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Seasonal Variation in Photosynthetically Active Radiation Interception and Radiation Use Efficiency in Green Gram [*Vigna radiata* (L.)Wilczek] in Lower Gangetic Plain of India

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Authors' contributions

This work was carried out in collaboration among all authors. Author SB performed the field data recording, statistical analysis, wrote the protocol and first draft of the manuscript. Authors PKC and RN managed the analyses of the study, field data observation and preparation of final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The present study was conducted for identifying sowing windows and cultivars of green gram in spring – summer and rainy seasons depending on light interception pattern and photo synthetically active radiation use efficiency (PARUE) in the lower Gangetic Plains of Eastern India.
Methodology: Five green gram varieties (V_1, V_2, V_3, V_4 and V_5) were sown on four dates (D_1, D_2, D_3 and D_4) in the spring –summer season starting from 15th February and on three dates (D_1, D_2 and D_3) in the rainy season, starting from 20th August at interval of 10 days. Cumulative intercepted PAR (CIPAR), PARUE for above ground biomass and green gram seed and the seed yield were measured. The experiments were conducted under strip –plot design.

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Results: Results showed that CIPAR increased gradually in both the seasons under different dates of sowing. The mean PARUE for above ground biomass were 3.97, 4.58, 3.18 and 2.64 gMJ^{-1} for D_1, D_2, D_3 and D_4 sowings during spring – summer season. In rainy season the same was declined from 8.67 to 3.73 g MJ^{-1} with the delay in sowing. Maximum seed yield was obtained under D_2 and V_3 in the spring –summer and under D_1 and V_5 in the rainy season. The mean PARUE for seed yield were 0.65 and 0.64 g MJ^{-1} and 0.40 and 0.42 g MJ^{-1} in the spring summer seasons of 2011 and 2012 respectively. In the rainy season the maximum PARUE were 0.91 and 0.55 g MJ^{-1} under D_1 for two experimental years.
Conclusion: Depending on PARUE *Pant Mung – 5* and *Meha*should be sown during 3rd week of February and August in this zone.

Keywords: Above ground biomass; intercepted PAR; green gram; PAR use efficiency; seed yield.

1. INTRODUCTION

Green gram is grown both in spring-summer (February to April) and rainy (June to September) seasons, in the lower Gangetic Plains of Eastern India, although farmers in this region prefer to grow the crop in spring – summer season. In the rainy season, medium or upland is used for cultivation of the crop as it cannot tolerate water stagnation and high soil moisture. Out of total area of 8684113 ha of cultivable land in West Bengal, the area of current fallow land during 2016 – 17, was 312802 ha. The area of green gram during rainy season was 1238 ha during 2016 – 17 [1]. The remaining upland is either used for some marginal crops like cowpea or remains as fallow during rainy season. The crop matures within 65 – 70 days during spring-summer and 75-85 days during rainy seasons respectively [2]. Temperature and light are the principal weather variables which affect the growth and yield of the crop. The air temperature i.e ambient temperature affects the growth [3], pollen germination and pollen tube growth [4] and yield of the crop [5,6]. It was observed that early sowing of green gram produced 1375 Kg ha^{-1} in spring-summer season [7]. When the crop was sown during third week of July in the rainy season the maximum seed yield was 1259.26 kg ha^{-1} [8]. In West Bengal, green gram yield varied from 869.90 to 983.28 kg ha^{-1} in spring-summer season [9]. Generally, the yield of green gram varied from 533 - 715 kg ha^{-1} during the period from 2001 – 02 to 2011 – 12 during the spring-summer season [10]. So far green gram yield has not increased inspite of introducing new varieties or improved cultivation techniques. Therefore, increasing the yield of this crop is a challenging task for the researchers. India produces 25% of the total world production and consumes 27% of the total pulses of the world. The domestic production is less than the estimated demand of 23 – 24 million tonnes which forces an import of 5 million tonnes [11]. The chief import sources of green gram are Myanmar, Kenya, Australia, Tanzania and Uzbekistan [11]. Green gram is a C_3 crop as it converts CO_2 into glucose following C_3 – cycle and has a low yielding potentiality because of its inability to re-fix CO_2 emanated from photorespiration like C_4 crops. Dry matter accumulation is regulated by photosynthetically active radiation interception in cereals [12,13], in cow-pea [14], in summer soybean [15], in groundnut [16] and in wheat [17]. Eighty five percent (85%) of the intercepted PAR is absorbed by the leaf canopy having high leaf area index greater than 5.0 [18,19]. The PAR interception to an extent of 70 – 80% by different crops has been reported in previous studies [20,21,22]. The radiation use efficiency (RUE) of cereals ranging from 1.3 to 5.3 g MJ^{-1} has been estimated by a large number of scientists [23, 24, 17, 25, 22]. Reports on interception of PAR by legume crops, especially green gram and the measurement of the PAR use efficiency (PARUE) are scanty. It was estimated by the researchers [26] that the absorption of PAR and PARUE in green gram during spring – summer season depending on absorption pattern rather than interception pattern of the canopy. PAR absorption differs from PAR interception where the former includes the soil reflection component. During rainy season cloudy condition prevails creating a great hurdle to estimate the incoming PAR. In India green gram, during the rainy season, is cultivated in large track of lower Gangetic Plains under upland condition. However, no reports are available on PAR interception pattern and PARUE of this crop. The present paper reports the PAR interception pattern and PARUE of the green gram crop, grown both in spring – summer and rainy seasons to evaluate the energy utilization pattern under different dates of sowing in the lower Gangetic Plains of Eastern

India and to determine the best time of sowing.

2. MATERIALS AND METHODS

2.1 Experimental Set Up

The experiment was conducted during spring–summer and rainy seasons of 2011 and 2012 at the District Seed farm, BCKV, Kalyani (22°56´N and 88°32´E; 9.75m above mean sea level), West Bengal, India. In the spring –summer season, the crop was sown on four dates spanning from 15th February to 17th March at 10 days interval. Five varieties (V_1: *IPM 2-3,* V_2: *Samrat,* V_3: *Pant Mung-5,* V_4:*Sonali and* V_5:*Meha*) were used in this season. The rainy season experiment had three sowing dates starting from 20th August to 9th September at 10 days interval with similar five varieties which were grown in spring–summer season.

