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.

Article Information

DOI: 10.9734/CJAST/2020/v39i2530891

Editors:
(1) Dr. Michael Ignatius Ferreira, Western Cape Department of Agriculture, South Africa.

Reviewers:
(1) Vanucha Misra, ICAR-Indian Institute of Sugarcane Research, India.
(2) Hla Myo Tun, Yangon Technological University (YTU), Myanmar.

Complete Peer review History: http://www.sdiarticle4.com/review-history/60279

Received 15 June 2020
Accepted 20 August 2020
Published 28 August 2020

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 photosynthetically active radiation use efficiency (PARUE) in the lower Gangetic Plains of Eastern India.

Methodology: Five green gram varieties (V₁, V₂, V₃, V₄ and V₅) were sown on four dates (D₁, D₂, D₃ and D₄) in the spring – summer season starting from 16th February and on three dates (D₁, D₂ and D₃) 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 D₁, D₂, D₃ and D₄ 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 D₂ and V₃ in the spring –summer and under D₁ and V₅ 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 D₁ for two experimental years.

Conclusion: Depending on PARUE Pant Mung – 5 and Mehashould 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 C₃ crop as it converts CO₂ into glucose following C₃ – cycle and has a low yielding potentiality because of its inability to re-fix CO₂ emanated from photosynthesis like C₄ 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.
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 (V1; IPM 2-3, V2; Samrat, V3; Pant Mung-5, V4; Sonali and V5; 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 P₂O₅ and K₂O 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 cm⁻³ 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-P₂O₅-K₂O 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 (LAI's) 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 m² 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
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 D₃ sowing at branch initiation, bud emergence and pod emergence stages during spring – summer season (Table 1). However, during rainy season, the D₁ 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 V₃ and V₅ 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 D₁, 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 D₁. 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 V₃ when the crop was sown on D₁, D₂ or D₃ in both the years during germination to branch initiation in the spring – summer season (Table 3). In the case of late sown crop (D₄), the maximum PARUE was recorded in V₁. 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 D₁, D₂, D₃ and D₄ sowings respectively in 2011. During 2012, the same were 3.27, 2.51, 1.83 and 1.99 g MJ⁻¹ for D₁, D₂, D₃ and D₄ 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 D₂ sowing during 2011. During 2012, the same date of sowing produced maximum yield. The pooled mean values recorded that the D₂ 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, V₃ 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 (D₂) during spring – summer season. During rainy season, seed yield was maximum when the crop was sown on D₁ 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)

| Treatments | Pooled LAI | Branch initiation | Bud emergence | 100% flowering |
|------------|------------|-------------------|---------------|----------------|
|            | D<sub>1</sub> | D<sub>2</sub> | D<sub>3</sub> | Mean | D<sub>1</sub> | D<sub>2</sub> | D<sub>3</sub> | Mean | D<sub>1</sub> | D<sub>2</sub> | D<sub>3</sub> | Mean |
| V<sub>1</sub> | 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<sub>2</sub> | 0.74 DC | 0.58 FG | 0.60 F | 0.50 H | 0.61 B | 1.48 C | 1.12 EF | 1.12 EF | 1.21 B | 1.93 E | 1.64 I | 1.23 L | 1.90 FE | 1.67 C |
| V<sub>3</sub> | 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<sub>4</sub> | 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<sub>5</sub> | 0.59 F | 0.51 HG | 0.77 C | 0.41 I | 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 | 1.61 C | 1.53 D | 1.83 B |
| S.Em (±)   | 0.015 | 0.011 | 0.022 | 0.002 | 0.022 | 0.017 | 0.033 | 0.017 | 0.012 | 0.024 |

| Treatments | Pod emergence | D<sub>1</sub> | D<sub>2</sub> | D<sub>3</sub> | Mean |
|------------|---------------|---------------|---------------|-------|
| V<sub>1</sub> | 0.97 P | 1.88 K | 2.51 E | 3.22 A | 2.14 C |
| V<sub>2</sub> | 1.82 LK | 2.49 FE | 2.20 G | 2.83 C | 2.33 B |
| V<sub>3</sub> | 2.08 IH | 2.70 D | 3.10 B | 2.43 F | 2.56 A |
| V<sub>4</sub> | 1.27 O | 1.69 M | 1.77 L | 1.97 J | 1.67 D |
| V<sub>5</sub> | 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 |
| 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)

