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RESEARCH ARTICLE

Performance evaluation of summer irrigated green gram (*Vigna radiata* L.) by combined application of basal nitrogen and foliar fertilization of nano urea

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Abstract
A field experiment was conducted at wetland farm of Tamil Nadu Agricultural University, Coimbatore during the summer season, 2022 to study the influence of integrated application of basal nitrogen and foliar feeding of nano and conventional urea on growth, physiology, yield parameters, yield and quality attributes of irrigated green gram. The experiment was laid out in Factorial Randomized Block Design (FRBD) with two factors *viz*, different basal nitrogen dose (N) and foliar supplementation of various concentration of nano and conventional urea at flower initiation (FI) stage and 15 days thereafter (F). There were four levels under each factor namely, N_1 - 100 % RDN (Recommended Dose of Nitrogen) (25 kg N ha^{-1}), N_2 - 80 % RDN (20 kg N ha^{-1}), N_3 - 60 % RDN (15 kg N ha^{-1}) and N_4 - Nitrogen free control under factor I. Likewise, F_1 - Nano urea @ 2 ml litre^{-1} of water, F_2 - Nano urea @ 3 ml litre^{-1} of water, F_3 - Nano urea @ 4 ml litre^{-1} of water and F_4 - 1 % conventional urea under factor II. The experimental outcomes revealed that the treatment combination of 100 % RDN + foliar spray of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter significantly recorded superior values of plant height, leaf area index, crop growth rate, relative growth rate, net assimilation rate, chlorophyll content, soluble protein content, nitrate reductase activity, fertility co-efficient, grain yield, protein content and protein yield. Nevertheless, it was on par with basal application of 80 % RDN + foliar nutrition of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter. Thus, adoption of 80 % RDN as basal dose integrated with foliar feeding of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter could be the viable integrated nitrogen management practice to enhance the performance of green gram under summer irrigated conditions.

Keywords
basal nitrogen; foliar nutrition; green gram; growth; nano urea; yield

Introduction
Pulses play an inevitable role in the modernized intensive cropping and farming system approaches because of their exceptional agroecological benefits like atmospheric nitrogen fixation, accumulation of organic matter in soil, weed smothering ability, enhancing the soil microbial activity, etc. Green gram or mung bean belonging to the family of Fabaceae has enormous benefits for the environment and mankind. The protein content of green gram is around 24-25 %, which makes it an alternate meat for the vegans. Usually, it is preferred by most of the people due to its excellent nutritional value and palatability. The

total area under the cultivation of green gram in India is around 5.19 Mha with a total production of 3.103 MT with a productivity level of 598 kg ha^{-1}. The production of green gram is highly dominated by the states of Madhya Pradesh, Rajasthan and Odisha (1). Generally, pulses are cultivated without any special care and attention like other crops and are left to the nature, thus resulting in the realization of poor yield and profit. The predominant problem in the cultivation of green gram is flower abortion and flower shedding, due to improper source-sink relationship and translocation of photosynthates from source to sink, thereby leading to a huge decline in the production potential of the crop (2). Nitrogen is one of the key nutrients required for each crop to nourish and nurture well. It is highly responsible for the plant growth and development as it is a vital component for the synthesis of protein and chlorophyll (3). Though there is plenty of nitrogen gas available in the atmosphere, only the plants of Fabaceae possess the ability to utilize it as their source of nitrogen (4). The deficiency of nitrogen in plants results in poor growth and development which negatively impacts the formation of yield components and yield (5). Hence, optimum supply of nitrogen is essential to support the establishment of crop during the grand vegetative growth and reproductive stages of green gram. Besides this, the crop also requires supplemental nutrition during its critical stages *i.e.*, mostly at their reproductive stages, in order to prevent flower abortion and dropping and this can be satisfied through foliar feeding of nutrients with the right source and right concentration applied through the right methods which aids in alleviating the nutrient deficiencies of the crop and also helps in the efficient translocation of nutrients from source to sink. The concept of foliar feeding has been producing noteworthy results and so it has been considered as the need of the hour for improving the performance of crops (6). In this regard, to overcome the persistent problems of green gram and to boost up its growth, yield and improve its quality parameters, an integrated approach involving basal and foliar application of nitrogen must be evolved. Recently, Indian Farmers Fertilizer Cooperative Limited (IFFCO) had released a novel product named “Nano Urea” in the form of liquid which has been producing notable results when sprayed at critical stages of crops. Correspondingly, its efficiency was also higher when compared to conventional urea fertilizer. With this background, a field investigation was carried out to evaluate and evolve an integrated nitrogen nutrient management practice for enhancing the performance of summer irrigated green gram by combining diverse levels of basal nitrogen and various concentration of nano and conventional urea foliar spray.

Materials and Methods

Field experiment was conducted at the wetland farm of Tamil Nadu Agricultural University, Coimbatore during the summer season (March - May) of 2022. The experimental area is located at 11° N latitude and 77° E longitude with an altitude of 426.7 m above MSL falling under the category of southern agro-climatic zone of India and western agro-climatic zone of Tamil Nadu. The weather conditions prevailed during the entire cropping period has been portrayed in Table 1.

Table 1. Weather conditions prevailed during the cropping period

Weather parameters	Values
Mean maximum temperature	34.5 °C
Mean minimum temperature	23.6 °C
Average relative humidity at morning	82.7 %
Average relative humidity at evening	45.6 %
Total rainfall	57.9 mm with 5 rainy days

The soil type of the experimental field was clay loam and the data pertaining to its physico-chemical properties are given in Table 2.