The soil comes under the order of *Entisol* according to USDA taxonomical classification. The soil was sandy-loam in texture with pH 7.1; organic carbon 0.54%, total nitrogen 0.053%, available P_2O_5 and K_2O were 19.72 kg ha^{-1} and 218.96 kg ha^{-1}. The sand, silt and clay percentage were 48.5, 30.0 and 21.5 respectively with a bulk density of 1.48 g cc^{-1} at 45 – 60 cm soil profile depth.

2.2 Weather Condition

The maximum temperature during 2011 ranged from 28.4 to 35.7°C during the experimental period (7th to 22nd Standard Meteorological Week) while during 2012, it was in between 27.9°C to 38.1°C. The mean maximum temperatures during these two experimental years were 33.5 °C and 34.8°C respectively, a rise of 1.3°C in the second year compared to previous year. The minimum temperature, during 2011, ranged from 13.6°C to 16.6°C. During 2012, the mean minimum temperature was 22.5°C during the growing period. The mean relative humidity (RH) was 90.6% and 89.1% for the first and second year. The crop received a total rainfall of 281.3 mm in the first year whereas during the second year it was 141.3 mm. The mean bright sun shine hours (BSS) were 8.2 hour and 8.4 hour respectively, for first and second year (Fig. 1).

During rainy season, the mean maximum temperature was 31.7°C and 32.3°C respectively for first and second year. The mean minimum temperature was 23.5°C and 23.2°C during the same period. The mean maximum RH was 94.4% and 94.3% for first and second year; whereas the average minimum RH was 68.1% and 66.6% during 2011and 2012, respectively. The crop received a total rainfall of 447.9 mm and 401.5 mm for first and second year. The mean BSS in the first and second year was 5.9 hr and 6.3 hr respectively(Fig. 2).

2.3 Calculation of PAR and Statistical Analysis

The experiment was carried out in strip–plot design where the dates of sowing were kept in horizontal strips and considered as main plot treatment and the varieties were in vertical strips, as sub-plot treatment. Each treatment was replicated thrice. Each plot size was 6m × 5m. In the spring–summer season, row to row and plant to plant distances were 25 cm and 10 cm, whereas in rainy season it was 30 cm and 10 cm respectively because of high vegetative growth attained by the crop during this season.

The experimental field was ploughed by tractor for deep ploughing followed by two power-tiller-driven ploughs to prepare a well pulverized soil. Seed was inoculated with *Rhizobium* sp. @ 4 g kg^{-1} of seed. Well decomposed Farm Yard Manure (FYM) was applied @ 8 t ha^{-1} to the field 15 days before sowing. Recommended fertilizer dose of 20:40:40 kg N-P_2O_5-K_2O per hectare [26] were applied just before sowing.

The second row of each plot was marked as sampling row. Plants from 50 cm row length were collected during specified phenophases, oven-dried for 72 h at 60°C for estimation of above ground biomass accumulation. The leaf area indices (LAIs) were estimated following globally accepted formula [27]. The observations were taken during different growth stages *viz.,* branch initiation, bud emergence, 100% flowering and pod emergence. The crop was harvested from a net area of 3×5 m^2 through picking of green gram pods at the time of maturity and seed yield was estimated at 14% moisture level.

The PAR was measured with the help of Line Quantum Sensor or LQS (Model: MQ -301, APOGEE, Logan UT, UK). The sensor has quantum (photon) response through the wavelength range of 400 nm -700 nm for photosynthetic photon flux density (PPFD) and output is in micromoles per second per square meter. The PPFD was converted into Wm^{-2} for computing the energy requirement using conversion factor suggested by scientists [28]. The LQS was used to measure the interception as described by researchers [22]. Intercepted PAR (IPAR) was computed by the following equation

IPAR = Incident PAR – Reflected PAR – Transmitted PAR [29]

The PAR value was expressed in MJ m^{-2} in case of cumulative intercepted PAR (CIPAR). The PAR use efficiency (PARUE) was computed as a ratio of total above ground biomass accumulation or seed yield to CIPAR and expressed in g MJ^{-1} [24].

Seed yield data were analyzed through Duncan's Multiple Range Test (DMRT) using SAS statistical software (SAS 9.1 for windows; copyright, 2002-2003 SAS Institute Inc., USA). The radiation data were not analyzed statistically. The observations were recorded from single replication to avoid the time-lag error.

3. RESULTS AND DISCUSSION

3.1 CIPAR and PAR Use Efficiency in Spring-Summer and Rainy Season

The pooled mean data (pooled over two years) of LAI showed that the LAI was maximum under D_3 sowing at branch initiation, bud emergence and pod emergence stages during spring – summer season (Table 1). However, during rainy season, the D_1 sown crop had the maximum LAI up to 100% flowering (Table 2). The pod emergence stage had maximum LAI in both the seasons. Among the varieties the V_3 and V_5 had the maximum LAI during spring –summer and rainy seasons, respectively.

Increasing trend in CIPAR was observed throughout the growth period of the crop during both the years in spring-summer (Fig. 3). In 2011, CIPAR at different phenophases ranged from 140.1 to 206.2 MJ m^{-2} under D_1, whereas in 2012, the CIPAR during similar phases was 84.4 – 147.1 MJ m^{-2}. The percent reduction in CIPAR under bud emergence and 100% flowering stages were 26.85 and 29.57% respectively in 2012 when compared with 2011 under D_1. The delayed sowing in 2012 resulted higher CIPAR at all phenophases than 2011. This was due to higher cloudy days in 2011 than in 2012. The PARUE for above ground biomass was maximum in V_3 when the crop was sown on D_1, D_2 or D_3 in both the years during germination to branch initiation in the spring – summer season (Table 3). In the case of late sown crop (D_4), the maximum PARUE was recorded in V_1. The PARUE increased gradually up to flowering and then declined. The mean PARUEs were 3.97, 4.58, 3.18 and 2.64 g MJ^{-1} for D_1, D_2, D_3 and D_4 sowings respectively in 2011. During 2012, the same were 3.27, 2.51, 1.83 and 1.99 g MJ^{-1} for D_1, D_2, D_3 and D_4 sowings respectively. The differences in PARUE observed during two different years were due to the variation in LAI and CIPAR. The varietal differences were also evident because of the variation in LAI observed in different varieties (Table 1). The vegetative stage of the crop had less PAR interception compared to the reproductive stage.