| Treatments | Pooled | Branch initiation | Bud emergence | 100% flowering | Pod emergence |
|------------|--------|-------------------|---------------|----------------|---------------|
| D1         | D2     | D3                | Mean          | D1             | D2            | D3           | Mean      | D1          | D2          | D3          | Mean       |
| V1         | 1.07 E | 1.05 FE           | 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      |
| V2         | 0.95 G | 0.82 H            | 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      |
| V3         | 1.15 D | 0.93 G            | 1.09 E        | 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      |
| V4         | 0.78 IH| 0.73 I            | 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      |
| V5         | 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      |             |             |             |             |
| 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 | Germination-Branch Initiation | Branch Initiation – Bud Emergence | 100% Flowering – Pod Emergence | Mean | Germination-Branch Initiation | Branch Initiation – Bud Emergence | 100% Flowering – Pod Emergence | Mean |
|------------|-------------------------------|----------------------------------|-------------------------------|------|-------------------------------|----------------------------------|-------------------------------|------|
|            | 2011                          |                                  |                               | 2012 |                               |                                  |                               |      |
| D1V1       | 0.37                          | 3.06                             | 4.83                          | 5.14 | 3.35                          | 0.41                            | 1.14                          | 5.31 | 2.20 | 2.27 |
| D1V2       | 0.64                          | 2.42                             | 9.12                          | 4.92 | 4.28                          | 0.50                            | 2.49                          | 7.92 | 2.21 | 3.28 |
| D1V3       | 0.71                          | 2.45                             | 10.00                         | 6.41 | 4.89                          | 0.54                            | 2.76                          | 8.78 | 4.31 | 4.10 |
| D1V4       | 0.40                          | 3.33                             | 4.71                          | 5.67 | 3.53                          | 0.41                            | 2.06                          | 7.42 | 2.60 | 3.12 |
| D1V5       | 0.56                          | 2.93                             | 8.17                          | 3.64 | 3.83                          | 0.45                            | 2.53                          | 8.12 | 3.17 | 3.57 |
| Mean       | 0.53                          | 2.94                             | 7.37                          | 5.15 | 3.97                          | 0.46                            | 2.20                          | 7.51 | 3.90 | 3.37 |
| D2V1       | 0.50                          | 5.42                             | 4.77                          | 4.16 | 3.71                          | 0.38                            | 3.49                          | 2.97 | 1.90 | 2.19 |
| D2V2       | 0.69                          | 6.66                             | 8.06                          | 4.81 | 5.06                          | 0.55                            | 5.01                          | 3.44 | 2.30 | 2.83 |
| D2V3       | 0.76                          | 8.54                             | 7.97                          | 7.06 | 6.08                          | 0.48                            | 6.12                          | 4.09 | 3.24 | 3.48 |
| D2V4       | 0.34                          | 4.36                             | 4.66                          | 4.10 | 3.37                          | 0.32                            | 3.28                          | 1.44 | 1.48 | 1.63 |
| D2V5       | 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 |
| D3V1       | 1.05                          | 4.44                             | 4.30                          | 2.16 | 2.99                          | 0.58                            | 1.13                          | 2.24 | 3.46 | 1.85 |
| D3V2       | 0.88                          | 3.81                             | 2.98                          | 2.27 | 2.49                          | 0.51                            | 0.91                          | 1.16 | 4.21 | 1.70 |
| D3V3       | 1.41                          | 4.75                             | 4.95                          | 6.74 | 4.46                          | 0.96                            | 1.33                          | 2.93 | 4.73 | 2.49 |
| D3V4       | 0.73                          | 3.53                             | 2.86                          | 1.63 | 2.19                          | 0.48                            | 0.63                          | 1.35 | 2.11 | 1.14 |
| D3V5       | 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 |
| D4V1       | 1.03                          | 4.26                             | 3.15                          | 4.76 | 3.30                          | 0.61                            | 1.06                          | 2.69 | 5.51 | 2.47 |
| D4V2       | 0.71                          | 4.21                             | 2.16                          | 4.39 | 2.87                          | 0.43                            | 1.89                          | 2.35 | 4.52 | 2.30 |
| D4V3       | 0.57                          | 3.82                             | 2.17                          | 4.03 | 2.65                          | 0.36                            | 1.68                          | 1.76 | 4.20 | 2.00 |
| D4V4       | 0.58                          | 2.86                             | 2.20                          | 1.96 | 1.90                          | 0.25                            | 0.87                          | 1.74 | 3.08 | 1.49 |
| D4V5       | 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 | 100% Flowering – Pod Emergence | Mean | Germination - Branch Initiation | Branch Initiation – Bud Emergence | 100% Flowering – Pod Emergence | Mean |
| D\(_1\)V\(_1\) | 1.88 | 18.48 | 7.48 | 6.06 | 8.48 | 1.52 | 8.41 | 16.81 | 10.01 | 9.19 |
| D\(_1\)V\(_2\) | 1.76 | 17.63 | 7.92 | 5.69 | 8.25 | 1.39 | 8.18 | 15.60 | 10.47 | 8.91 |
| D\(_1\)V\(_3\) | 1.90 | 20.00 | 7.49 | 6.14 | 8.88 | 1.52 | 8.41 | 17.15 | 7.72 | 8.70 |
| D\(_1\)V\(_4\) | 1.68 | 17.45 | 9.52 | 5.97 | 8.66 | 1.21 | 12.18 | 14.64 | 7.85 | 8.97 |
| D\(_1\)V\(_5\) | 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\(_2\)V\(_1\) | 2.41 | 3.98 | 5.00 | 6.80 | 4.55 | 2.66 | 10.69 | 9.91 | 15.62 | 9.72 |
| D\(_2\)V\(_2\) | 2.13 | 3.72 | 4.18 | 6.48 | 4.13 | 2.50 | 9.32 | 10.00 | 16.01 | 9.46 |
| D\(_2\)V\(_3\) | 2.18 | 3.82 | 4.77 | 6.42 | 4.30 | 2.60 | 9.25 | 10.54 | 16.03 | 9.61 |
| D\(_2\)V\(_4\) | 2.32 | 5.25 | 3.95 | 6.11 | 4.41 | 2.68 | 9.19 | 7.95 | 16.77 | 9.15 |
| D\(_2\)V\(_5\) | 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\(_3\)V\(_1\) | 1.38 | 4.27 | 4.53 | 3.66 | 3.46 | 2.20 | 7.87 | 11.37 | 6.70 | 7.04 |
| D\(_3\)V\(_2\) | 1.57 | 4.73 | 5.92 | 2.92 | 3.79 | 2.14 | 10.64 | 8.45 | 6.64 | 6.97 |
| D\(_3\)V\(_3\) | 1.37 | 4.28 | 5.43 | 2.96 | 3.51 | 2.21 | 9.40 | 10.72 | 6.66 | 7.25 |
| D\(_3\)V\(_4\) | 1.44 | 4.21 | 3.96 | 4.43 | 3.51 | 2.15 | 7.88 | 10.00 | 5.97 | 6.50 |
| D\(_3\)V\(_5\) | 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\textsuperscript{-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  | 1020.46 CB| 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\(\times V\) S.Em (±)

