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# Seed Priming and Foliar Application of Nutrients Influence the Productivity of Relay Grass Pea (*Lathyrus sativus* L.) through Accelerating the Photosynthetically Active Radiation (PAR) Use Efficiency

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**Abstract:** The efficiency of a crop to intercept and utilize solar radiation for photosynthates production serves as one of the deciding factors of the productive potential of the crop stand. Interception and use efficiency of photosynthetically active radiation (PAR) were estimated in relay grass pea under different nutrient management schedules in consecutive two crop seasons of 2017–2018 and 2018–2019. Treatments were two levels of seed priming (i.e., 1. $S_1$: Without seed priming and 2. $S_2$: Seed priming with ammonium molybdate at 0.5 g $kg^{-1}$ seed) and five levels of foliar-applied nutritions with various combinations of 2% Urea and 0.5% NPK (19:19:19) shuffling their times of application, replicated thrice laying out in a factorial randomized block design. Seed priming along with twice sprays of NPK (19:19:19) at pre-flowering followed by a second one after 15 days recorded maximum leaf area index (LAI) and total chlorophyll content augmenting greater interception and use efficiency of PAR with highest biomass accumulation, crop growth rate (CGR) and leaf nutrient contents leading to a significant increase in seed yield over control (1696.70 and 1182.00 kg $ha^{-1}$, respectively) in a pooled analysis. LAI and total chlorophyll content established linear relationships with PAR interception explaining about 94 and 88% variations in intercepted PAR at 90 DAS. Intercepted PAR during different phenophases was positively correlated to dry matter accumulation and net photosynthetic rate with polynomial relationships. Seed yield of grass pea varied about 95 and 96% respectively during 2017–2018 and 2018–2019 with the variations in PAR interception at the pod developmental stage.

**Keywords:** foliar spray; grass pea; intercepted PAR; PAR use efficiency; seed priming

## 1. Introduction

Light interception and its direct impact on crop growth have been important concepts with respect to field crops [1]. Like many other crops, the amounts of incoming intercepted photosynthetically active radiation (I PAR) and radiation use efficiency (RUE) of the canopy for biomass production have been highlighted as the most important determinants of the productive potentiality of the leguminous crop stands like mungbean [2], pigeon pea [3], lentil [4], etc. Basu et al. [5] recorded up to 97% variation in intercepted PAR, which could be explained by the biomass accumulation in case of transplanted rice. On the other hand, Oluwasemire and Odugbenro [6] noted the maximum increment in plant biomass for groundnut with a PAR interception to the tune of 55–60%. Further studies indicated that the incoming PAR intercepted by crop canopy is largely governed by the leaf area index (LAI) and canopy architecture [7]. Basically, leaf area is one of the major determinants of PAR interception and its utilization for biomass accumulation and net photosynthesis [8]. Expanding leaf area is a commendable attribute to the overall growth rate of any crop leading to extensive interception of solar radiation and eventually contributing to better economic harvests [9]. On the other hand, the radiation conversion efficiency of a crop into plant biomass equally depends upon the physiological characteristics of the crop [10] as well as on environmental conditions [11]. In this context, the leaf chlorophyll content of a plant is one of the fundamental attributing physiological characteristics related to photosynthetic capacity. Accelerated chlorophyll biosynthesis invariably leads to capturing more incoming solar radiation and a greater rate of net photosynthesis [12]. Notably, RUE is also enhanced with the increase in PAR interception [13]. However, improvement in RUE clearly indicates a higher rate of photosynthesis, which in turn contributes to better yield and nutrient use efficiency. In this context, Worku and Demisie [3] observed around 88% correlation between dry matter production and RUE regarding pigeon pea. In addition, Jena et al. [7] registered up to 4.12 g $MJ^{-1}$ RUE in mustard with increasing biomass production.

Grass pea (*Lathyrus sativus* L.) is generally relay-cropped using the residual soil moisture in rice-fallow during *rabi* season in India [14]. Basically, it is a protein-rich pulse crop (28%) containing considerable proportions of several minerals like calcium, phosphorus and iron [15]. It is considered as an 'insurance crop' as it produces reliable yields when all other crops fail due to a harsh environment. Compared to the other pulse crops, grass pea is a remarkable drought-tolerant crop that thrives with minimal external inputs and consequently is an ideal legume for resource-poor farmers [16].

Seed priming is a recent technology to magnify the rate and synchrony of crop seeds germination, vigour and establishment of seedlings and subsequent attainments of biomass, yield attributing characters and yield of pulse crops [17]. Nutrient seed priming can serve as a simple but effective agronomic practice to meet the nutrient demand of the crop in the early growth stages and eventually increase the final yield in case of relay sowing of pulse crops. In rice fallows, seed priming with $KH_2PO_4$ [18], sodium molybdate [19] has been earlier reported to increase grass pea production owing to accelerated crop growth and better uptake of nutrients from soil. Basically, molybdenum (Mo) is a vital micronutrient regulating different physiological and biochemical mechanisms in grain legumes [20]. In particular, its direct involvement in the synthesis and activity of nitrogenase and nitrate reductase enzymes, regulating symbiotic N fixation and N assimilation by triggering rhizobial activity has been cited by earlier literature [21]. Application of ammonium molybdate at a dose of 0.5 g $kg^{-1}$ seed has been observed to increase root nodulation of grass pea up to 80–90% along with up-gradation of economic yield to the tune of 30% [14].

The foliar fertilization technique provides the crops plants with a quick supply of nutrients reaching directly to the site of photosynthesis without any wastage [22]. Especially in indeterminate legumes, foliar application of nutrients is very much proficient as it provides sufficient time for conversion of late formed flowers into pods in addition to stimulation of balanced partitioning of photoassimilates from source to sink [23]. Foliar feeding of urea and NPK (19:19:19) was found to be beneficial in the case of green gram, black gram, lentil, grass pea and chickpea [24,25] by delaying senescence and thereby facilitating photosynthesis. The positive influences of NPK foliar nutrition and their interactions are inevitably attributed to the indispensable role of nitrogen (N), phosphorus (P) and potassium (K) in the physiological development of plants [15]. Application of N helps to expand leaf area as N is considered as the primary constituent of leaf chlorophyll maximizing the photosynthetic capacity and overall growth of crop plants [26]. Generally, fertilization with N increases the vegetative growth, total carbohydrate, soluble sugars and NPK content of plants [27]. Modulation of dry matter and protein contents in grain legume crops in terms of both qualitative and quantitative points of view through N application is a very well-known fact. Legume crops go through gradual leaf senescence well before their maturity, which obstructs the yield by breaking the normal source–sink relationship [28]. This specific setback can be overcome through the foliar spray of nitrogen [29], whereas P stimulates root, seed and fruit development along with aiding in vital metabolic functions of plants [30]. In addition, P also departs energy in the form of ATP for nitrogen metabolism and hence enhances BNF, increasing rhizobial colonization, leaf area, photosynthesis, carbon partitioning and biomass accumulation [31]. Phosphorus has a stimulating effect on the growth parameters, total carbohydrate, soluble sugars and minerals contents and influences the productivity by affecting the processes of energy storage and transfer [32]. Potassium addition significantly stimulates root and shoot growth, and enhances the BNF and protein content of pulse grains [33], besides regulating the water economy in the plant body through osmoregulation and maintenance of leaf water potential [34]. Notably, Randhawa et al. [35] reported an interception of PAR of around 460 MJ $m^{-2}$ along with maximum total dry matter and RUE using a nutrient management schedule consisting of NPK in terms of maize.

Indeed, there is a paucity of information regarding the impact of PAR interception and PAR use efficiency on grass pea production in the lower Gangetic plains of Eastern India. This study had been undertaken with the specific objectives of quantifying the amount of intercepted PAR and PAR use efficiency of winter grown grass pea as well as evaluating their interaction with the growth, physiology and seed yield of relay grass pea as influenced by seed priming with Mo and foliar nutrition with urea and NPK.