During rainy season the mean PARUEs declined from 8.67 to 3.73 g MJ^{-1} due to delay in sowing in 2011 because of low availability of light during later period of growth evident from bright sunshine hour data. The mean PARUEs in rainy season for above ground biomass were remarkably higher than the spring-summer season (Table 4). During rainy season 100% flowering and pod emergence stages had maximum interception of PAR (Fig 4). PAR use efficiency based on absorbed PAR in green gram ranged from 1.21 g MJ^{-1} to 2.78 g MJ^{-1} for biomass production in spring – summer season [26] while in the present experiment the values are marginally higher because of variation in intercepted PAR and LAI.

3.2 Seed Yield in Spring – Summer and Rainy Season

Mean seed yield of green gram varied from 681.73 – 1507.46 kg ha^{-1}, the maximum seed yield was recorded under D_2 sowing during 2011. During 2012, the same date of sowing produced maximum yield. The pooled mean values recorded that the D_2 sown crop had maximum seed yield of 1251.87 kg ha^{-1}, which was significantly greater than the seed yield obtained on other dates of sowing. Among the varieties, V_3 produced significantly greater yield than other varieties during both the years (Table 5). The pooled mean data indicated that green gram should be sown during 20th – 25th February (D_2) during spring – summer season. During rainy season, seed yield was maximum when the crop was sown on D_1 in both the years (Table 6). Significant differences in seed yield were obtained due to variation in dates of sowing and

Table 1. Change in leaf area index (LAI) of green gram varieties under different dates of sowing during spring summer season (pooled mean over two years)

Pooled	LAI														
	Branch initiation					Bud emergence					100% flowering				
Treatments	**D_1**	**D_2**	**D_3**	**D_4**	**Mean**	**D_1**	**D_2**	**D_3**	**D_4**	**Mean**	**D_1**	**D_2**	**D_3**	**D_4**	**Mean**
V_1	0.48 H	0.48 H	0.68 DE	0.64 FE	0.57 C	0.76 J	0.88 IH	1.20 ED	1.45 C	1.07 C	1.33 K	1.48 J	1.45 J	2.34 B	1.65 C
V_2	0.74 DC	0.58 FG	0.60 F	0.50 H	0.61 B	1.48 C	1.12 EF	1.12 EF	1.12 EF	1.21 B	1.93 E	1.64 I	1.23 L	1.90 FE	1.67 C
V_3	0.84 B	0.69 DE	1.01A	0.47 H	0.75 A	1.78 A	1.48 C	1.65 B	1.00 G	1.48 A	2.75 A	2.17 C	2.03 D	1.79 G	2.18 A
V_4	0.51 HG	0.34 J	0.46 HI	0.31 J	0.41 D	0.97 GH	0.79 IJ	1.03 GF	0.57 K	0.84 D	1.71 H	1.18 ML	1.13 M	1.50 J	1.38 D
V_5	0.59 F	0.51 HG	0.77 C	0.41I	0.57 C	1.24 D	1.05 GF	1.41 C	0.77 J	1.12 C	1.84 FG	1.58 I	1.80 G	1.62 I	1.71 B
Mean	0.63 B	0.52 C	0.70 A	0.47 D		1.25 A	1.06 B	1.28 A	0.98 C		1.91 A	1.61C	1.53 D	1.83 B	
	D	V	D×V			D	V	D×V			D	V	D×V		
S.Em (±)	0.015	0.011	0.022			0.022	0.017	0.033			0.017	0.012	0.024		

Treatments	Pod emergence				
	D_1	**D_2**	**D_3**	**D_4**	**Mean**
V_1	0.97 P	1.86 K	2.51 E	3.22 A	2.14 C
V_2	1.82 LK	2.49 FE	2.20 G	2.83 C	2.33 B
V_3	2.08 IH	2.70 D	3.10 B	2.43 F	2.58 A
V_4	1.27 O	1.69 M	1.77 L	1.97 J	1.67 D
V_5	1.47 N	2.12 H	2.79 C	2.04 I	2.11 C
Mean	1.52 C	2.17 B	2.47 A	2.50 A	
	D	V	D×V		
S.Em (±)	0.017	0.012	0.024		

Note: Means with the same letter are not significantly different

Table 2. Change in leaf area index (LAI) of green gram varieties under different dates of sowing during rainy season (pooled mean over two years)

	LAI															
Pooled	**Branch initiation**				**Bud emergence**				**100% flowering**				**Pod emergence**			
Treatments	**D_1**	**D_2**	**D_3**	**Mean**	**D_1**	**D_2**	**D_3**	**Mean**	**D_1**	**D_2**	**D_3**	**Mean**	**D_1**	**D_2**	**D_3**	**Mean**
V_1	1.07 E	1.05 FE	1.01F	1.04 B	2.08 ED	2.02 EF	1.82 G	1.97 C	2.99 D	2.59 F	2.34 H	2.64 D	3.13 G	3.57 E	3.54 E	3.41 B
V_2	0.95 G	0.82 H	1.18 DC	0.98 C	1.81 G	1.62 H	2.16 D	1.86 D	2.83 E	2.16 I	3.06 C	2.68 C	2.74 H	2.79 H	4.03 C	3.19 C
V_3	1.15 D	0.93 G	1.09 E	1.06 B	2.40 C	1.78 G	1.95 F	2.04 B	3.40 B	2.46 G	2.59 F	2.82 B	3.38 F	3.10 G	3.79 D	3.42 B
V_4	0.78 IH	0.73 I	0.78 IH	0.76 D	1.55 H	1.17 I	1.59 H	1.44 E	2.55 F	1.68 J	2.18 I	2.14 E	2.54 I	2.54 I	3.11 G	2.73 D
V_5	1.50 A	1.21 C	1.29 B	1.33 A	2.71 A	2.60 B	2.49 C	2.60 A	3.77 A	3.39 B	3.78 A	3.64 A	3.95 C	4.31 B	4.59 A	4.28 A
Mean	1.09 A	0.95 B	1.07 A		2.11 A	1.84 C	2.00 B		3.11 A	2.46 C	2.79 B		3.15 C	3.26 B	3.81 A	
	D	V	D×V		D	V	D×V		D	V	D×V		D	V	D×V	
S.Em (±)	0.009	0.010	0.017		0.007	0.018	0.032		0.009	0.014	0.024		0.015	0.016	0.029	