|          | \(D_1\)       | \(D_2\)       | \(D_3\)  | \(D_4\)  | Mean     | \(D_1\)  | \(D_2\)  | \(D_3\)  | \(D_4\)  | Mean     |          |
|          | D\(\times V\)  | D\(\times V\)  | D\(\times V\) |          |          |          |          |          |          |          |          |

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     | 654.56G     | 663.89E     | 586.78D  |
| V\(_3\)    | 1637.86B     | 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     | 1202.51B     | 951.91C     | 714.31A   | 681.78B     | 669.00C     | 550.87A     | 904.30A  |
| S.Em (±)   | 2.193        | 6.661        | 11.537      | 5.551     | 6.106       | 10.577      |

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\(_3\)     | Mean     | D\(_1\)      | D\(_2\)      | D\(_3\)     | 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 |       |       |
|------------|------|-------|-------|------|-------|-------|
|            |      | D₁    | D₂    | Mean | D₁    | D₂    | D₃    | Mean |
| V₁         | 0.90 | 0.74  | 0.35  | 0.66 | 0.60  | 0.56  | 0.34  | 0.50 |
| V₂         | 0.77 | 0.61  | 0.46  | 0.61 | 0.45  | 0.46  | 0.41  | 0.44 |
| V₃         | 1.11 | 0.65  | 0.38  | 0.71 | 0.62  | 0.51  | 0.40  | 0.51 |
| V₄         | 0.49 | 0.50  | 0.31  | 0.43 | 0.46  | 0.43  | 0.18  | 0.36 |
| V₅         | 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, V₅ produced the maximum yield. The pooled mean results also revealed similar trend. The yield reduction for a 10 day delay from D₁ 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 V₅ 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 D₁ and D₂ 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 D₁ and D₂ sowings respectively (Table 7). Among the varieties V₅ had the maximum PARUE in both the years.

During the rainy season, the mean PARUE was the maximum under D₁, while it was reduced when the sowing was delayed (Table 8). Among the varieties, V₅ 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 D₃ received the maximum intercepted PAR during its growth period in the first year, while during the second year, the D₁ 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, V₃ 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].
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* (V₃) 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* (V₅) 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.

ACKNOWLEDGEMENT

The first author acknowledges Department of Science and Technology, Ministry of Science and Technology, Government of India for providing the fund through INSPIRE Fellowship to carry out the research programme.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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