Table 2. Physico-chemical properties of the soil of the experimental field

Particulars	Values
Physical properties	
Bulk density	1.25 g cc^{-1}
Particle density	2.43 g cc^{-1}
Porosity	48.6 %
Chemical properties	
pH (1:2.5 soil and water suspension solution)	8.19
EC (1:2.5 soil and water suspension solution)	0.42 dSm^{-1}
Organic carbon content (chromic acid wet digestion method)	0.66 %
Available nitrogen (alkaline permanganate method)	224.0 kg ha^{-1} (low)
Available phosphorus (Olsen method)	16.4 kg ha^{-1} (medium)
Available potassium (neutral normal ammonium acetate method)	879.0 kg ha^{-1} (high)

This field study was laid out in Factorial Randomized Block Design with two factors viz., diverse levels of basal nitrogen (Factor I) and different concentration of nano and conventional urea as foliar spray (Factor II). Each factor consists of four levels. Under factor I, the following basal nitrogen dose viz., N_1 - 100 % Recommended Dose of Nitrogen (RDN) (25 kg N ha^{-1}), N_2 - 80 % RDN (20 kg N ha^{-1}), N_3 - 60 % RDN (15 kg N ha^{-1}) and N_4 - Absolute nitrogen control (0 kg N ha^{-1}) was assigned. Similarly, under factor II the following foliar feeding practices *viz.*, F_1 - Nano urea @ 2 mL $litre^{-1}$ of water at Flower Initiation (FI) stage and 15 days thereafter, F_2 - Nano urea @ 3 mL $litre^{-1}$ of water at FI stage and 15 days thereafter, F_3 - Nano urea @ 4 mL $litre^{-1}$ of water at FI stage and 15 days thereafter, F_4 - 1 % urea (conventional fertilizer) at FI stage and 15 days thereafter were assigned. All the treatment combinations (Factor I x Factor II) were replicated thrice. Besides the experimental treatments, basal application of phosphorus (50 kg P_2O_5 ha^{-1}) and potassium (25 kg K_2O ha^{-1}) were applied uniformly to all the experimental plots at the time of sowing. The nutrient content of the fertilizers used in the study is given in Table 3. The following are the specifications of IFFCO’s nano urea liquid fertilizer, the particle size of nano urea is about 20-50 nm, it possesses more surface area (10000 times over 1 mm conventional urea prill) and number of particles (55000 nitrogen particles over 1 mm urea prill).

Table 3. Nutrient content of the fertilizers used in the study

Fertilizers	Nutrient content (%)
Urea	46 % N
Single super phosphate	16 % P_2O_5
Muriate of potash	60 % K_2O
Nano urea	4 % N w/v basis

Gross and net plot size of 4.0 m × 4.0 m and 2.8 m × 3.6 m respectively was adopted in this study. Certified seeds of green gram variety CO 8 were used in the experiment. The certified seeds were treated with bioferilizers (*Rhizobium* and *Phosphobacteria*) and bio-control agent (*Bacillus subtilis*) as per the recommendation and they were sown in lines by adopting the recommended row and plant spacing of 30 cm × 10 cm respectively with a seed rate of 20 kg ha^{-1}. As per the treatment schedule, for imposing the treatment factor I, the required quantity of urea was weighed and applied basally at the time of sowing. Similarly for imposing the treatment factor II, the required quantity of nano urea and conventional urea were measured and mixed thoroughly with the recommended spray volume (500 litres of water ha^{-1}). For effective and efficient absorption of foliar nutrients, foliar feeding of nutrients was carried out during morning hours (before 9 AM). The crop was irrigated five times from sowing to harvest in addition to the supplemental rainfall. Suitable plant protection measures were adopted to control the pest and diseases. The data on plant height was recorded from the five randomly tagged plants in the net plot area. Plant height was measured using a ruler from the base of the plant to the tip where the last leaf emerges and expressed in cm. For computing the Leaf Area Index (LAI), five plants were pulled out randomly from the sampling rows and all the leaves of individual plants were plucked and were placed in the leaf area meter to record the total leaf area $plant^{1}$ and its average value was arrived and expressed in cm^2. From leaf area $plant^{-1}$, LAI was calculated by dividing the leaf area $plant^{-1}$ to the ground area occupied by the individual plant. Both plant height as well as LAI was calculated at FI, PS and harvest stage. After recording the leaf area, the plucked leaves along with other plant parts were dried at 65 ± 5 ^{0}C until a constant weight was obtained. The weight was quantified using an electronic balance and it was used to compute crop growth rate, relative growth rate and net assimilation rate.

Crop growth rate (CGR) was calculated using the formula (7).

$$\text{CGR} = \frac{W_2 - W_1}{P\,(t_1 - t_2)} \quad \text{g m}^{-2}\ \text{day}^{-1}$$

where,

W_1 and W_2 are dry weight (g) of plants at time t_1 and t_2 respectively

t_1 and t_2 indicates the initial and final day of observation

P is the ground cover occupied by the plant in m^2

Relative growth rate (RGR) was estimated by adopting the formula (8).

$$\text{RGR} = \frac{\text{Log}_e W_2 - \text{Log}_e W_1}{t_1 - t_2} \quad \text{g g}^{-1}\ \text{day}^{-1}$$

where,

W_1 and W_2 are dry weight (g) of plants at time t_1 and t_2 respectively

t_1 and t_2 denotes the initial and final day of observation respectively

Net assimilation rate (NAR) was calculated by using the formula (8).

$$\text{RGR} = \frac{(W_2 - W_1)}{(t_1 - t_2)} \times \frac{\text{Log}_e L_2 - \text{Log}_e L_1}{L_2 - L_2} \quad \text{mg cm}^{-2}\text{day}^{-1}$$

where,

W_1 and W_2 are dry weight (mg) of plants at time t_1 and t_2 respectively

t_1 and t_2 are initial and final day of observation respectively

L_1 and L_2 indicates the leaf area at time t_1 and t_2 respectively

CGR, RGR and NAR were recorded between FI - Pod Setting (PS) stage and PS - harvest stage.

Chlorophyll content was estimated by following the method (9) and expressed in mg g^{-1} of leaf sample. Soluble protein content was calculated (10) and expressed in mg g^{-1} of leaf sample. Nitrate reductase activity was estimated (11) and expressed in µg NO_2 g^{-1} hr^{-1}. All the physiological parameters were recorded at FI, PS and harvest stage. The number of flowers produced $plant^{-1}$ was counted in five randomly tagged plants from the start of flowering until the flowering ceases. Likewise, the number of pods produced $plant^{-1}$was counted in five plants which were randomly tagged. Fertility co-efficient was worked out by adopting the formula (12).

$$\text{Fertility co-efficient or pod setting percentage} = \frac{\text{Number of pods plant}^{-1}}{\text{Number of flowers plant}^{-1}} \times 100$$

After threshing the grains from the net plot area of the respective treatments, they were winnowed and dried to 12 per cent moisture content and thereafter the grain yield was recorded by using an electronic balance and expressed in kg ha^{-1}. For analysing the protein content in grains, the cleaned grains from the respective treatments were dried and finely ground using Wiley mill, then they were subjected to digestion using diacid mixture for estimating the nitrogen content in seed. To estimate the protein content of the grain samples, the obtained nitrogen content in grain had been multiplied with the factor 6.25 (13).