Note: Means with the same letter are not significantly different

Table 3. PAR use efficiency (g MJ^{-1}) for above ground biomass production during growth phases in green gram varieties sown under different dates in spring-summer season

Treatments	2011					2012				
	Germination-Branch Initiation	**Branch Initiation – Bud Emergence**	**Bud Emergence –100% Flowering**	**100% Flowering – Pod Emergence**	**Mean**	**Germination-Branch Initiation**	**Branch Initiation – Bud Emergence**	**Bud Emergence –100% Flowering**	**100% Flowering –Pod Emergence**	**Mean**
D_1V_1	0.37	3.06	4.83	5.14	3.35	0.41	1.14	5.31	2.20	2.27
D_1V_2	0.64	2.42	9.12	4.92	4.28	0.50	2.49	7.92	2.21	3.28
D_1V_3	0.71	2.45	10.00	6.41	4.89	0.54	2.76	8.78	4.31	4.10
D_1V_4	0.40	3.33	4.71	5.67	3.53	0.41	2.06	7.42	2.60	3.12
D_1V_5	0.56	2.93	8.17	3.64	3.83	0.45	2.53	8.12	3.17	3.57
Mean	0.53	2.84	7.37	5.15	3.97	0.46	2.20	7.51	2.90	3.27
D_2V_1	0.50	5.42	4.77	4.16	3.71	0.38	3.49	2.97	1.90	2.19
D_2V_2	0.69	6.66	8.06	4.81	5.06	0.55	5.01	3.44	2.30	2.83
D_2V_3	0.76	8.54	7.97	7.06	6.08	0.48	6.12	4.09	3.24	3.48
D_2V_4	0.34	4.36	4.66	4.10	3.37	0.32	3.28	1.44	1.48	1.63
D_2V_5	0.45	6.52	6.86	4.95	4.70	0.47	4.04	3.34	1.86	2.43
Mean	0.55	6.30	6.47	5.02	4.58	0.44	4.39	3.06	2.16	2.51
D_3V_1	1.05	4.44	4.30	2.16	2.99	0.58	1.13	2.24	3.46	1.85
D_3V_2	0.88	3.81	2.98	2.27	2.49	0.51	0.91	1.16	4.21	1.70
D_3V_3	1.41	4.75	4.95	6.74	4.46	0.96	1.33	2.93	4.73	2.49
D_3V_4	0.73	3.53	2.86	1.63	2.19	0.48	0.63	1.35	2.11	1.14
D_3V_5	1.22	4.94	4.01	4.87	3.76	0.70	1.82	2.37	3.02	1.98
Mean	1.06	4.29	3.82	3.54	3.18	0.65	1.17	2.01	3.50	1.83
D_4V_1	1.03	4.26	3.15	4.76	3.30	0.61	1.06	2.69	5.51	2.47
D_4V_2	0.71	4.21	2.16	4.39	2.87	0.43	1.89	2.35	4.52	2.30
D_4V_3	0.57	3.82	2.17	4.03	2.65	0.36	1.68	1.76	4.20	2.00
D_4V_4	0.58	2.86	2.20	1.96	1.90	0.25	0.87	1.74	3.08	1.49
D_4V_5	0.74	3.21	2.21	3.69	2.46	0.34	1.29	1.66	3.57	1.72
Mean	0.73	3.67	2.38	3.76	2.64	0.40	1.36	2.04	4.17	1.99

Table 4. PAR use efficiency (g MJ^{-1}) for above ground biomass production during growth phases in green gram varieties sown under different dates in rainy season

Treatments	2011					2012				
	Germination-Branch Initiation	Branch Initiation –Bud Emergence	Bud Emergence – 100% Flowering	100% Flowering –Pod Emergence	Mean	Germination- Branch Initiation	Branch Initiation –Bud Emergence	Bud Emergence – 100% Flowering	100% Flowering – Pod Emergence	Mean
D_1V_1	1.88	18.48	7.48	6.06	8.48	1.52	8.41	16.81	10.01	9.19
D_1V_2	1.76	17.63	7.92	5.69	8.25	1.39	8.18	15.60	10.47	8.91
D_1V_3	1.90	20.00	7.49	6.14	8.88	1.52	8.41	17.15	7.72	8.70
D_1V_4	1.68	17.45	9.52	5.97	8.66	1.21	12.18	14.64	7.85	8.97
D_1V_5	1.91	19.00	8.74	6.67	9.08	1.69	7.06	18.05	6.34	8.29
Mean	1.83	18.51	8.23	6.11	8.67	1.47	8.85	16.45	8.48	8.81
D_2V_1	2.41	3.98	5.00	6.80	4.55	2.66	10.69	9.91	15.62	9.72
D_2V_2	2.13	3.72	4.18	6.48	4.13	2.50	9.32	10.00	16.01	9.46
D_2V_3	2.18	3.82	4.77	6.42	4.30	2.60	9.25	10.54	16.03	9.61
D_2V_4	2.32	5.25	3.95	6.11	4.41	2.68	9.19	7.95	16.77	9.15
D_2V_5	2.27	3.95	5.63	7.16	4.75	2.35	10.84	16.02	9.17	9.60
Mean	2.26	4.14	4.71	6.59	4.43	2.56	9.86	10.88	14.72	9.51
D_3V_1	1.38	4.27	4.53	3.66	3.46	2.20	7.87	11.37	6.70	7.04
D_3V_2	1.57	4.73	5.92	2.92	3.79	2.14	10.64	8.45	6.64	6.97
D_3V_3	1.37	4.28	5.43	2.96	3.51	2.21	9.40	10.72	6.66	7.25
D_3V_4	1.44	4.21	3.96	4.43	3.51	2.15	7.88	10.00	5.97	6.50
D_3V_5	1.59	5.15	5.55	5.30	4.40	2.57	9.79	7.98	7.57	6.98
Mean	1.47	4.53	5.08	3.85	3.73	2.26	9.12	9.70	6.71	6.95