## 2. Materials and Methods

### *2.1. Location of the Study*

The field experiment was pursued at the 'A–B' block, District Seed Farm (22°93′ N, 88°53′ E, 9.75 m above the mean sea level) of Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, India during two subsequent *rabi* seasons (October–March) of 2017–2018 and 2018–2019.

### *2.2. Soil and Weather Conditions*

The soil of the study site was well-drained Gangetic alluvium (order: Inceptisol, suborder: Aqepts, great group: Haplaquepts) with moderate fertility and nearly neutral in reaction, categorised under the textural class of sandy loam with a neutral soil reaction. The detailed physicochemical properties of the soil of the research plots have been depicted in Table 1. Meteorological features of the experimental site in both years have been presented graphically in Figure 1.

**Table 1.** Details of the experimental soil before experimentation.

| Soil Property | Value | | Procedures Followed |
|---|---|---|---|
| | 2017–2018 | 2018–2019 | |
| pH | 7.3 | 7.4 | Glass electrode pH meter [36] |
| Electrical conductivity (dS $m^{-1}$) | 0.18 | 0.17 | EC meter [37] |
| Organic carbon (%) | 0.56 | 0.54 | Wet oxidation method [38] |
| Available nitrogen (kg $ha^{-1}$) | 231.28 | 227.17 | Modified Kjeldahl method [39] |
| Available phosphate (kg $ha^{-1}$) | 34.51 | 35.73 | 0.5 M $NaHCO_3$ extract [40] |
| Available potassium (kg $ha^{-1}$) | 188.83 | 190.75 | Neutral N $NH_4OAc$ extract [39] |
| Available molybdenum (ppm) | 0.03 | 0.04 | Ammonium oxalate extract [41] |
| Available boron (ppm) | 0.51 | 0.53 | Azomethine H [42] |
| Available zinc (ppm) | 0.26 | 0.21 | DTPA-TEA extract [43] |
| Available manganese (ppm) | 0.85 | 0.94 | DTPA-TEA extract [43] |
| Available iron (ppm) | 0.59 | 0.56 | DTPA-TEA extract [43] |

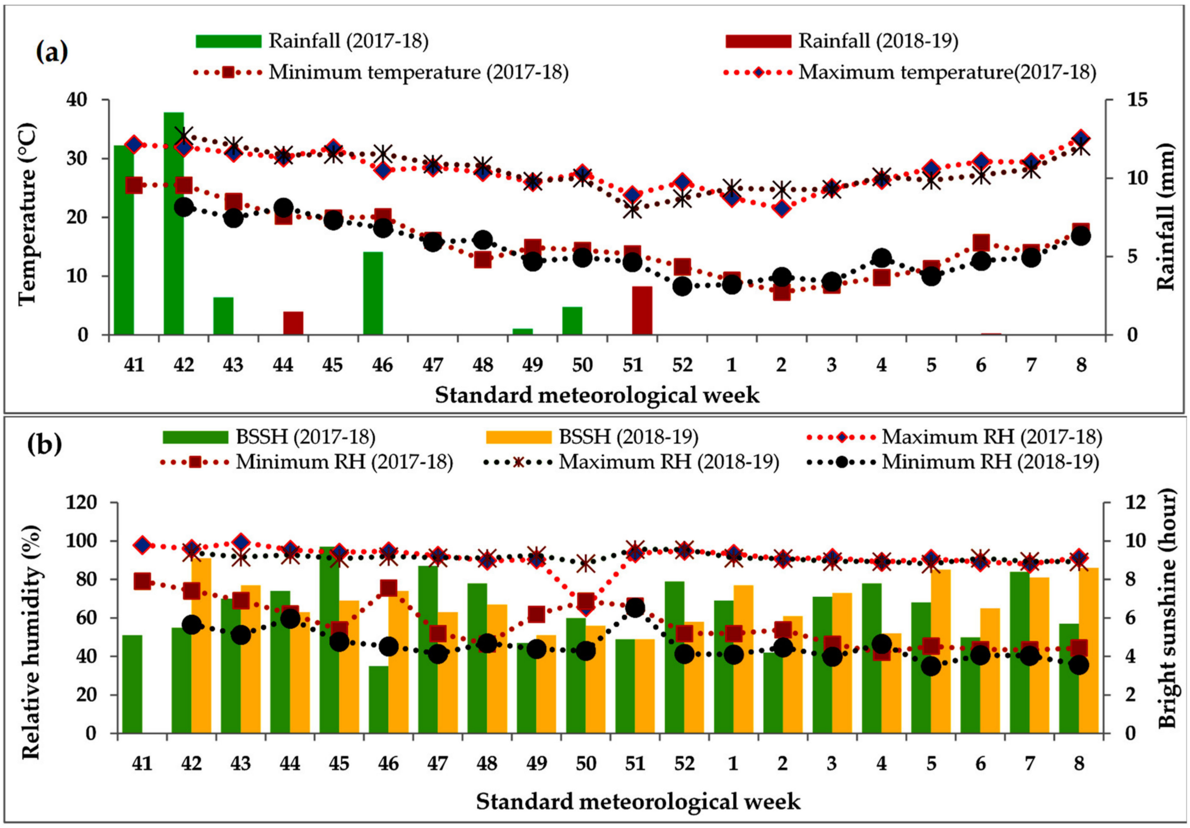



**Figure 1.** Meteorological features (**a**) rainfall and temperature; (**b**) relative humidity (RH) and bright sunshine hours (BSSH)) of the experimental site during 2017–2018 and 2018–2019.

### 2.3. Treatments and Design

The field experiment was arranged in a factorial randomized block design consisting of 2 levels of the 1st factor (seed priming) and 5 levels of the 2nd factor (foliar sprays) in various combinations with a total of 10 treatments replicated thrice. Grass pea seeds of the variety Ratan (Bio L-212) were used for the whole experiment. Detailed treatments are presented in Table 2.

**Table 2.** Treatment details of the experiment.

| | **Treatments** |
|---|---|
| | Seed priming (S) |
| $S_1$ | No seed priming |
| $S_2$ | Seed priming with ammonium molybdate at 0.5 g kg$^{-1}$ seed |
| | Foliar sprays of nutrient (F) |
| $F_1$ | No foliar spray |
| $F_2$ | Foliar spray of 2% Urea at the pre-flowering stage |
| $F_3$ | Foliar spray of 2% Urea at the pre-flowering stage and 15 days after 1st spray |
| $F_4$ | Foliar spray of 0.5% NPK (19:19:19) at the pre-flowering stage |
| $F_5$ | Foliar spray of 0.5% NPK (19:19:19) at the pre-flowering stage and 15 days after 1st spray |

### 2.4. Experimental Procedures

The event of land preparation was completely excluded for relay grass pea crop in this experiment. Generally, grass pea crop requires a seed rate of 40 kg ha$^{-1}$ for line sowing. However, the seeds were sown at the rate of 80 kg ha$^{-1}$ in individual experimental plots of 5 m × 3 m through broadcasting on a standing rice crop as per the recommended practices of relay cropping. Half of the seeds were primed with ammonium molybdate at the rate of 0.5 g kg$^{-1}$ of seed for 8 h followed by shade dry and the rest were kept dry on the day before sowing. Before an hour of sowing, all the seeds were treated with *Rhizobium* biofertilizer at the rate of 20 g kg$^{-1}$ of seed for better nodulation. Basal dose of fertilizers application as well as irrigation were completely excluded in case of cultivation of relay grass pea.