Protein yield of green gram grains was computed by using the formula proposed by Kushwaha & Chandel (14) and denoted in kg ha^{-1}.

$$\text{Protein yield} = \frac{\text{Grain yield (kg ha}^{-1}) \times \text{Protein content (\%)}}{100}$$

All the data recorded were statistically analysed using AGRESS software (15). For significant treatments, the critical difference was worked out at 5 % probability level, whereas in case of treatments that were non-significant at 5 % probability level were denoted as NS.

Results and Discussion

Growth parameters

Plant height and LAI were significantly influenced by varied dose of basal nitrogen at all stages of observation *viz.*, FI, PS and at harvest stage (Table 4 and 5).

Basal application of 100 % RDN (N_1 - 25 kg N ha^{-1})

Table 4. Influence of varied levels of basal nitrogen and diverse concentration of nano and conventional urea foliar spray on plant height (cm) of green gram

Treatments	At flower initiation stage (cm)					At pod setting stage (cm)					At harvest stage (cm)				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
N_1	25.0	24.9	25.7	24.8	**25.1**	38.7	45.9	47.1	35.4	**41.8**	46.2	49.1	51.4	38.2	**46.2**
N_2	22.5	21.9	22.0	21.8	**22.1**	38.1	44.0	46.7	35.0	**41.0**	41.0	48.9	49.3	38.0	**44.3**
N_3	21.0	19.6	19.3	20.5	**20.1**	37.5	38.0	38.3	34.7	**37.1**	39.8	40.5	41.4	37.9	**39.9**
N_4	19.0	18.8	17.8	18.4	**18.5**	33.8	34.0	34.4	32.3	**33.6**	36.4	36.5	36.6	35.4	**36.2**
Mean	**21.9**	**21.3**	**21.2**	**21.4**		**37.0**	**40.5**	**41.6**	**34.4**		**40.9**	**43.8**	**44.7**	**37.4**	

Treatments	N	F	N X F	N	F	N X F	N	F	N X F
SEd	0.7	0.7	1.5	1.2	1.2	2.4	1.3	1.3	2.7
CD (P=0.05)	1.5	NS	NS	2.5	2.5	5.0	2.7	2.7	5.4

Recommended dose of nitrogen			Foliar spray of nano and conventional urea		
N_1	-	100 % RDN (25 kg N ha^{-1})	F_1	-	Nano urea @ 2 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_2	-	80 % RDN (20 kg N ha^{-1})	F_2	-	Nano urea @ 3 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_3	-	60 % RDN (15 kg N ha^{-1})	F_3	-	Nano urea @ 4 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_4	-	Control	F_4	-	1 % urea (conventional) at flower initiation stage and 15 days thereafter

Table 5. Effect of diverse dose of basal nitrogen and different concentration of nano and conventional urea foliar spray on leaf area index of green gram

Treatments	At flower initiation stage					At pod setting stage					At harvest stage				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
N_1	1.64	1.63	1.60	1.67	**1.64**	3.30	3.75	3.82	3.00	**3.47**	2.93	3.33	3.47	2.62	**3.09**
N_2	1.66	1.57	1.60	1.62	**1.61**	3.13	3.75	3.80	2.97	**3.41**	2.78	3.33	3.45	2.57	**3.03**
N_3	1.56	1.64	1.62	1.55	**1.59**	3.10	3.11	3.24	2.95	**3.10**	2.67	2.76	2.80	2.51	**2.68**
N_4	1.43	1.44	1.44	1.50	**1.45**	2.87	2.92	2.94	2.64	**2.84**	2.42	2.46	2.48	2.22	**2.39**
Mean	**1.57**	**1.57**	**1.57**	**1.59**		**3.10**	**3.38**	**3.45**	**2.89**		**2.70**	**2.97**	**3.05**	**2.48**	

Treatments	N	F	N X F	N	F	N X F	N	F	N X F
SEd	0.05	0.05	0.10	0.10	0.10	0.20	0.08	0.08	0.16
CD (P=0.05)	0.10	NS	NS	0.21	0.21	NS	0.16	0.16	0.33

Recommended dose of nitrogen			Foliar spray of nano and conventional urea		
N_1	-	100 % RDN (25 kg N ha^{-1})	F_1	-	Nano urea @ 2 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_2	-	80 % RDN (20 kg N ha^{-1})	F_2	-	Nano urea @ 3 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_3	-	60 % RDN (15 kg N ha^{-1})	F_3	-	Nano urea @ 4 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_4	-	Control	F_4	-	1 % urea (conventional) at flower initiation stage and 15 days thereafter

produced taller plants (25.1 cm, 41.8 cm and 46.2 cm at FI, PS and harvest stage respectively) with enhanced LAI (1.64, 3.47 and 3.09 at FI, PS and harvest stage respectively) and this was closely followed by application of basal dose of 80 % RDN (N_2 - 20 kg N ha^{-1}). On contrary, the lowest plant height and LAI were noticed in absolute nitrogen free control plots (N_4). This significant enhancement in the growth of green gram plants was mainly attributed to the application of higher dose of basal nitrogen, which facilitated the uniform establishment of the crop with better canopy development. Moreover, it also ensured the higher availability of nutrients at critical stages of the crop for their further growth and development. Availability of nitrogen at optimum level helps in the synthesis of proteins and various enzymes required for the metabolic activities of plants and as a result, it considerably increased the plant height and LAI of green gram. The finding of this field experiment is in conformity with the results previous works (16-18).