Table 5. Changes in seed yield (kg ha^{-1}) of green gram varieties under different dates of sowing (spring-summer season)

Treatments	2011					2012				
	D_1	D_2	D_3	D_4	Mean	D_1	D_2	D_3	D_4	Mean
V_1	999.32H	1358.63 F	1242.02G	837.30J	1109.32 D	556.95K	941.83D	740.25H	1020.46CB	814.87D
V_2	1779.35B	1664.97C	976.33H	736.32K	1289.24 B	895.46E	1045.90B	672.81I	948.68D	890.71B
V_3	1873.63A	1680.70C	1441.32E	679.65 L	1418.83A	955.19D	1162.00A	1182.60A	824.17F	1030.99A
V_4	1330.68 F	1243.02G	888.00I	553.29N	1003.75 E	624.40J	837.58F	620.33J	570.29 K	663.15E
V_5	1459.33E	1590.00D	1259.32G	602.08 M	1227.68C	755.92HG	994.06C	949.30D	787.37G	871.66C
Mean	1488.46A	1507.46A	1161.40B	681.73C		757.58C	996.27A	833.06B	830.19B	
	D	V	D×V			D	V	D×V		
S.Em (±)	6.173	6.968	13.936			3.912	5.714	11.427		

Pooled					
Treatments	D_1	D_2	D_3	D_4	Mean
V_1	778.13K	1150.23 E	991.14H	928.88I	962.09D
V_2	1337.41CB	1355.43 B	824.57J	842.50J	1089.98 B
V_3	1414.41A	1421.35A	1311.96CD	751.91 K	1224.91A
V_4	977.54H	1040.30G	754.17 K	561.79M	833.45E
V_5	1107.63F	1292.03D	1104.31F	694.73L	1049.67C
Mean	1123.02B	1251.87A	997.23C	755.96D	
	D	V	D×V		
S.Em (±)	3.654	4.506	9.011		

Note: Means with the same letter are not significantly different

Table 6. Changes in seed yield (kg ha^{-1}) of green gram varieties under different dates of sowing (rainy season)

Treatments	2011				2012			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
V_1	1279.66E	1362.56D	769.11I	1137.11C	761.33D	752.22D	493.44H	669.00C
V_2	1066.11G	1053.22G	1068.11G	1062.48D	541.88G	554.56G	663.89E	586.78D
V_3	1637.86 B	1168.33F	873.78H	1226.66B	835.56C	644.00E	590.33F	689.96B
V_4	596.11J	760.67I	615.78J	657.52E	481.11H	470.78H	232.78I	394.89E
V_5	1982.03A	1667.78B	1432.78C	1694.20A	951.67B	987.33A	773.89D	904.30A
Mean	1312.36A	1202.51 B	951.91C		714.31A	681.78B	550.87C	
	D	V	D×V		D	V	D×V	
S.Em (±)	2.193	6.661	11.537		5.551	6.106	10.577	

Pooled				
Treatments	D_1	D_2	D_3	Mean
V_1	1020.50F	1057.39E	631.28K	903.05C
V_2	804.00I	803.89 I	866.00H	824.63D
V_3	1236.71C	906.17G	732.06J	958.31B
V_4	538.61L	615.72K	424.28M	526.20E
V_5	1466.85A	1327.55B	1103.33D	1299.25A
Mean	1013.33A	942.14B	751.39C	
	D	V	D×V	
S.Em (±)	2.984	4.518	7.826	

Note: Means with the same letter are not significantly different

Table 7. PAR Use efficiency (g MJ^{-1}) for seed yield in green gram varieties under different dates of sowing (spring-summer season)

Treatments	2011					2012				
	D_1	D_2	D_3	D_4	Mean	D_1	D_2	D_3	D_4	Mean
V_1	0.47	0.59	0.57	0.34	0.49	0.32	0.41	0.26	0.35	0.34
V_2	0.77	0.70	0.44	0.31	0.55	0.44	0.44	0.25	0.34	0.37
V_3	0.77	0.69	0.61	0.28	0.59	0.47	0.46	0.42	0.29	0.41
V_4	0.60	0.55	0.41	0.24	0.45	0.36	0.38	0.22	0.21	0.29
V_5	0.66	0.66	0.55	0.25	0.53	0.43	0.41	0.33	0.28	0.36
Mean	0.65	0.64	0.52	0.28		0.40	0.42	0.30	0.29	

Table 8. PAR Use efficiency (g MJ^{-1}) for seed yield in green gram varieties under different dates of sowing (rainy season)

Treatments	2011				2012			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
V_1	0.90	0.74	0.35	0.66	0.60	0.56	0.34	0.50
V_2	0.77	0.61	0.46	0.61	0.45	0.46	0.41	0.44
V_3	1.11	0.65	0.38	0.71	0.62	0.51	0.40	0.51
V_4	0.49	0.50	0.31	0.43	0.46	0.43	0.18	0.36
V_5	1.30	0.86	0.57	0.91	0.63	0.65	0.45	0.58
Mean	0.91	0.67	0.41		0.55	0.52	0.36	

varieties. In both the year, V_5 produced the maximum yield. The pooled mean results also revealed similar trend. The yield reduction for a 10 day delay from D_1 would be 7.12 kg $ha^{-1}day^{-1}$. As sowing was delayed, reproductive growth was hampered due to lowering of temperature as well as greater fluctuations in day and night temperature during reproductive phase [5, 6]. All the varieties, except V_5 produced greater yield during spring–summer season than the rainy season. This variety is an ideal variety for rainy season cultivation in this zone.