One manual weeding was done at 25–30 days after sowing for proper stand establishment of the crop. Foliar sprays with 2% Urea and 0.5% NPK (19:19:19) were done as per the treatment wise allotments in the morning hours spraying with the help of a knapsack sprayer by one labourer simply walking along with the individual plots. The exact amounts per plot requirements of fertilizers were calculated as per the treatment schedule and the same was mixed with the tap water (at the rate of 500 lit ha$^{-1}$) inside the spray tank for better accuracy of the dose. Spraying of fungicide including SAAF (Mancozeb + Carbendazim) @ 2.5 g lit$^{-1}$ of water was done at 60 DAS as a plant protection measure.

### *2.5. Data and Their Estimation Procedures*

The observations of PAR were measured starting from vegetative (15–45 DAS) up to the pod filling stage (75–105 DAS) at 11.30 h at 30 days intervals using Line quantum sensor (APOGEE Logan UT). The instrument was placed 25 cm above the crop across the rows to estimate incident radiation. Then, it was kept horizontally under the canopy and placed likewise 25 cm higher the soil surface to measure the transmitted radiation from the bottom of the canopy. The reflected PAR was measured from the same position by simply inverting the sensor. Intercepted PAR (I PAR) and PAR use efficiency (PARUE) were calculated following Equations (1) and (2) [44]:

$$\text{I PAR } (\%) = \frac{\text{PAR}_{(O)} - \text{T PAR} - \text{R PAR}_{(C)}}{\text{PAR}_{(O)}} \times 100 \quad (1)$$

where $\text{PAR}_{(O)}$ = incident PAR above the canopy, T PAR = transmitted PAR through the canopy towards the soil surface, and $\text{R PAR}_{(C)}$ = reflected PAR from the canopy

$$\text{PARUE (g/Mega mole)} = \frac{\text{Dry matter accumulation } \left(\text{g/m}^2\right)}{\text{I PAR } \left(\text{Mega mole/m}^2\right)} \quad (2)$$

For taking observations of growth attributes of grass pea, 20 plants were tagged through random selection excluding the border rows from each plot. For growth analysis, dry matter accumulation, crop growth rate (CGR), and leaf area index (LAI) of grass pea crop was worked out at vegetative (30 DAS), flowering (60 DAS) and pod filling stage (90 DAS) from 10 randomly selected plants.

LAI was computed following the expression [45]:

$$\text{LAI} = \frac{\text{Leaf area per plant } \left(\text{m}^2\right) \times \text{ Number of plants}}{\text{Ground area } \left(\text{m}^2\right)} \quad (3)$$

CGR was estimated using the following formula of Watson [45] and expressed in g m$^{-2}$ day$^{-1}$:

$$\text{CGR} = \frac{1}{\text{G}} \times \frac{W_2 - W_1}{t_2 - t_1} \quad (4)$$

where $W_1$ = total dry weight of plant at time $t_1$, $W_2$= total dry weight of plant at time $t_2$ and G = ground area.

The leaf chlorophyll contents were estimated at 30, 60 and 90 DAS. It was measured by taking absorbance readings at 480, 510, 645 and 663 nm wavelengths against a blank one with only 80% acetone in a Systronics-105 spectrophotometer. The chlorophyll a and b, total chlorophyll and carotenoid were estimated with the following formula given by Arnon [46], all expressed in mg $g^{-1}$ of fresh leaf weight:

$$\text{Chlorophyll a} = (12.7 \times A_{663}) - (2.69 \times A_{645}) \times V/W \times 1000 \quad (5)$$

$$\text{Chlorophyll b} = (22.9 \times A_{665}) - (4.68 \times A_{663}) \times V/W \times 1000 \quad (6)$$

$$\text{Total chlorophyll} = (20.2 \times A_{645}) + (8.02 \times A_{663}) \times V/W \times 1000 \quad (7)$$

$$\text{Carotenoid} = (7.6 \times A_{480}) - (1.49 \times A_{510}) \times V/W \times 1000 \quad (8)$$

where V = Extract volume (mL), W = Fresh weight of leaf tissue (g), and A = Absorbance.

The net photosynthetic rate of grass pea leaves was measured with a portable handheld photosynthesis system (CI-340 Handheld Photosynthesis system, CID Bio-Science, Inc. Camas, WA, USA) and expressed in μmol $m^{-2}$ $s^{-1}$. The measurements were obtained on clear sunny days from the fully developed upper leaves of five selected plants from 11:30 a.m. to 12.30 p.m. at 30, 60 and 90 DAS.

The available nitrogen, phosphorous and potassium content in grass pea leaves were determined respectively by the modified Kjeldahl method [39], Olsen's method [40] and flame photometer method [39].

### *2.6. Statistical Analysis*

Data were statistically analysed by implementing the analysis of variance (ANOVA) techniques proposed by Gomez and Gomez [47] for factorial randomized block design. Pooled analysis was exercised in case of similar data from both years. Treatment means were compared by employing the F-test. The significant differences between the treatments were compared by a critical difference at a 5% level of significance. The regression analysis was carried out by SPSS 7.5 software, (SPSS 7.5 copyright, 1997 by SPSS Inc., USA Base 7.5 Application guide). Tukey's posthoc test was performed to compare the differences between mean values.

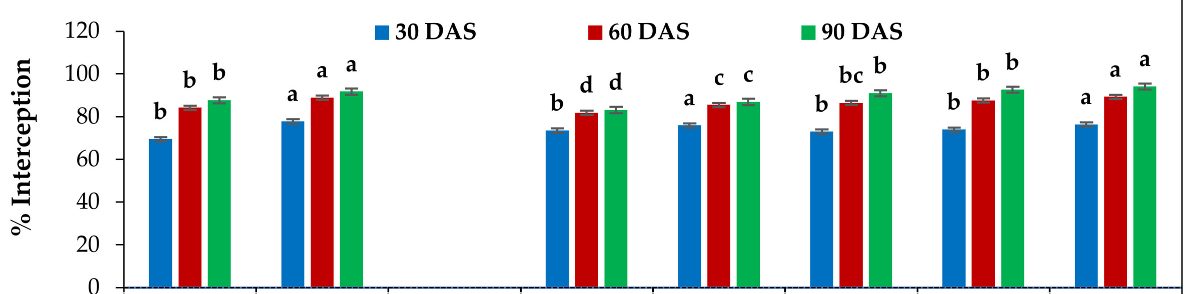
## 3. Results

### *3.1. Prevailing Weather Conditions during Grass Pea Growth*

The details of the meteorological parameters pertaining to the period of experimentation are presented in Figure 1a,b. The temperature throughout the months of the cropping period during *rabi* seasons (October 2017 to February 2018 and October 2018 to February 2019) ranged between 8.8 to 32.1 °C and 10.1 to 32.4 °C, respectively. During both of the years under experimentation, the average maximum and minimum temperature showed a decreasing trend from November to January. However, the average mean temperature tended to increase thereafter up to February. The crop experienced a very scanty rainfall during its growing seasons during both the experimental years. The maximum relative humidity varied between 90.0 to 97.5% and 89.8 to 92.9% while minimum relative humidity ranged from 44.5 to 75.2% and 32.8 to 59.6% during the experimentation period of 2017–2018 and 2018–2019. There was a variation in the bright sunshine hour being maximum in 2017–2018 and 2018–2019 in November (7.6 h) and February (7.9 h), respectively, while minimum sunshine hours were recorded in October (5.6 h) and December (5.9 h) during the consecutive seasons of the experiment. Maximum rainfall during the cropping period of 2017–2018 and 2018–2019 was 7.7 mm (October) and 0.7 mm (February), respectively.