Regarding foliar application of nitrogen fertilizers, foliar feeding of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter (F_3) significantly recorded the highest plant height of 41.6 cm and 44.7 cm at PS and harvest stage respectively with improved LAI of 3.45 at PS stage and 3.05 at harvest stage which was on par with foliar spray of nano urea @ 3 ml litre^{-1} of water at FI stage and 15 days thereafter (F_2). While the minimum plant height and LAI were recorded in foliar nutrition of 1 % conventional urea at FI stage and 15 days thereafter (F_4). As foliar spray was applied at FI stage, there was no significant difference in the observation recorded at FI stage. Foliar application of higher concentration of nano urea at critical stages of crop resulted in rapid and effective utilization of nutrition, thereby improving the physiological efficiency of plants and offering an adequate role in enhancing the growth parameters of green gram under summer irrigated conditions. The role of foliar fertilization and its potential benefits on crop growth and development had been clearly discoursed (19). The larger surface area attributed to nano synthesized urea, ensured smart delivery of nutrients to the plant system which facilitated effective absorption and utilization of applied nutrients through foliar spray and thus resulted in significant improvement in the growth of green gram. The earlier research findings (20) also revealed that nano-based and nano-synthesized fertilizers significantly improved the efficiency of applied nutrients than the application of conventional fertilizers.

Pertaining to the interaction effect of the treatment factors *viz*., basal nitrogen dose and foliar nutrition of nano and conventional urea, plant height was found to be significant at PS and harvest stage. Whereas LAI was significant only at the harvest stage. Treatment combination of 100 % RDN and foliar supplement of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter (N_1F_3) significantly produced taller plants of 47.1 cm and 51.4 cm at PS and harvest stage respectively with enhanced LAI of 3.82 at PS stage and 3.47 at harvest stage. This was almost comparable with integrated application of 80 % RDN and foliar nutrition of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter (N_2F_3). Conversely, the lowest plant height and LAI were noticed in nitrogen free control plots supplemented with 1 % conventional urea foliar spray at FI stage and 15 days thereafter (N_4F_4). This considerable improvement in growth of green gram might be due to the synergistic effect of soil application of nutrients combined with foliar supplementation of nano urea at critical stages of crop. Application of 100 % and 80 % RDN as basal dose, augments the growth of green gram at seedling stage and it further supports the crop up to the grand vegetative stage. In addition to basal application of nutrients, the growing crop also requires a sufficient level of nutrients which has to be supplemented for their further growth and development and this was satisfied by foliar feeding of nano urea @ 4 ml litre^{-1} of water at flower initiation stage and 15 days thereafter. This cumulative effect of both the basal and foliar applied nitrogen, thus enabled the crop to grow to their fullest potential with production of a greater number of primary and secondary branches with enlarged leaves and higher biomass accumulation. Thus, the integrated nutrient approach favourably promoted the plant height and LAI of summer irrigated green gram. The result obtained in the present field investigation corroborates with the findings of previous works (21) in maize, (22) in potato and (23) in pearl millet.

Growth analysis

Perusal of the data on crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) revealed that all these parameters were significantly influenced by the treatment factors only at FI - PS stage. Whereas, at PS - harvest stage, CGR and NAR exhibited significant difference only with varied basal nitrogen dose. While RGR was not significantly influenced by both the treatment factors at PS - harvest stage. At both stages of observation, interaction effect does not exist. Despite non-significant variation recorded in the values of CGR, RGR and NAR, there existed trivial numerical variation in those values as influenced by the treatment factors and their interaction outcome (Fig. 1).

At both stages of observation, CGR (12.79 and 9.26 g m^{-2} day^{-1} at FI - PS stage and PS - harvest stage respectively), RGR (0.078 and 0.027 g g^{-1} day^{-1} at FI - PS stage and PS - harvest stage respectively) and NAR (0.53 and 0.28 mg cm^{-2} day^{-1} at FI - PS stage and PS - harvest stage respectively) were numerically higher when the crop was supplied with basal nutrition of 100 % RDN (N_1) than application of 80 % RDN (N_2), 60 % RDN (N_3) and nitrogen free control (N_4). Soil application of nitrogen at optimum level considerably improved the availability of nutrients for better uptake and effective utilization by green gram, thus leading to the accelerated activity of auxin metabolism in plant, which in turn stimulates cell division and cell elongation and ultimately resulted in the development of more vegetative branches with a greater number of leaves and dry matter production. The validated result of the present field experiment agrees with earlier works (18).

