing to physiological maturity	2012-13	3510.1	3449.4	3398.3	3452.6
	2013-14	3593.5	3489.7	3395.6	3492.9
ICPL 88039					
Sowing to emergence	2012-13	78.8	102.8	80.5	87.4
	2013-14	72.4	103.7	76.8	84.3
Sowing to flower bud initiation	2012-13	2209.9	2099.7	2050.8	2120.1
	2013-14	2216.7	2093.8	2042.9	2117.8
Flower bud initiation to 1st pod initiation	2012-13	358.0	389.4	344.3	363.9
	2013-14	355.3	364.5	367.5	362.4
Flower bud initiation to 50% flowering	2012-13	315.2	363.6	319.8	332.9
	2013-14	284.5	303	330.4	306.0
1st pod initiation to 1st seed formation	2012-13	55.3	49.7	48.8	51.3
	2013-14	50.3	45.8	34.2	43.4
Flower bud initiation to physiological maturity	2012-13	1053.4	1018.7	894.2	988.8
	2013-14	1080.0	1034.1	916.3	1010.1
Sowing to physiological maturity	2012-13	3263.3	3118.4	2945.0	3108.9
	2013-14	3296.7	3127.9	2959.2	3127.9

and crop seasons (Table 1). It was observed that the long duration cultivar BC (local) matured between 250 to 252 days in different sowings in the first season while it took 248 to 250 days to mature in the second season. On the contrary, medium duration cultivar ICPL 88039 matured between 199 to 214 days in different sowings in the first crop season while the duration ranged between 196 to 207 days in the second season. The crop matured early during the second season in both the cultivars irrespective of sowing dates. Relatively high daily maximum and minimum temperatures coupled with less rainfall during second crop season lead to shortening of crop growth period in that season, especially at pod development and maturity stage. In case of BC (local), during the first crop season, more number of days was required to attain emergence (1-2 days), initiation of first flower bud (5-7 days), flower bud initiation to 50% flowering (2-4 days), first pod initiation to first seed formation (1 day), flower bud initiation to physiological maturity (3- days) and for physiological maturity (2 days) as compared to the second crop season. The medium duration variety, ICPL 88039, also showed the similar trend. The growth period was gradually reduced in both the cultivars in both the crop seasons as the sowing was

TABLE 3

Seed Yield HUE (kgha^{-1} °Cday^{-1}) in BC (Local) and ICPL 88039 under different sowings during *Kharif* 2012-13 and 2013-14

Date of sowing	Seed Yield HUE (kg ha^{-1} °C day^{-1})			
	BC (Local)		ICPL 88039	
	2012-13	2013-14	2012-13	2013-14
3rd June	0.207	0.224	0.201	0.231
13th June	0.284	0.296	0.273	0.312
23rd June	0.263	0.281	0.270	0.307
Mean	0.251	0.267	0.248	0.283

delayed. This reduction in growth period under late sowing condition might be attributed to prevalence of high temperature and less rainfall. A similar reduction in crop duration of up to 30 days due to delayed sowing from onset of monsoon to delay in 10 days interval in a sandy loam soil under rainfed condition in Gujrat was reported by Patel *et al.* (1999). Similar findings were also reported by Carberry *et al.* (2001) and Kumar *et al.* (2008).

3.3. *Growing degree days*

The thermal time expressed in terms of growing degree days (GDD) required for attaining maturity varied considerably across the two varieties, under different sowing dates. In case of BC (local), the degree day accumulation from sowing to physiological maturity were found to be relatively higher and varied from 3395.6 to 3593.5 °C day in the second crop season and 3398.3 to 3510.1 °C day in the first crop season (Table 2). In ICPL 88039, GDD were found to be relatively higher in the second crop season (2959.2 to 3296.7 °C day) than the first crop season (2945.0 to 3263.3 °C day). However, in both the years, the relative heat units recorded by ICPL 88039 were lower than those recorded under BC (Local). These differences could probably be due to relatively longer duration of BC local variety of pigeon pea and high temperatures in the second crop season. However, the differences in GDD accumulation during flower bud initiation to maturity were found to be marginal in case of the crop sown on the same date in different seasons. A decreasing trend in accumulated GDD for attaining all Phenological stages was observed to increase with successive delay (2959.2 to 3296.7 °C day) in sowings in both the cultivars and in both the seasons. Crop sown on early dates accumulated higher degree-days quicker in shorter time due to relatively higher ambient temperatures coupled with longer sunshine hours. These results are supported by the findings of Neog and Chakravarty (2005a) and Singh *et al.*, 2004 in rapeseed and mustard crop. Thus thermal requirement for attaining any phenological event in pigeon pea crop, varied between the cultivars and its accumulation decreased gradually as sowing was delayed. Among the planting dates, first sowing (1st fortnight of June) accumulated more GDD to attain various phenophases, *i.e.*, sowing to emergence, sowing to flower bud initiation, flower bud initiation to 1st pod initiation, flower bud initiation to 50% flowering, 1st pod initiation to 1st seed formation, flower bud initiation to physiological maturity and sowing to physiological maturity as compared to subsequent sowing dates. This may be due to delayed attainment of various phenophases in early sown pigeon pea as compared to later planting dates due to favourable environment prevailing during the crop growing period, especially temperature and better rainfall. Similar decreasing trend in accumulated GDD with delayed sowing was observed by Ranganathan *et al.* (2001) and Kumar *et al.* (2008).