### *3.2. Interception of Photosynthetic Active Radiation (PAR) by Grass Pea Canopy*

The percent interception of PAR has gradually escalated accordingly with the advancement of phenophases of the crop up to 90 DAS in the pooled estimation of the experimental years (Figure 2). Maximum interceptions were recorded with seed priming with ammonium molybdate (84.18 and 87.72%) and sprays of 0.5% foliar NPK (19:19:19) (88.87 and 91.79%) twice during 60 and 90 DAS, respectively, which were significantly higher compared to their corresponding treatments.




| | No priming | Seed priming with A. molybdate | | No spray | 2% urea (once) | 2 % urea (twice) | NPK 19:19:19 (once) | NPK 19:19:19 (twice) |
|---|---|---|---|---|---|---|---|---|
| 30 DAS | 69.51 | 77.84 | | 73.53 | 75.92 | 73.01 | 73.94 | 76.37 |
| 60 DAS | 84.18 | 88.87 | | 81.83 | 85.53 | 86.44 | 87.61 | 89.32 |
| 90 DAS | 87.72 | 91.79 | | 83.11 | 86.91 | 91.01 | 92.63 | 94.15 |

**Figure 2.** Percent interception of PAR during at different growth stages of grass pea (pooled means of 2 years) (Different letters in all bars indicate the significant differences between means.)

### *3.3. Effect of Seed Primimg and Foliar Spray of Nutrients on Growth Characters of Grass Pea*

Dry matter accumulation of relay grass pea progressively advanced with the development of the crop up to the pod development stage, i.e., 90 DAS (Figure 3). Interestingly, LAI and CGR also exhibited similar increasing trends till 90 DAS but with a decreasing rate from flowering (60 DAS) towards pod development.

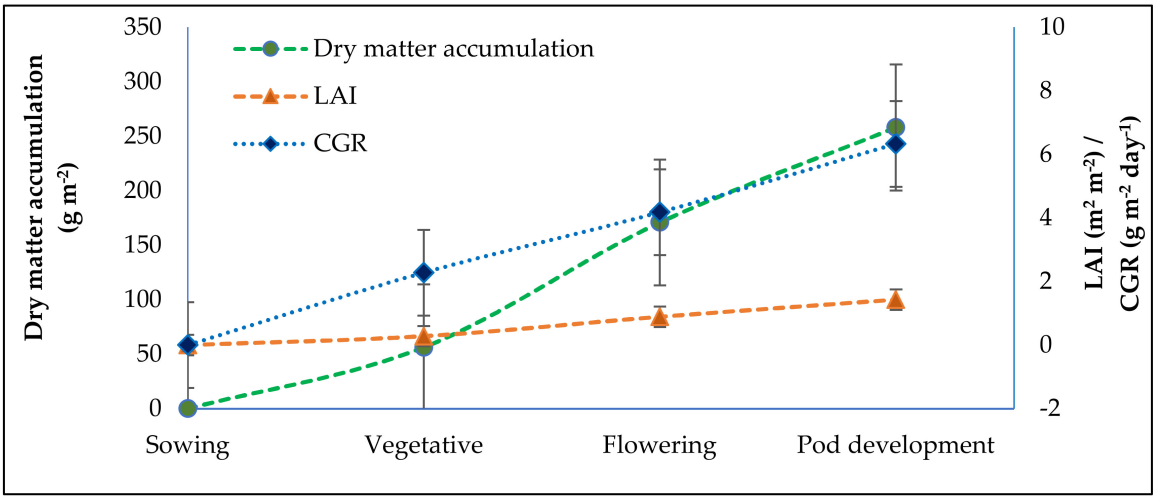



**Figure 3.** Growth characters at different phenophases of grass pea (pooled means of 2 years).

Significant variation was observed regarding growth traits of grass pea in terms of dry matter accumulation, LAI and CGR among the seed priming and foliar sprayed plots under pooled estimation (Tables 3–5, respectively). Molybdenum seed priming recorded greater dry biomass accumulation (58.84, 174.55 and 264.45 g $m^{-2}$) and crop growth rate (2.68, 4.23 and 6.95 g $m^{-2}$ $day^{-1}$) at 30, 60 and 90 DAS, respectively, which were statistically significant over control. Accordingly, seed priming also attained enlarged LAI of about 19.23, 4.59 and 4.28%, respectively, at 30, 60 and 90 DAS according to the pooled over data. During 60 and 90 DAS, higher dry biomass accumulation (176.97 and 269.40 g $m^{-2}$) and CGR (5.55 and 7.74 g $m^{-2}$ $day^{-1}$) were attained with the treatments where 0.5% NPK (19:19:19) spray was applied twice irrespective of seed priming. In case of foliar sprays, the lowest LAI was found without sprays. At the pod developmental stage (90 DAS), foliar sprays of 2% urea two times recorded a 9.09% increase, whereas a 16.67% increase was achieved with 0.5% NPK (19:19:19) foliar spray at pre-flowering and pod developmental stages. Interaction effects among the two factors of the experiment were found to be statistically significant in the later stages of growth of grass pea.

**Table 3.** Dry matter accumulation (g $m^{-2}$) in grass pea at different growth stages (pooled means of 2 years).

| Treatment | 30 DAS | 60 DAS | 90 DAS |
|---|---|---|---|
| Seed priming (S) | | | |
| No priming | 50.75 ± 0.38 b | 167.19 ± 0.25 b | 251.54 ± 0.25 b |
| Mo seed priming | 58.84 ± 0.19 a | 174.55 ± 0.48 a | 264.45 ± 0.54 a |
| CD ($p \leq 0.05$) | 3.36 | 3.48 | 4.47 |
| Foliar sprays of nutrient (F) | | | |
| No spray | 55.82 ± 0.76 b | 163.93 ± 0.25 e | 246.63 ± 0.28 e |
| 2% Urea (once) | 56.38 ± 0.60 a | 168.41 ± 0.54 d | 252.21 ± 0.38 d |
| 2% Urea (twice) | 56.23 ± 0.50 a | 170.77 ± 0.14 c | 258.04 ± 0.42 c |
| 0.5% NPK 19:19:19 (once) | 56.18 ± 0.20 a | 174.27 ± 0.27 b | 263.69 ± 0.25 b |
| 0.5% NPK 19:19:19 (twice) | 56.86 ± 0.29 a | 176.97 ± 0.47 a | 269.40 ± 0.37 a |
| CD ($p \leq 0.05$) | 0.03 | 2.13 | 3.65 |
| Interaction | | | |
| S F | NS | 3.82 | 5.86 |

NS—Non-significant. Different letters denote significant differences between means.

**Table 4.** LAI of grass pea at different growth stages (pooled means of 2 years).

| Treatment | 30 DAS | 60 DAS | 90 DAS |
|---|---|---|---|
| Seed priming (S) | | | |
| No priming | 0.26 ± 0.01 b | 0.87 ± 0.01 b | 1.40 ± 0.01 b |
| Mo seed priming | 0.31 ± 0.02 a | 0.91 ± 0.02 a | 1.46 ± 0.02 a |
| CD ($p \leq 0.05$) | 0.02 | 0.02 | 0.03 |
| Foliar sprays of nutrient (F) | | | |
| No spray | 0.27 ± 0.01 d | 0.85 ± 0.01 e | 1.32 ± 0.01 e |
| 2% Urea (once) | 0.28 ± 0.01 c | 0.88 ± 0.01 d | 1.39 ± 0.02 d |
| 2% Urea (twice) | 0.29 ± 0.02 b | 0.89 ± 0.01 c | 1.44 ± 0.02 c |
| 0.5% NPK 19:19:19 (once) | 0.30 ± 0.01 a | 0.92 ± 0.01 b | 1.48 ± 0.01 b |
| 0.5% NPK 19:19:19 (twice) | 0.28 ± 0.01 c | 0.92 ± 0.01 a | 1.54 ± 0.02 a |
| CD ($p \leq 0.05$) | NS | 0.02 | 0.04 |
| Interaction | | | |
| S × F | NS | 0.02 | 0.03 |

NS—Non-significant. Different letters designate significant differences between means.