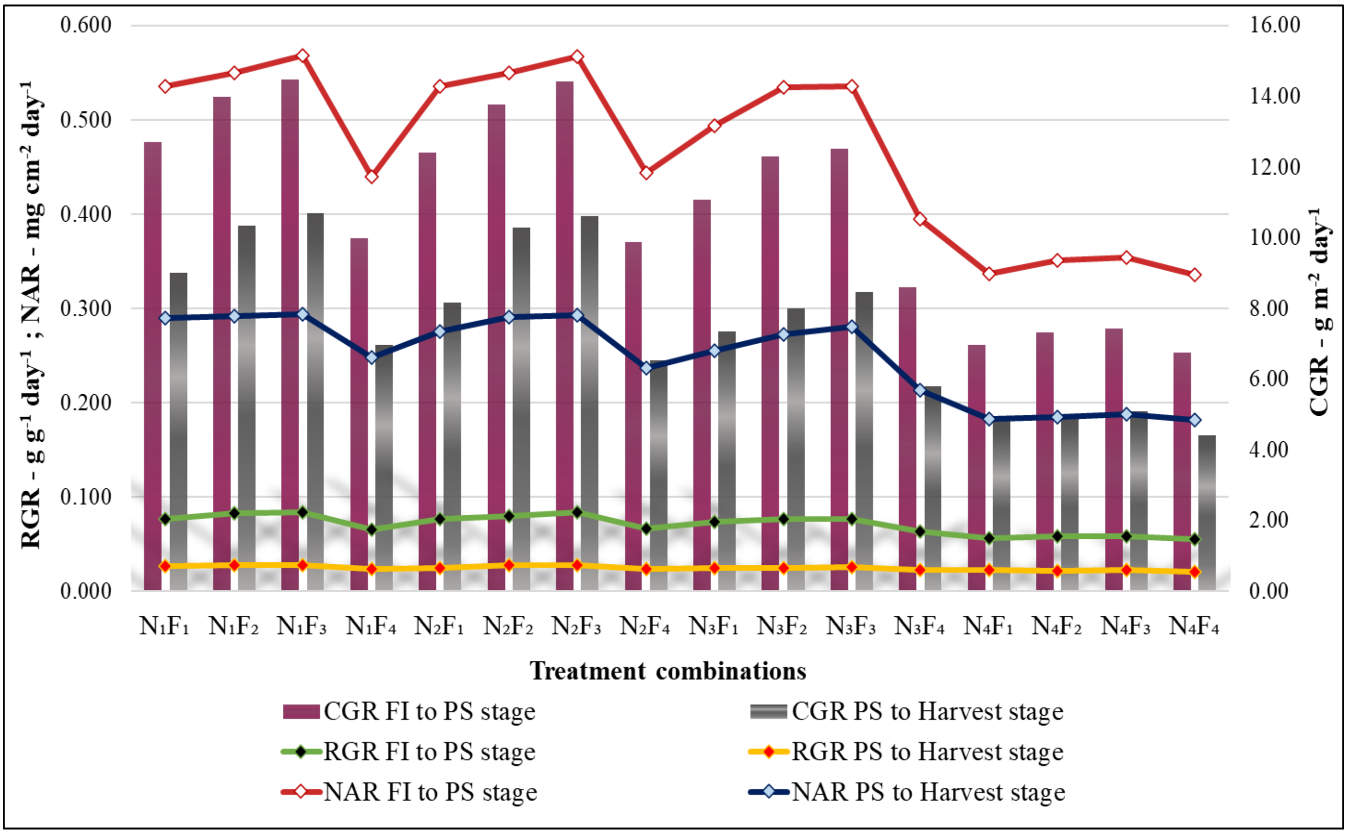

Fig. 1. Crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) of green gram as influenced by varied dose of basal nitrogen and foliar spray of diverse concentration of nano and conventional urea.

Considering the foliar nutrition practices, nano urea foliar spray @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter (F_3) numerically recorded the maximum CGR (12.21 and 8.72 g m^{-2} day^{-1} at FI - PS stage and PS - harvest stage respectively), RGR (0.076 and 0.026 g g^{-1} day^{-1} at FI - PS stage and PS - harvest stage respectively) and NAR (0.51 and 0.27 mg cm^{-2} day^{-1} at FI - PS stage and PS - harvest stage respectively) at both stages of observation followed by foliar application of nano urea @ 3 ml litre^{-1} of water at FI stage and 15 days thereafter (F_2). Foliar application of nutrients besides soil application aids in rapid absorption and effective uptake of applied nutrients and it also helps in amending their nutritional deficiencies. These advantages of foliar nutrition resulted in overall enhancement of plant growth and development (24). The larger surface area and smart nutrient delivery system possessed by nano urea, supports in enhancing the availability of nutrients to the crop at critical growth stages and thus improved the CGR, RGR and NAR of summer irrigated green gram.

With regard to the interaction effect of the treatment factors, combined application of 100 % RDN as basal dose and foliar feeding of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter (N_1F_3) numerically registered greater CGR (14.46 and 10.69 g m^{-2} day^{-1} at FI - PS stage and PS - harvest stage respectively) and RGR (0.084 and 0.028 g g^{-1} day^{-1} at FI - PS stage and PS - harvest stage respectively) at both stages of observation followed by basal application of 80 % RDN + foliar fertilization of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter (N_2F_3). In case of NAR, both the treatment combinations of N_1F_3 and N_2F_3 almost recorded almost similar values (0.57 and 0.29 - 0.30 mg cm^{-2} day^{-1} at FI - PS stage and PS - harvest stage respectively). This might be due to the balanced and adequate supply of nitrogen through basal dose and through the foliage of plants, which enhanced the uptake of nutrients from rhizosphere, as well as effective absorption from phyllosphere, which facilitated substantial improvement in growth rate of summer irrigated green gram. This finding corroborates with the results of previous works (25, 26).

Physiological attributes

The data pertaining to chlorophyll content is provided in Table 6 whereas for soluble protein content and nitrate reductase activity it is depicted in Fig. 2. Chlorophyll content (0.662, 1.183 and 0.798 mg g^{-1} at FI, PS and harvest stage respectively), soluble protein content (10.32 mg g^{-1} at FI, 13.14 mg g^{-1} at PS and 8.53 mg g^{-1} at harvest stage) and nitrate reductase activity (N_1 - 114.4, 134.2 and 90.5 µg NO_2 g^{-1} hr^{-1} at FI, PS and at harvest stage respectively) were significantly superior with application of 100 % RDN (N_1) as basal nutrition than application of 60 % RDN (N_3) as well as nitrogen free control (N_4) treatment at all stages of estimation. Nevertheless, all these physiological parameters were on par with basal application of 80 % RDN (N_2). While the least chlorophyll content was estimated in nitrogen free control plots.

Foliar feeding of nitrogen fertilizer did not express any significant variation at FI stage, however significant difference was observed at PS and harvest stage. Among the various foliar sprays investigated, foliar supplementation of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter (F_3) considerably enhanced the chlorophyll content (1.168 and 0.783 mg g^{-1} at PS and harvest stage respectively), soluble protein content (12.93 and 8.41 mg g^{-1} at PS and harvest stage respectively) and nitrate reductase activity (131.5 and 89.9 µg NO_2 g^{-1} hr^{-1} at PS and harvest stage respectively) of summer irrigated green gram, which was comparable with nano urea foliar spray @ 3 ml litre^{-1} of water at FI stage and 15 days thereafter (F_2) and significantly higher than foliar spray of nano urea @ 2 ml litre^{-1} of water at FI stage and 15 days thereafter (F_1).