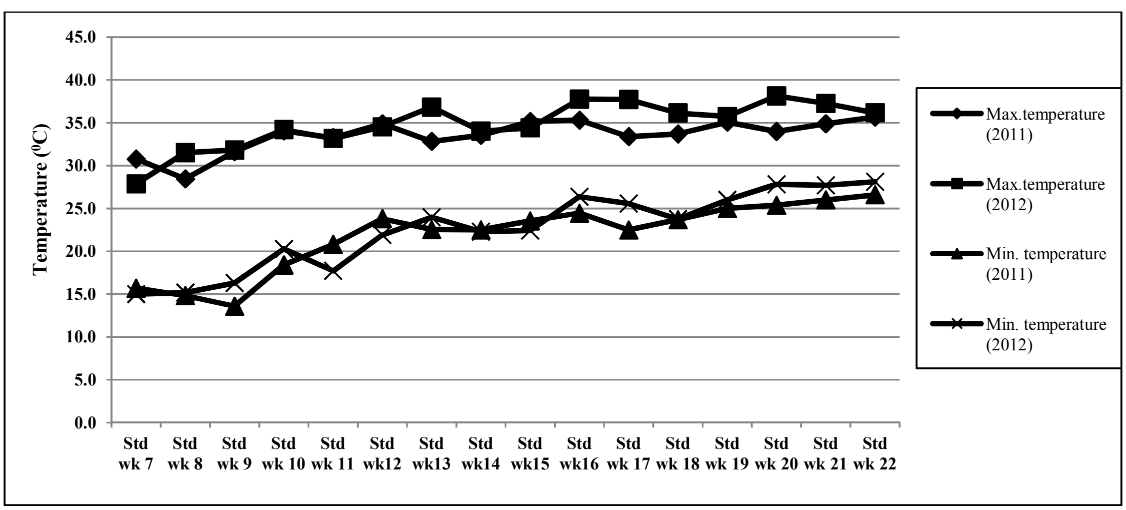
The mean PARUE during spring–summer season was almost at par under D_1 and D_2 sowing dates in both the years; while it was drastically reduced with the delay in sowing. The mean PARUEs were 0.65 and 0.64 g MJ^{-1} during 2011; 0.40 and 0.42 g MJ^{-1} during 2012 for D_1 and D_2 sowings respectively (Table 7). Among the varieties V_3 had the maximum PARUE in both the years.

During the rainy season, the mean PARUE was the maximum under D_1, while it was reduced when the sowing was delayed (Table 8). Among the varieties, V_5 had the maximum PARUE for seed yield.

The LAI has an immense importance in capturing the radiation falling over the canopies [22,30]. The foliage structure, canopy architecture and cloud condition regulate the availability of solar radiation to the crop canopy [31,32]. The light harvesting potentiality varies due to foliar traits in a growing canopy [33]. A variation in absorption of PAR by green gram and other crop because of variation in year during spring-summer season was recorded in this climatic zone by different scientists [26,22]. In rainy season, the green gram crop sown under D_3 received the maximum intercepted PAR during its growth period in the first year, while during the second year, the D_1 sown crop had maximum intercepted PAR. This variation appeared due to the variation in cloud condition during rainy season which was evident from greater number of rainy days during the second year. During rainy season 100% flowering and pod emergence stages had maximum interception of PAR. This was due to greater LAI during these two growth stages. It was reported that higher PAR interception in wheat due to greater LAI [30].

The varietal differences were also evident during the experiment. The crop intercepted higher PAR at the reproductive stages in rainy season. This was utilized for leaf production because of the indeterminate habit of this crop. Similar observations were reported by other workers in summer rape, *Brassica* sp., winter rape and Indian mustard [34,35,36,37,38]. Seasonal variation in radiation use efficiency in maize was also reported by other researchers [39].

A delay in sowing for 10 days from 25th February onwards, the yield reduction per day will be 25.46 kg ha^{-1} due to increase in temperature during reproductive stage [40]. Among the varieties, V_3 is suitable for spring – summer season because of its greater productivity. The yield reduction was mainly due to variation in temperature and radiation interception pattern by the crop. Similar findings based on the variation of dates of sowing were also reported by other workers [41,6].