### *3.4. Effect of Seed Priming and Foliar Spray of Nutrients on Physiology of Grass Pea*

Relatively higher total chlorophyll contents in grass pea leaves were observed with Mo seed priming as compared to no priming (1.09 vs. 1.15, 1.40 vs. 1.50, 0.93 vs. 1.02 mg $g^{-1}$ of fresh weight) at 30, 60 and 90 DAS, respectively (Figure 4). Foliar spray of nutrients took a significant positive role in improving the total chlorophyll content. This varied in the range of 1.09–1.27 mg $g^{-1}$ of fresh weight (30 DAS), 1.41–1.62 mg $g^{-1}$ of fresh weight (60 DAS), and 0.92–1.15 mg $g^{-1}$ of fresh weight in the pooled estimation. However, the twice foliar spray of 0.5% NPK (19:19:19) attained the highest values followed by twice 2% urea spray, which were statistically significant over control.

**Table 5.** CGR (g $m^{-2}$ $day^{-1}$) of grass pea at different growth stages (pooled means of 2 years).

| Treatment | 30 DAS | 60 DAS | 90 DAS |
|---|---|---|---|
| Seed priming (S) | | | |
| No priming | 1.89 ± 0.03 b | 3.84 ± 0.02 b | 5.49 ± 0.02 b |
| Mo seed priming | 2.68 ± 0.04 a | 4.23 ± 0.02 a | 6.95 ± 0.03 a |
| CD ($p \leq 0.05$) | 0.11 | 0.12 | 0.19 |
| Foliar sprays of nutrient (F) | | | |
| No spray | 2.21 ± 0.01 b | 2.42 ± 0.02 d | 5.02 ± 0.01 e |
| 2% Urea (once) | 1.58 ± 0.04 b | 3.56 ± 0.02 c | 6.36 ± 0.02 d |
| 2% Urea (twice) | 2.22 ± 0.03 b | 4.49 ± 0.03 b | 7.18 ± 0.02 c |
| 0.5% NPK 19:19:19 (once) | 2.81 ± 0.02 a | 4.90 ± 0.01 b | 7.32 ± 0.03 b |
| 0.5% NPK 19:19:19 (twice) | 2.85 ± 0.03 a | 5.55 ± 0.03 a | 7.74 ± 0.04 a |
| CD ($p \leq 0.05$) | 0.20 | 0.23 | 0.30 |
| Interaction | | | |
| S × F | NS | 0.32 | 0.43 |

NS—Non-significant. Different letters indicate significant differences between means.

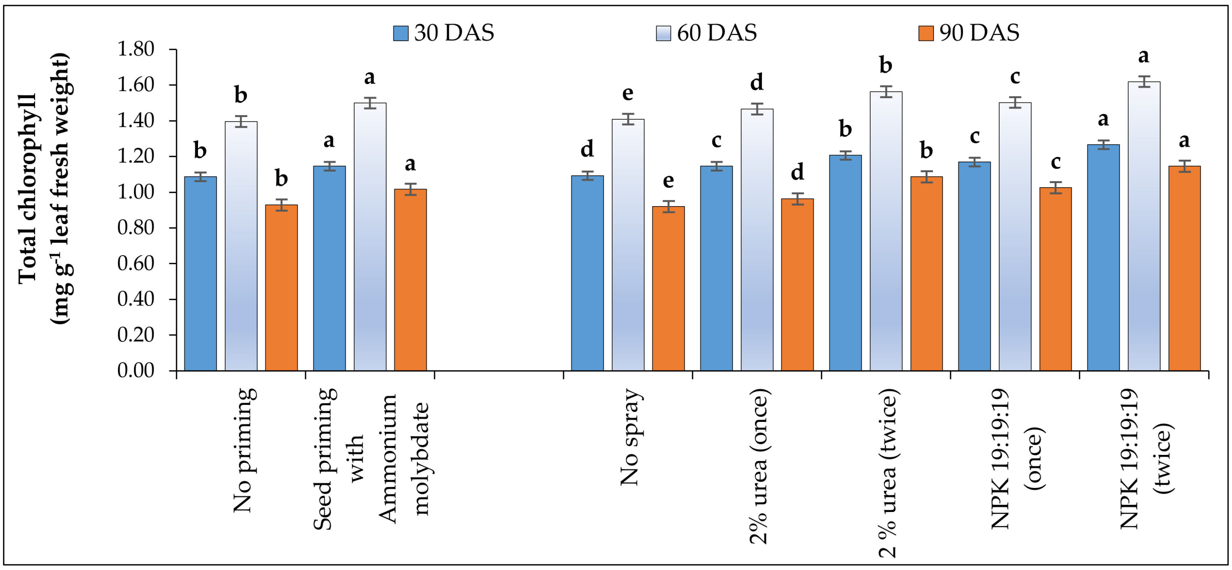



**Figure 4.** Effect of seed priming and foliar sprays on total leaf chlorophyll content of grass pea at different growth stages (pooled means of 2 years) (Different letters in all bars denote significant differences between means.)

The rate of photosynthesis in the above-ground parts of relay grass pea grown during *rabi* seasons of 2017–2018 and 2018–2019 progressively increased up to 60 DAS and afterwards a gradual decrease was observed (Figure 5). In accordance with leaf chlorophyll content, a significantly higher rate of net photosynthesis was observed under the treatment with seed priming irrespective of foliar nutrients application throughout the growing period as compared to control. Pooled results showed that Mo seed priming attained a higher rate of photosynthesis (7.98, 16.27 and 6.13 µmol $m^{-2}$ $s^{-1}$) at 30, 60 and 90 DAS, respectively, which were statistically significant over control. Among the different foliar sprayed treatments, 0.5% NPK (19:19:19) spray at pre-flowering and 15 days after 1st spray reached the maximum rate of net photosynthesis (18.25 µmol $m^{-2}$ $s^{-1}$) followed by 2% urea spray at pre-flowering and 15 days after 1st spray (16.82 µmol $m^{-2}$ $s^{-1}$) at the flowering stage concerning the pooled over means.

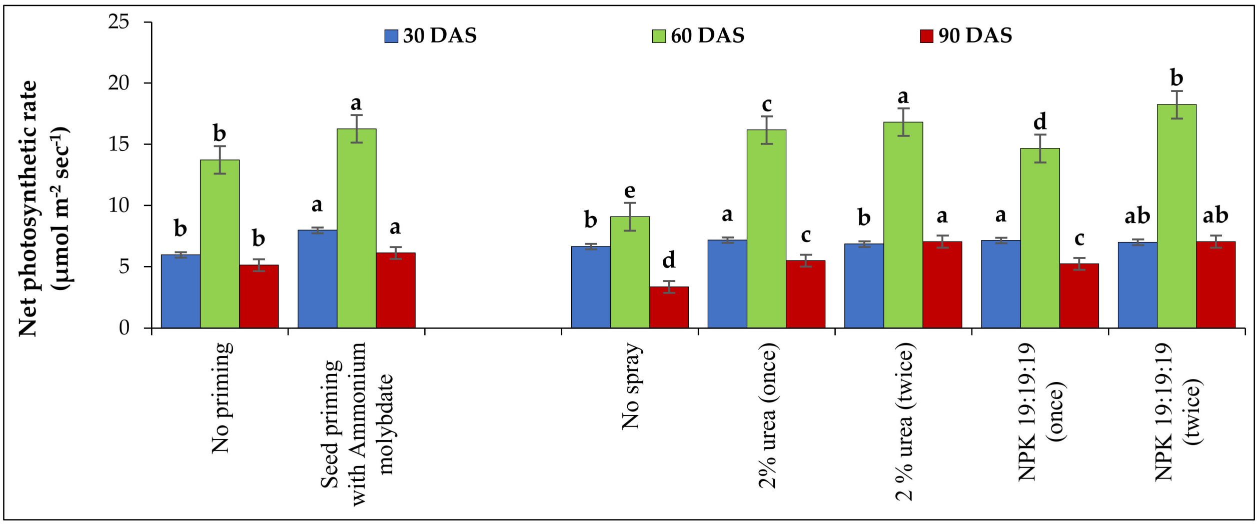



**Figure 5.** Effect of seed priming and foliar sprays on net photosynthetic rate of grass pea at different growth stages (pooled means of 2 years) (Different letters in all bars indicate significant differences between means.)