The interaction outcome of treatment factors showed dismal variation in chlorophyll content, soluble protein content and nitrate reductase activity at FI and PS stages of crop growth, however extensive and significant variation was noted at harvest stage. At harvest stage, the highest chlorophyll content (0.867 mg g^{-1}), soluble protein content

Table 6. Influence of diverse basal nitrogen levels and foliar feeding of various concentration of nano and conventional urea on chlorophyll content (mg g^{-1}) of green gram

Treatments	At flower initiation stage (mg g^{-1})					At pod setting stage (mg g^{-1})					At harvest stage (mg g^{-1})				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
N_1	0.659	0.651	0.671	0.668	**0.662**	1.146	1.249	1.279	1.056	**1.183**	0.822	0.845	0.867	0.657	**0.798**
N_2	0.638	0.641	0.644	0.633	**0.639**	1.130	1.241	1.261	1.036	**1.167**	0.740	0.837	0.863	0.647	**0.772**
N_3	0.593	0.603	0.590	0.599	**0.596**	1.075	1.125	1.134	1.015	**1.087**	0.679	0.730	0.806	0.631	**0.712**
N_4	0.554	0.549	0.540	0.542	**0.546**	0.875	0.977	0.996	0.816	**0.916**	0.576	0.590	0.597	0.571	**0.584**
Mean	**0.611**	**0.611**	**0.611**	**0.611**		**1.057**	**1.148**	**1.168**	**0.981**		**0.704**	**0.751**	**0.783**	**0.627**	

Treatments	N	F	N X F	N	F	N X F	N	F	N X F
SEd	0.018	0.018	0.037	0.023	0.023	0.046	0.016	0.016	0.032
CD (P=0.05)	0.038	NS	NS	0.047	0.047	NS	0.032	0.032	0.065

Recommended dose of nitrogen			Foliar spray of nano and conventional urea		
N_1	-	100 % RDN (25 kg N ha^{-1})	F_1	-	Nano urea @ 2 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_2	-	80 % RDN (20 kg N ha^{-1})	F_2	-	Nano urea @ 3 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_3	-	60 % RDN (15 kg N ha^{-1})	F_3	-	Nano urea @ 4 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_4	-	Control	F_4	-	1 % urea (conventional) at flower initiation stage and 15 days thereafter

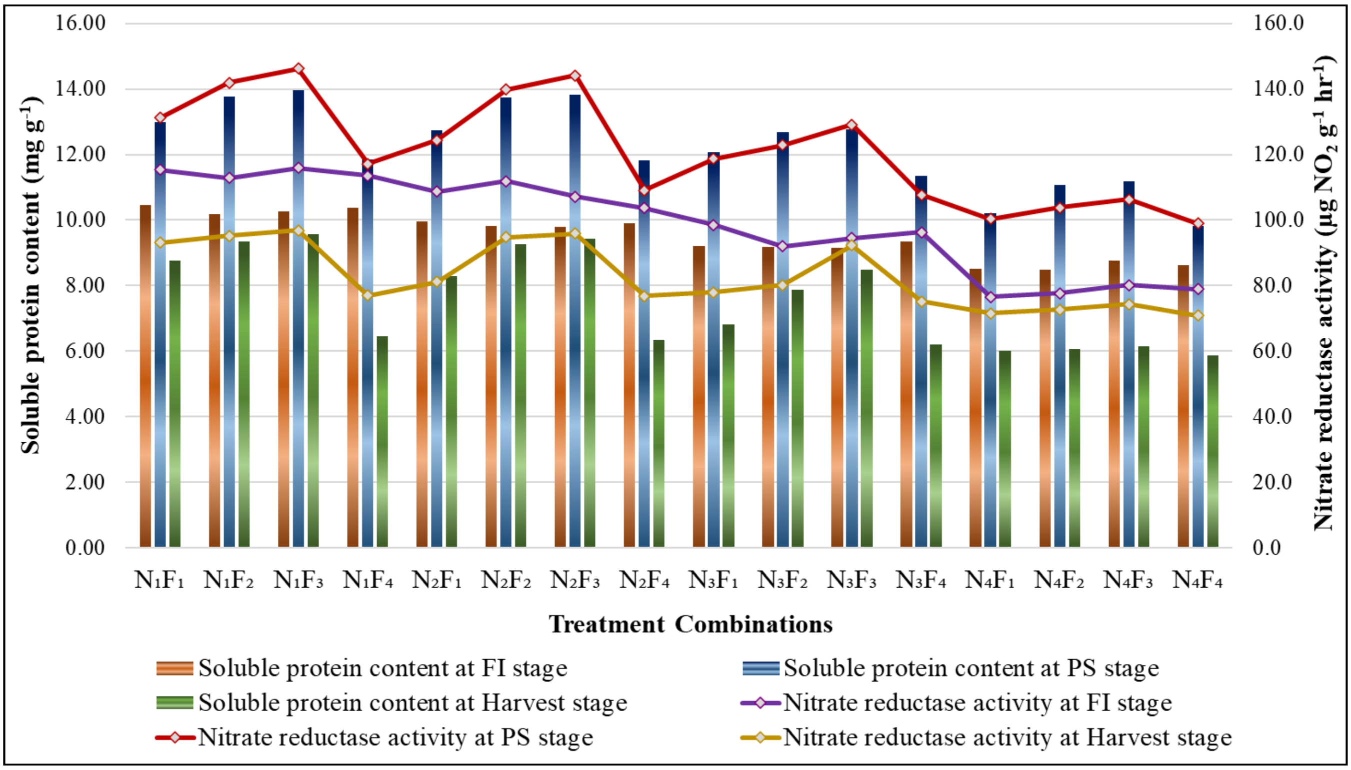

Fig. 2. Soluble protein content (mg g^{-1}) and nitrate reductase activity (µg NO_2 g^{-1} hr^{-1}) of green gram as influenced by diverse levels of basal nitrogen and foliar feeding of varied concentration of nano and conventional urea.

(9.56 mg g^{-1}) and nitrate reductase activity (96.9 µg NO_2 g^{-1} hr^{-1}) were noticed under integrated application of 100 % RDN as basal fertilizer dose + foliar nutrition of nano urea @ 4 ml $litre^{-1}$ of water applied at FI stage and 15 days thereafter followed by combined application of 80 % RDN + foliar fertilization of nano urea @ 4 ml $litre^{-1}$ of water at FI stage and 15 days thereafter (N_2F_3). While the lowermost values of physiological parameters were registered under the treatment combination of nitrogen free control plots fertilized with 1 % conventional urea spray at FI stage and 15 days thereafter (N_4F_4).