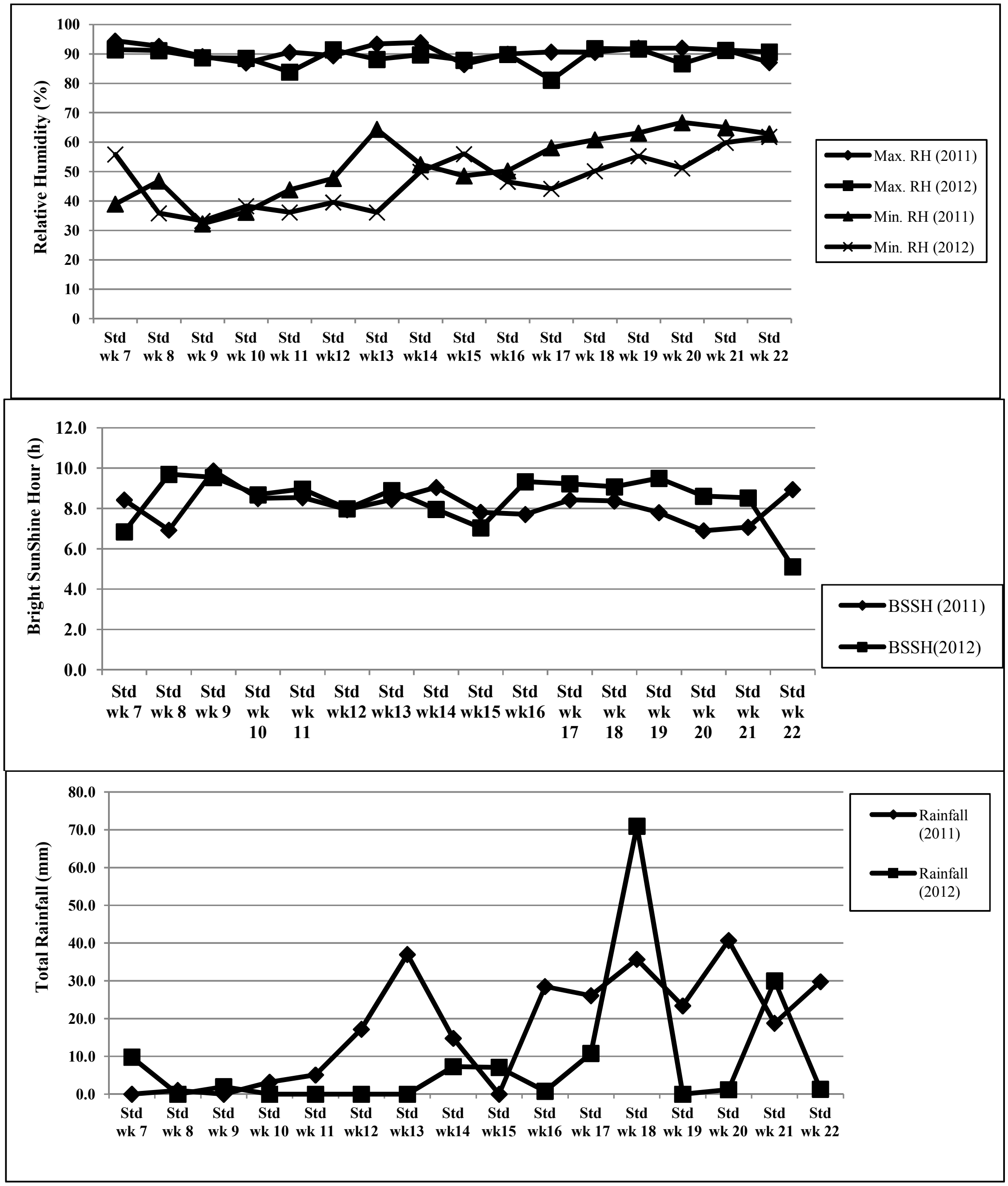


Fig. 1. Climatic condition during experimental period in spring-summer season

Researchers [26] obtained the mean PARUE for different varieties ranging from 0.75 to 0.88 g MJ^{-1} in green gram during spring –summer season planting. A radiation use efficiency of 0.81 g MJ^{-1} is recorded in groundnut [42]. PAR use efficiency for grain production is not static. Some doubtful relationship between CIPAR and crop growth is also reported by the scientists [43]. However, other researchers [44,45,46] firmly established the relationship between CIPAR and the crop yield. The variability of PARUE due to season, varieties and canopy structure (particularly LAI) was also established [47,22]. In the present experiment, the PARUEs of different varieties had marginally higher values in rainy season than the spring–summer season.