### *3.5. Growth and Physiology of Grass Pea with Respect to Intercepted PAR*

Intercepted PAR established linear relationships with respect to both LAI and total leaf chlorophyll contents of grass pea throughout its growing period under this study (Table 6). Pooled estimation revealed that about 94% and 88% variations in intercepted PAR could be explained by the variations, respectively, in LAI and total chlorophyll content at 90 DAS.

**Table 6.** Impact of leaf area index (x) and total chlorophyll (z) on cumulative intercepted PAR (y).

| Growth Stages | Impact of Leaf Area Index (x) | | | Impact of Total Chlorophyll (z) | | |
|---|---|---|---|---|---|---|
| | Regression Equation | $R^2$ | Relation | Regression Equation | $R^2$ | Relation |
| 30 DAS | y = 2.2063x + 0.0368 | 0.74 | Linear | y = 0.5551z + 0.0173 | 0.67 | Linear |
| 60 DAS | y = 0.7066x − 0.0256 | 0.83 | Linear | y = 0.2237z + 0.2717 | 0.85 | Linear |
| 90 DAS | y = 0.3957x + 0.1251 | 0.94 | Linear | y = 0.3772z + 0.2965 | 0.88 | Linear |

The efficiency in PAR interception among the various treatments was verified with the trend in dry biomass accumulation as well as with the pattern of net photosynthetic rate. Both the dry matter accumulation and net photosynthetic rate were estimated to be polynomial functions of intercepted PAR throughout the growth stages of grass pea. The magnitude of $R^2$ values showed its significance in those relationships (Figure 6). $R^2$ values indicated that about 83.15, 93.76 and 96.69% variations in dry matter accumulation at 30, 60 and 90 DAS, respectively, could be explained by the differentiation in cumulative intercepted PAR, whereas these variations reached the tune of 76.74, 78.64 and 83.33% at the respective intervals with respect to the rate of net photosynthesis.

### *3.6. Photosynthetic Active Radiation Use Efficiency (PARUE) of Grass Pea*

The accumulation rate of dry biomass per unit interception of PAR i.e., the PARUE were found to be significantly higher in case of seed priming (0.09, 0.22 and 0.43 g Mega mole$^{-1}$) compared to without priming (0.07, 0.19 and 0.41 g Mega mole$^{-1}$) at 30, 60 and 90 DAS. However, the application of 0.5% NPK (19:19:19) spray at pre-flowering following the second one at 15 days intervals recorded the highest PARUE (0.25 and 0.50 g Mega mole$^{-1}$) at the respective intervals among all the foliar-applied treatments (Figure 7).

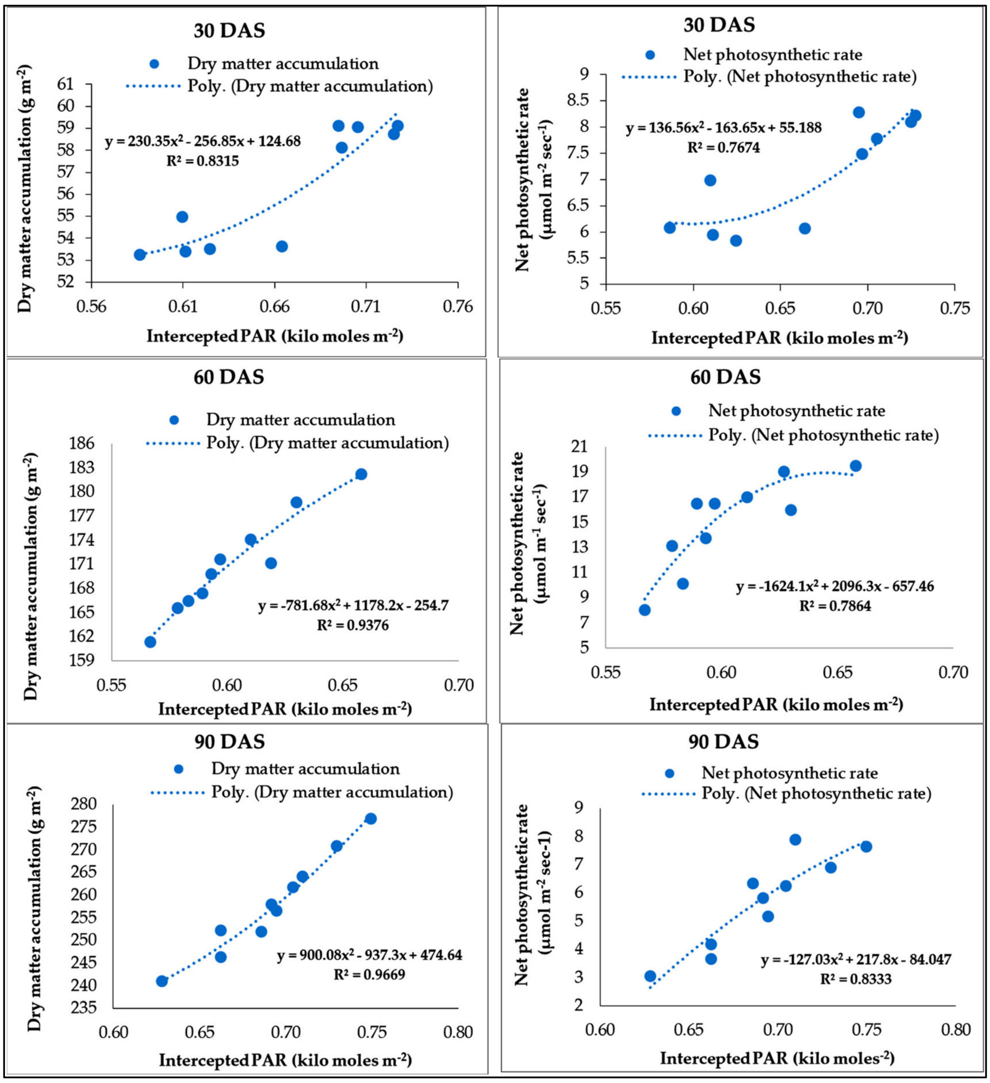



**Figure 6.** Impact of intercepted PAR on dry matter accumulation and net photosynthetic rate of grass pea.

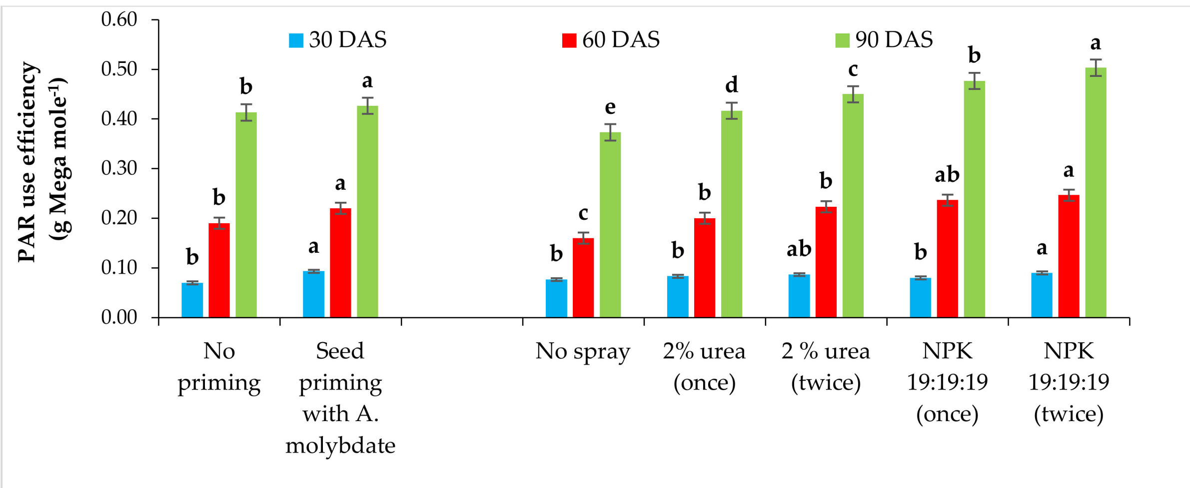



**Figure 7.** PAR use efficiency at different growth stages of grass pea (pooled means of 2 years). (Different letters in all bars indicate significant differences between means.)