The maximum level of chlorophyll content, soluble protein content and nitrate reductase activity recorded in the integrated application of basal nitrogen and foliar spray of nano-synthesized nitrogen fertilizer might be due to the fact that nitrogen is a critical component in chlorophyll synthesis and it has been reported that augmentation of chlorophyll content in the crop is directly related to the supply of adequate level of nitrogen at critical stages of the crop. Further, the supply of nitrogen considerably enhanced the soluble protein content, nitrate reductase activity thus leading to maximum photosynthetic process through increased PS II photochemistry, dry matter production and photosynthates accumulation in the plant. The results of the present field investigation were also in corroboration with previous findings (25, 27, 28).

Yield components and yield

Both the treatment factors under investigation significantly influenced the yield components (Fig. 3) and yield of summer irrigated green gram (Table 7). Application of higher dose of basal nitrogen (N_1 - 100 % RDN) significantly produced a greater number of flowers $plant^{-1}$ (49 nos.), pods $plant^{-1}$ (32 nos.), fertility co-efficient (65.1 %) and ultimately yield (1158 kg ha^{-1}) which was comparable with application of 80 % RDN. Generally, application of nitrogen enhances the growth and physiology of plant which in turn augments the formation of yield attributing traits. In the current study, optimum supply of nitrogen *i.e.*, 100 % and 80 % RDN significantly enhanced the flower production, effective conversion of flowers into pods indicating that the plants supplied with enough nitrogen experiences vigorous growth with enhanced photosynthetic activity and its partitioning and accumulation in yield components. Similar findings were also reported by (29, 30).

Considering foliar supplementation of nitrogen, foliar spray of nano urea @ 4 ml $litre^{-1}$ of water at FI stage and 15 days thereafter (F_3) significantly recorded higher count of flowers $plant^{-1}$ (48 nos.), pods $plant^{-1}$ (31 nos.), fertility co-efficient (64.4 %) and yield (1123 kg ha^{-1}) than the rest of the treatments but was comparatively on par with foliar spray of nano urea @ 3 ml $litre^{-1}$ of water at FI stage and 15 days thereafter (F_2). This enhancement in yield attributes and yield of green gram was due to the slow and smart nutrient release pattern of nano synthesized urea which facilitated effective absorption of nutrients by plants and it also extended the retention of photo-assimilatory surface till the physiological maturity stage of the crop thereby improving the yield. The obtained results are in accordance with previous findings (31).

Regarding the interaction effect of treatment factors N and F, the treatment combination of 100 % RDN + foliar nutrition of nano urea @ 4 ml $litre^{-1}$ of water at FI stage and 15 days thereafter (N_1F_3) significantly enhanced the flower count $plant^{-1}$ (54 nos.), pod count $plant^{-1}$ (39 nos.), fertility co-efficient (71.2 %) and subsequently grain yield (1291 kg ha^{-1}) which was almost comparable with the results obtained from integrated application of 80 % RDN + foliar nutrition of nano urea @ 4 ml $litre^{-1}$ of water at FI stage and 15 days thereafter (N_2F_3). Addition of adequate amount of basal nitrogen