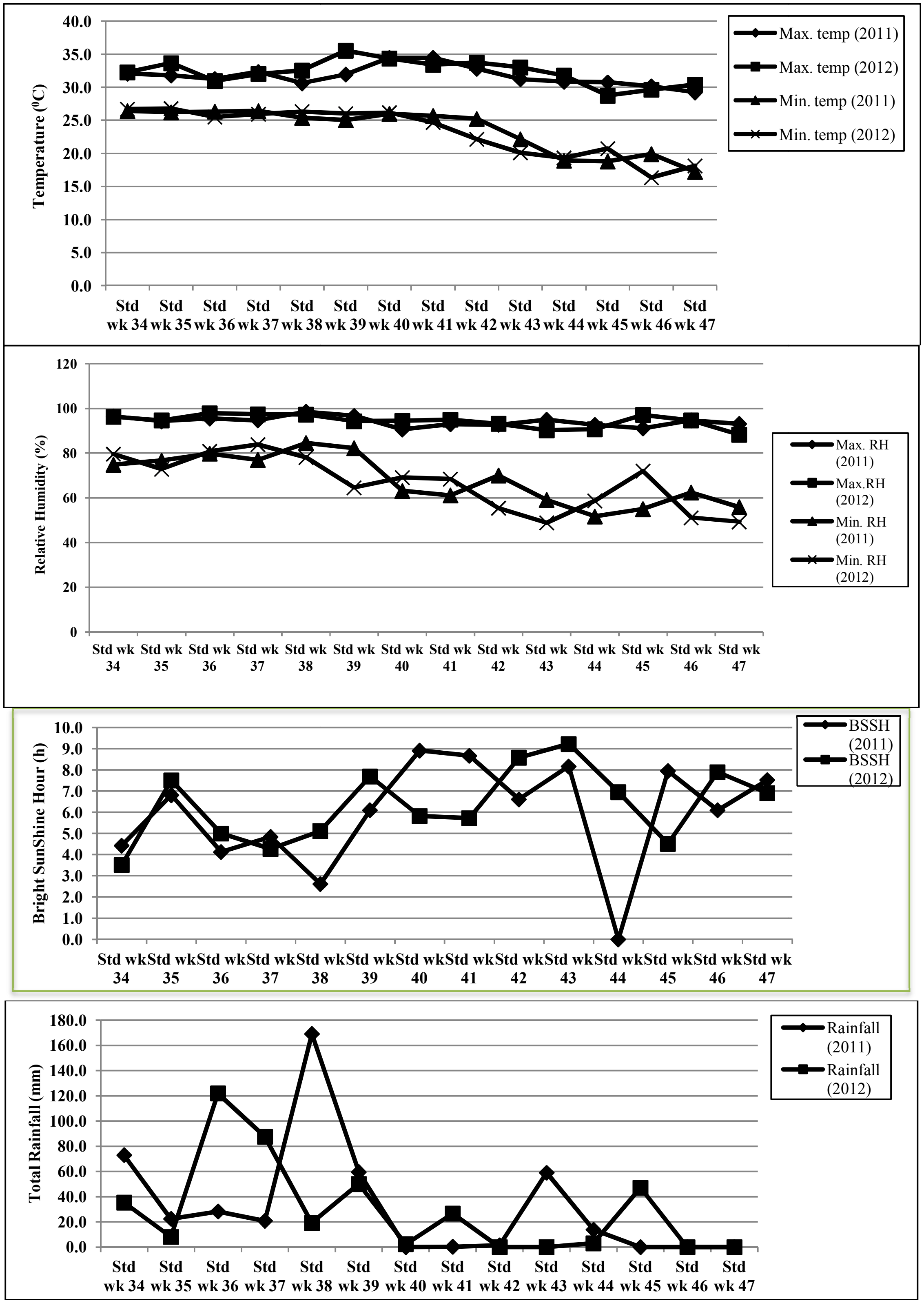


Fig. 2. Climatic condition during experimental period in rainy season

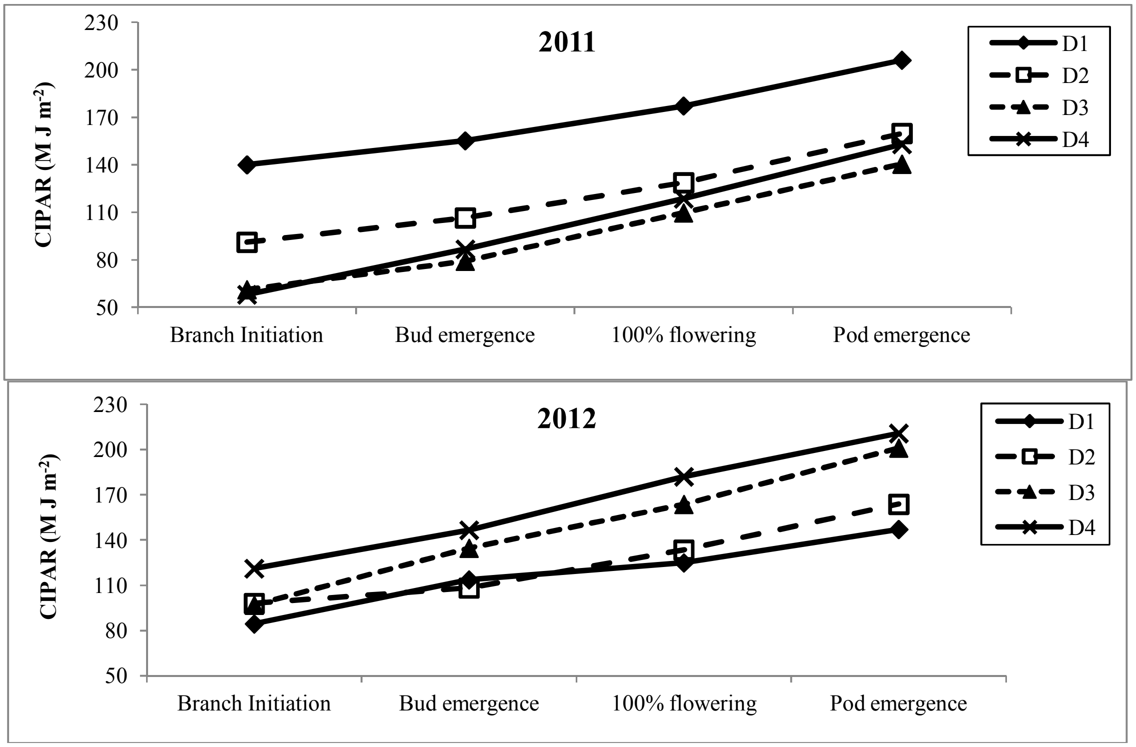


Fig. 3. Variation in CIPAR at different phenophases of green gram under different dates of sowing in spring – summer season (varietal values were pooled)

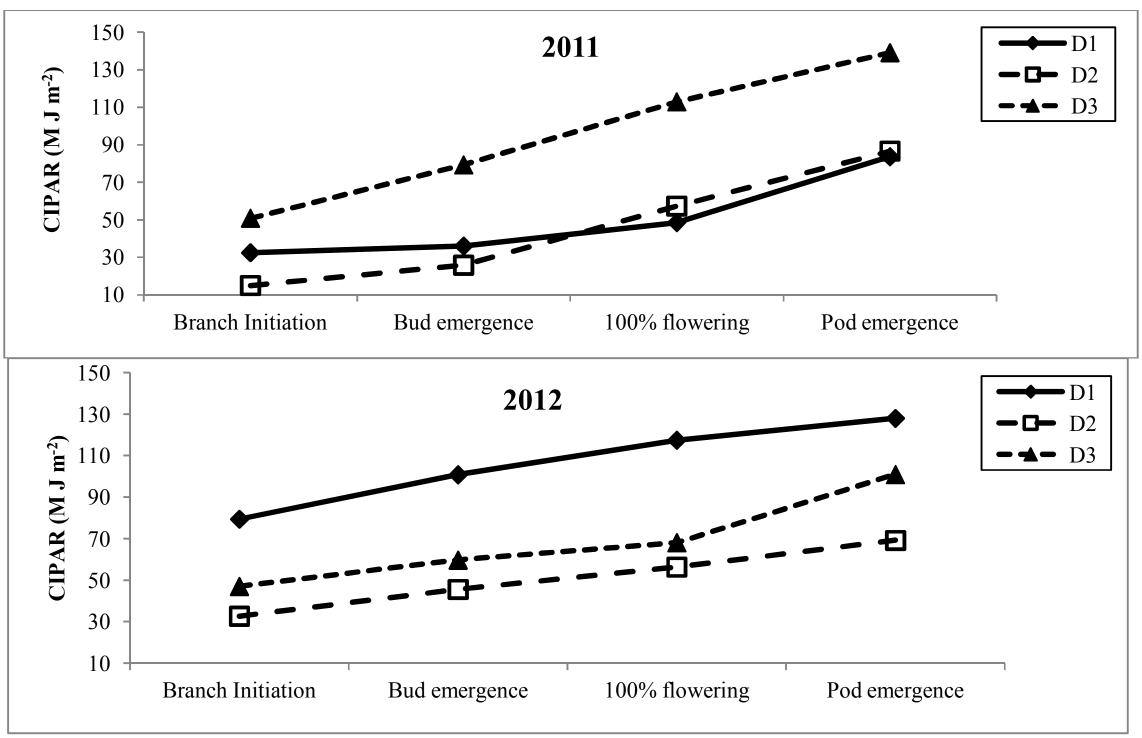


Fig. 4. Variation in CIPAR at different phenophases of green gram under different dates of sowing in rainy season (varietal values were pooled)

4. CONCLUSION

Considering PAR interception pattern and PARUE of green gram, it is concluded that the green gram should be sown during 3rd week of February in spring –summer season. Among the varieties, *Pant Mung-5* (V_3) should be selected for its higher potential to utilize the PAR for better productivity. During rainy season, green gram may be sown during 3rd week of August. The variety *Meha* (V_5) is suitable for its better productivity considering PAR interception pattern and PAR use efficiency. Productivity of green gram can be enhanced by planting the crop during rainy season under upland condition which otherwise remain fallow.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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