### 3.7. Seed Yield of Grass Pea

Seed yield of grass pea was magnified with the treatments efficiently enhancing crop growth and net photosynthetic rate, eventually intercepting a greater amount of PAR in both years. Seed priming with ammonium molybdate recorded significantly higher seed yield compared to control (1509.99 and 1350.40 kg ha$^{-1}$) under pooled estimation of 2017–2018 and 2018–2019. Among the foliar sprayed plots, foliar 0.5% NPK (19:19:19) at pre-flowering and 15 days after 1st spray registered to the tune of 1589.39 kg ha$^{-1}$ seed yield, which was statistically significant over the others (Figure 8).

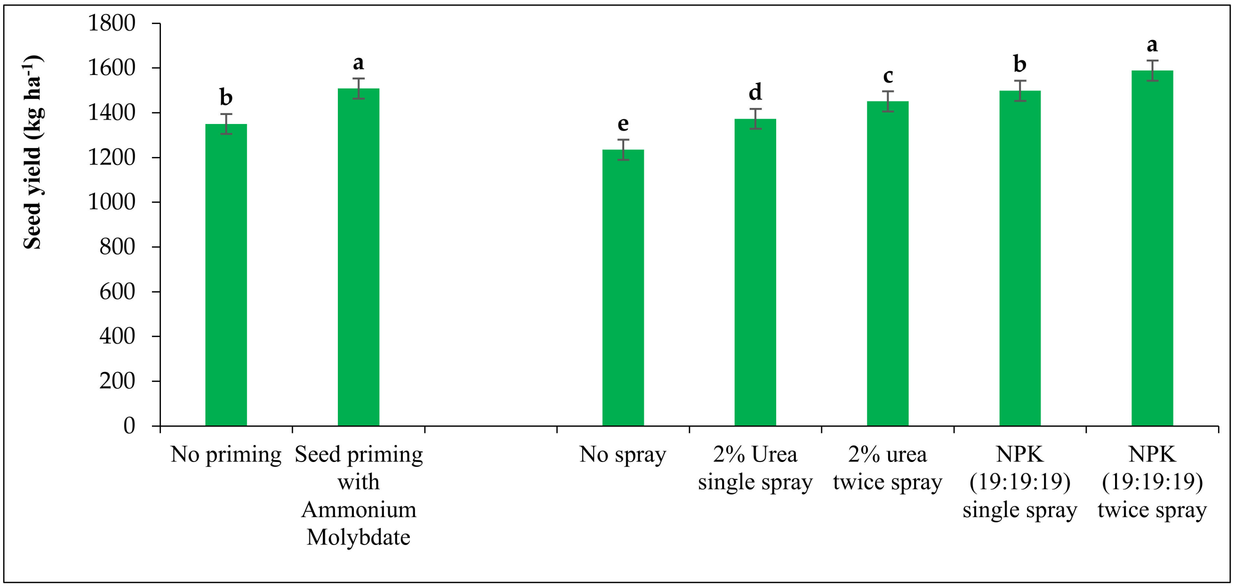



**Figure 8.** Seed yield of grass pea as influenced by seed priming and foliar nutrition (pooled means of 2 years) (Different letters in all bars denote significant differences between means.)

For the season 2017–2018, the variations obtained in yield was 96.2% governed by the variations in PAR at 30 DAS and PAR at 90 DAS (Table 7). Moreover, variations in PAR at 90 DAS alone dictates 98.3% of the variations observed in yield. The variations in PAR at 90 DAS govern 95.1% of the variations obtained in yield in 2018–2019.

**Table 7.** Effect of intercepted PAR on seed yield of grass pea.

| Regression Equations | $R^2$ | Adj. $R^2$ | Significance |
|---|---|---|---|
| 2017–2018 | | | |
| $Y = -1090.263 + 3483.124\ PAR_{90}$ ** + $317.668\ PAR_{30}$ * | 0.966 | 0.962 | 30.530 |
| $Y = -1013.469 + 3676.854\ PAR_{90}$ | 0.987 | 0.983 | 20.637 |
| 2018–2019 | | | |
| $Y = -2225.833 + 5096.12\ PAR_{90}$ ** | 0.957 | 0.951 | 33.626 |

* Significant at 5%, ** significant at 1% level of probability.

### 3.8. Impact of Seed Primimg and Foliar Nutrition on Nutrients Content in Grass Pea Leaves

Pooled analysis presented in Table 8 revealed that seed priming with ammonium molybdate facilitated maximum leaf N, P and K contents (0.86, 0.25 and 1.11%, respectively) which were statistically significant over control. Twice foliar spray of 0.5% NPK (19:19:19) attained maximum nutrients in leaf estimation among the foliar sprayed plots. Next to this, the treatment with twice sprays of 2% urea recorded higher values of leaf N content. However, a single spray of NPK (19:19:19) achieved more P and K contents as compared to twice sprays of 2% urea.

**Table 8.** Effect of seed priming and foliar sprays on leaf nutrients (N, P and K) content (%) in grass pea (pooled means of 2 years).

| Treatment | N (%) | P (%) | K (%) |
|---|---|---|---|
| Seed priming (S) | | | |
| No priming | 0.78 ± 0.01 b | 0.22 ± 0.01 b | 1.07 ± 0.01 b |
| Mo seed priming | 0.86 ± 0.02 a | 0.25 ± 0.01 a | 1.11 ± 0.02 a |
| CD ($p \leq 0.05$) | 0.01 | 0.01 | 0.01 |
| Foliar sprays of nutrient (F) | | | |
| No spray | 0.65 ± 0.01 e | 0.17 ± 0.01 e | 0.99 ± 0.01 e |
| 2% Urea (once) | 0.84 ± 0.01 d | 0.21 ± 0.01 d | 1.06 ± 0.01 d |
| 2% Urea (twice) | 0.88 ± 0.01 b | 0.24 ± 0.01 c | 1.11 ± 0.02 c |
| 0.5% NPK 19:19:19 (once) | 0.79 ± 0.01 c | 0.27 ± 0.02 b | 1.13 ± 0.25 b |
| 0.5% NPK 19:19:19 (twice) | 0.93 ± 0.01 a | 0.30 ± 0.02 a | 1.17 ± 0.37 a |
| CD ($p \leq 0.05$) | 0.02 | 0.01 | 0.02 |
| Interaction | | | |
| S × F | 0.02 | NS | NS |

NS—Non-significant. Different letters designate significant differences between means.

## 4. Discussion

### 4.1. Impact of Seed Primimg and Foliar Spray of Nutrients on Growth Traits and Physiology

Initial Mo application was found to be strongly associated with extension of canopy coverage, which maintained a progressive increment in LAI and CGR even after the reproductive growth set in. Nevertheless, an increasing rate of LAI and CGR with a declining pattern after flowering (60 DAS) might be due to a simultaneous onset of the reproductive stage with leaf senescence and a reduced rate of newer leaf emergence of grass pea owing to terminal heat and moisture stress [48]. In fact, the crop was exposed to a constant rise in ambient temperature coupled with deficit atmospheric humidity and soil moisture particularly at the time of seed filling due to lack of rainfall and exclusion of irrigation and a decline in soil moisture storage due to and irrigation. As a consequence, the crop might have survived with lower water consumption hampering the normal rate of net photosynthesis. Probably, this phenomenon was more prevalent in case of avoidance of any kind of nutrient use, which drastically brought down the overall growth rate in those treatments. Enhancement in plant growth with Mo application was cited with respect to several winter pulse crops including lentil [49], chickpea [50], garden pea [51], grass pea [16], etc. No specific pattern in crop growth was found among the foliar sprayed treatments at 30 DAS as the spraying schedule started from 45 DAS onwards. Additionally, foliar spray of NPK at the pre-flowering stage followed by an additional one after 15 days with special reference to grass pea happened to be a fantastic way out to flourish with extended leaf area throughout the reproductive phase of this crop.