3.4. *Heat use efficiency*

Seed yield heat use efficiency (HUE) in BC (local) varied from 0.207 to 0.296 kgha^{-1} °C day^{-1}, whereas, in ICPL 88039 it varied from 0.201 to 0.312 kgha^{-1}°Cday^{-1} under different sowing dates in the two cropping seasons (Table 3). The values of HUE were comparatively higher in second crop season than the first crop season in all sowings in both the cultivars which can be attributed to the relatively higher seed yield production in second crop season probably due to prevailing congenial weather conditions during second crop season. Therefore, these indices can be used to assess seed yield as well as total dry matter in relative terms. The HUE is an analogy of water use efficiency (WUE) in the sense that the HUE gives us an idea about the heat utilized to produce one unit of biomass where as the WUE denotes water utilized to produce one unit of biomass. From the Table 3, it is evident that the HUE was more in the plants of second and third sowing indicating the higher HUE to produce a unit of biomass under delayed sowings. This sort of relative assessment could be used to decide the optimum dates of

TABLE 4

Phenothermal Index (°C day growthday^{-1}) in cultivars BC (Local) and ICPL 88039 under different sowings during *Kharif* 2012-13 and 2013-14

Phenological events	Year	Sowing dates			Mean
		D_1	D_2	D_3	
BC (Local)					
Sowing to emergence	2012-13	17.39	17.74	16.34	17.16
	2013-14	18.51	19.82	19.02	19.12
Sowing to flower bud initiation	2012-13	17.28	16.94	16.67	16.96
	2013-14	18.18	17.73	17.15	17.69
Flower bud initiation to 1st pod initiation	2012-13	10.33	9.74	8.64	9.57
	2013-14	9.96	9.93	9.75	9.88
Flower bud initiation to 50% flowering	2012-13	10.40	9.93	8.93	9.75
	2013-14	10.11	9.87	10.14	10.04
1st pod initiation to 1st seed formation	2012-13	10.25	7.45	6.13	7.94
	2013-14	11.27	9.97	4.80	8.68
Flower bud initiation to physiological maturity	2012-13	7.96	8.03	8.22	8.07
	2013-14	8.23	7.99	8.05	8.09
Sowing to physiological maturity	2012-13	14.04	13.74	13.49	13.76
	2013-14	14.49	14.01	13.58	14.03
ICPL 88039					
Sowing to emergence	2012-13	15.76	17.13	16.10	16.33
	2013-14	18.10	20.74	19.20	19.35
Sowing to flower bud initiation	2012-13	18.42	18.42	18.31	18.38
	2013-14	19.11	19.03	18.74	18.96
Flower bud initiation to 1st pod initiation	2012-13	15.57	14.98	13.77	14.77
	2013-14	16.92	16.57	15.31	16.27
Flower bud initiation to 50% flowering	2012-13	15.76	15.15	13.90	14.94
	2013-14	16.74	16.83	15.73	16.43
1st pod initiation to 1st seed formation	2012-13	13.83	12.43	12.20	12.82
	2013-14	16.77	15.27	11.40	14.48
Flower bud initiation to physiological maturity	2012-13	11.21	10.84	10.28	10.77
	2013-14	11.87	11.36	10.53	11.25
Sowing to physiological maturity	2012-13	15.25	14.99	14.80	15.01
	2013-14	15.93	15.56	15.10	15.53

sowing based on thermal regimes in any given locality depending upon the thermal time (Khan *et al*., 2010; Saha and Ghosh, 2012). Heat use efficiency increased with the delay in sowing for all the treatment combinations. The results corroborate the findings of Balakrishnan and Natarajaratanam (1981).

3.5. *Phenothermal index*

The Phenothermal index gives us an idea about the rate of development and completion of the various phenological events with reference to the thermal time, which will eventually help in evaluating the relative performance of different varieties. The PTI was comparatively more during the second crop season than the first crop season in both the cultivars (Table 4). In the two crop seasons, Phenothermal index (PTI) varied from 16.67 to 18.18 °C day growthday^{-1} in BC (local) and 18.31 to 19.11 °C day growthday^{-1} in ICPL 88039 during the vegetative growth period while, in the reproductive growth stage, it was comparatively lower and ranged from 7.96 to 8.23 °C day growthday^{-1} in BC (local) and 10.28 to 11.87 °C day growthday^{-1} in ICPL 88039 (Table 5). The prevailing high day and night temperatures during

TABLE 5

Seed Yield (Qha^{-1}) in BC (Local) and ICPL 88039 under different sowings during *Kharif* 2012-13 and 2013-14

Date of Sowing	Seed Yield (Qha^{-1})			
	BC (Local)		ICPL 88039	
	2012-13	2013-14	2012-13	2013-14
3rd June	7.3	7.9	6.6	7.4
13th June	9.8	10.1	8.5	9.5
23rd June	8.9	9.4	8.0	8.8
Mean	8.7	9.1	7.7	8.6

vegetative growth stages of plants resulted in higher PTI. The PTI during vegetative stage of both the cultivars was more variable than reproductive stage, which might be attributed to higher sensitivity of the vegetative growth period of both the cultivars to the prevailing weather conditions.

3.6. *Seed yield*

The seed yield (Q/ha) was maximum in the second season as compared to first season irrespective of the cultivars and date of sowings. The seed yield was maximum in BC (local) as compared to ICPL 88039 resulting in higher HUE. Lower HUE in the crops sown in late conditions was reflected by lower seed yield in these sowings.

4. Conclusions

Thus, it can be concluded that both the phenothermal and heat use efficiency indices can be used to assess the crop performance in assessing the suitability of the variety to a particular locality depending on the thermal environment and will be a useful input in crop modeling of Pigeon pea crop.

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