### 4.2. Growth and Physiology of Grass Pea in Connection with Intercepted PAR

From Table 2 and Figure 2, it was evident that grass pea crop intercepted a greater amount of PAR with successive enlargement in leaf area throughout the growing period. This finding was in agreement with Worku and Demisie [3]. The introduction of the exclusive combination of micronutrient Mo and macronutrients (NPK) might have helped in profuse branching and leaf production resulting in higher final biomass production. Due to lesser canopy coverage, the treatment without priming or foliar spray always intercepted least amount of PAR. Availability of Mo in the form of seed priming might have facilitated better nitrogen metabolism. In addition, Mo is associated with the absorption and translocation of iron (Fe) in plants [52]. In this connection, Fe plays a pivotal role in chloroplast development, chlorophyll biosynthesis and energy transfer in plants [53]. Thus, the physiological efficiency in terms of photosynthetic activity of grass pea was probably boosted with the active participation of Mo in this regard [54]. In addition, application of NPK might be attributed to amplifying the expansion of leaf area, chlorophyll content and nutrients assimilation capacity of the crop [55]. The efficiency of foliar NPK was clearly portrayed by the study of leaf photosynthesis. Maximum photosynthesis was positively correlated with leaf nitrogen, phosphorus and potassium content [56]. Longstreth and Nobel [57] reported that plant mineral status could markedly influence the photosynthesis owing to modified leaf chlorophyll content. These improved features related to leaf area expansion and enhanced production of photosynthetic pigments augmented better PAR interception and photosynthetic efficiency, ultimately magnifying the productivity of crops [35]. Positive interaction between leaf area extension and PAR interception have already been recorded earlier [8]. Interception of PAR and its impact on growth and physiology has been recorded by a number of authors in terms of different legumes. In some of the cases, the relationships were linear [9] and, in other instances, these were found to be polynomial [58].

### 4.3. PAR Use Efficiency (PARUE)

Higher use efficiency of I PAR with the application of Mo seed prining and 0.5% NPK (19:19:19) spray at pre-flowering following the second one at a 15 day interval recorded implied better efficiency in terms of conversion of energy to dry matter in the particular treatments. In other words, this treatment with seed priming along with ammonium molybdate at 0.5 g $kg^{-1}$ seed combined with twice foliar sprays of 0.5% NPK (19:19:19) utilized maximum energy to produce the greater volume of biomass with better LAI and improved rate of crop growth. Foliar nutrition might have triggered the grass pea crop growth and aided in flourishing profuse canopy coverage, which in turn led to greater interception and use efficiency of solar radiation [4]. Rosati and Dejong [59] suggested that PARUE was improved with N fertilization. Randhawa et al. [35] observed a positive impact of supplemental NPK on plant growth by modification of the shape and size of the crop canopy, thereby obtaining higher use efficiency of intercepted solar radiation. Notably, biomass accumulation per unit energy use was at a maximum during the later phases of grass pea growth under the present experiment. Similar trends were found under mungbean [2] and lentil [60]. This might occur in the pulse crops because of late emerging vegetative flushes in these crops with the intercepted solar radiation.

### 4.4. Yield and Leaf Nutrients Content of Grass Pea in Relation to I PAR

In the present experiment, seed priming with ammonium molybdate at the rate of 0.5 g $kg^{-1}$ seed and foliar 0.5% NPK (19:19:19) at pre-flowering and 15 days after the 1st spray established a remarkable influence regarding augmentation of seed yield. Similar positive outcomes in response to seed priming with Mo in economic yield of chickpea [61], cowpea [62] and grass pea [63] and that of lentil [64] and grass pea [54] with respect to foliar spraying of 0.5% NPK (19:19:19) was reported earlier. Increment in leaf nutrient contents through Mo seed priming were cited by a number of literature works regarding chickpea [65], lentil [66], mungbean [67], peanut [68], etc. Involvement of Mo in vital physiological and biochemical functions, especially regarding the functioning of leghemoglobin protein and nitrogenase enzyme required for rhizobial activity in legumes for N fixation and its subsequent assimilation related to nitrate reductase activity has already been reported to manifest momentous impact on legume growth and productivity [20]. Navaz et al. [19] revealed the synergistic effect of Mo on escalating the N, P and K contents in grass pea stover. However, foliar NPK induced enhancement in nutrient content in pigeon pea leaves was reported by Gowda et al. [69]. In a nutshell, nutrient application in the form of seed priming with Mo and foliar NPK remarkably contributed to improved photosynthesizing capacity and better source to sink partitioning through considerable capture of solar radiation eventually brought about a spectacular increase in biomass and seed yield. In particular, foliar nutrition with NPK might have fostered the cell division and enzymatic activity through regulation of water economy inside the grass pea plants. This eventually accelerated the flower production, photosynthetic rate, translocation of photosynthates to the seed, pod formation and seed development and turning up with higher seed yield [16].

Basically, the optimum temperature range for grass pea growth ranges from 10–25 °C. However, it requires around 15 °C temperature for healthier seedling growth during the vegetative stage [70]. In fact, mean daily maximum temperature above 25 °C has been considered as the upper threshold limit for heat stress in cool season crops [71]. The higher mean daily maximum temperature coupled with lower mean relative humidity that the crop experienced during the pod developmental stage were visibly beyond the optimum range (Figure 1). Hence, the crop had definitely been exposed to heat stress during this stages, which is critical from the production point of view of grass pea. On the other hand, higher temperatures combined with lower relative humidity have a specific role in increasing the evapotranspiration loss from soil as well as crop canopy, which can imply apparent moisture stress at the reproductive stage of this crop. Decline in relative humidity in the air owing to the higher atmospheric temperature and rainfall scarcity might have substantially attributed to intensifying the impacts of heat and moisture stress inside the crop by means of depleting the soil moisture storage [63,72]. In this context, the crop faced adverse impacts of these abiotic stresses on overall growth and physiological development without the external supply of plant nutrients, consequently acquiring lesser photosynthetic area and harvesting lower amounts of photosynthetically active portion of solar radiation biomass production, ultimately hampering seed set and yield potential [73]. Optimum supply of plant nutrients might have successfully endeavoured for mitigation of the terminal heat and moisture stress with simultaneous increment in PAR interception in the crop of the corresponding treatments. Apart from this, the greater sunshine hours during the growing period of grass pea in both years might have contributed to better interception of solar radiation and corresponding upgradation of photosynthetic activity [54].

## 5. Conclusions

Characteristics of radiation interception is one of the fundamental contributing unique features with respect to field crops production. On the other hand, LAI and CGR could be considered as vital indices to influence light interception in grass pea crop through expansion of canopy coverage. Limitations in production owing to restricted PAR capture and photosynthetic activity were evident from the reduced growth rate, depleted chlorophyll, and nutrients content in leaves. Considering the findings of the present experiment, it may be concluded that integration of seed priming with ammonium molybdate at 0.5 g $kg^{-1}$ seed along with exogenous application of 0.5% NPK (19:19:19) spray at pre-flowering and 15 days after 1st spray may be adopted by the grass pea farmers in case of its relay sowing for immense potential of this combination with respect to interception and use efficiency of PAR sustaining growth and production potential under Lower Gangetic plains of Eastern India.

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