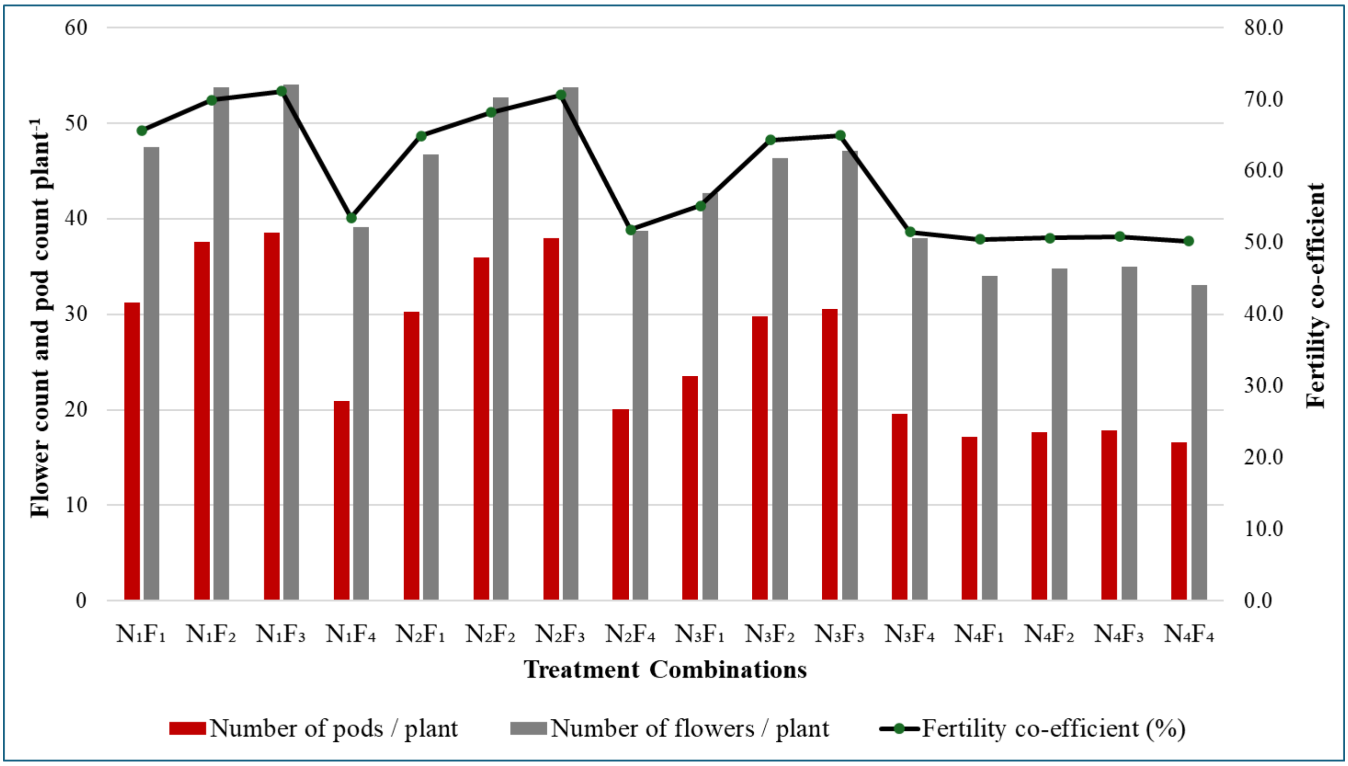

Fig 3. Influence of various levels of basal nitrogen and foliar supplementation of diverse concentration of nano and conventional urea on number of flowers plant^{-1}, number of pods plant^{-1} and fertility co-efficient (%) of summer irrigated green gram.

supplied essential nutrition to the crop till the grand vegetative stage. Further supplementation of nutrition through foliar feeding of nano urea at a higher dose during the early reproductive stage and 15 days thereafter facilitated the production of more number of flowers, improved the flower retention rate and effectively enhanced the pod setting percentage thereby producing more number of pods plant^{-1} and hence maximized the yield. The obtained result corroborates with early findings (32) in wheat, (33) in sweet corn, (34) in rice, (35) in maize and (36) in finger millet.

Quality parameters

The data on protein content and protein yield of green gram presented in Table 7 clearly indicates that the treatment factors and their interaction had a significant influence on the protein yield of green gram whereas no significant difference was observed in the protein content, however there existed a numerical variation.

The protein content (23.16 %) and protein yield (268.6 kg ha^{-1}) were higher in basal application of N @ 100 % recommended level (N_1). Nevertheless, it was on par with protein content and protein yield obtained in basal application of N @ 80 % recommended level. Conversely, the least protein content and protein yield were registered in absolute nitrogen control treatment. The increment in protein yield observed in 100 % RDN and 80 % RDN was attributable to the application of basal N at higher level. The higher availability of nitrogen significantly enhanced the N uptake as well as the effective utilization of nutrients by the crop for producing more grain yield with improved protein content and subsequently enhanced the protein yield of

Table 7. Effect of different dose of basal nitrogen and foliar spray of various concentration of nano and conventional urea on grain yield (kg ha^{-1}), protein content (%) and protein yield (kg ha^{-1}) of green gram

Treatments	Grain yield (kg ha^{-1})					Protein content (%)					Protein yield (kg ha^{-1})				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
N_1	1154	1250	1291	935	**1158**	23.00	23.29	23.76	22.60	**23.16**	265.4	291.1	306.7	211.3	**268.6**
N_2	1125	1234	1289	916	**1141**	22.81	23.16	23.64	22.48	**23.02**	256.6	285.8	304.8	205.9	**263.3**
N_3	969	1087	1145	841	**1010**	22.68	22.78	22.89	22.31	**22.67**	219.7	247.6	262.1	187.6	**229.3**
N_4	718	743	768	686	**729**	21.81	21.98	22.12	21.74	**21.91**	156.5	163.2	169.9	149.1	**159.7**
Mean	**991**	**1078**	**1123**	**844**		**22.58**	**22.80**	**23.10**	**22.28**		**224.6**	**246.9**	**260.9**	**188.5**	

Treatments	N	F	N X F	N	F	N X F	N	F	N X F
SEd	29	29	59	0.74	0.74	1.47	7.5	7.5	15.1
CD (P=0.05)	60	60	120	NS	NS	NS	15.4	15.4	30.8

Recommended dose of nitrogen			**Foliar spray of nano and conventional urea**		
N_1	-	100 % RDN (25 kg N ha^{-1})	F_1	-	Nano urea @ 2 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_2	-	80 % RDN (20 kg N ha^{-1})	F_2	-	Nano urea @ 3 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_3	-	60 % RDN (15 kg N ha^{-1})	F_3	-	Nano urea @ 4 ml litre^{-1} of water at flower initiation stage and 15 days thereafter
N_4	-	Control	F_4	-	1 % urea (conventional) at flower initiation stage and 15 days thereafter

green gram. A similar finding was also reported through basal application of nitrogen in cowpea (37).

Regarding foliar feeding practices, protein content (23.10 %) and protein yield (260.9 kg ha^{-1}) were maximum in foliar nutrition of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter (F_3). However, it was on par with foliar feeding of nano urea @ 3 ml litre^{-1} of water at FI stage and 15 days thereafter. On the contrary, the minimum protein content and protein yield were observed in foliar spray of conventional urea @ 1 % concentration at FI stage and 15 days thereafter (F_4). The highest protein yield accounted in F_3 might be due to the efficient absorption of nano-synthesized liquid N fertilizer applied on the plant foliage as well as its effective utilization for the derivation of amino acids in plants which in turn enhances the protein content in green gram grains thus recording higher protein yield. Plants fertilized with enough nutrients through foliar application might have experienced high rate of photosynthesis and naturally exhibited vigorous growth and development . Plants fertilized with enough nutrients through foliar application might have experienced high rate of photosynthesis and naturally exhibited vigorous growth and development (38).

Equally, the interaction between basal N application and foliar N nutrition markedly improved the protein content and protein yield of green gram. Among the combination of factorial treatments, treatment combination of 100 % RDN with foliar supplementation of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter (N_1F_3) considerably registered the maximum protein content of 23.76 % and protein yield of 306.7 kg ha^{-1}, which was on par with integrated application of 80 % RDN + foliar feeding of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter. Whereas the treatment combination of nitrogen free control supplied with 1 % conventional urea foliar spray at FI stage and 15 days thereafter (N_4F_4) significantly recorded the lowest protein content and protein yield. Balanced supply of nitrogen through basal and foliar application enables the crop to absorb more nutrients through root and foliage which in turn enhances the cell division, improves the plant growth and development, chlorophyll content, protein synthesis, protein content in green gram grain and consequently protein yield. Results show similarity in cowpea by adopting integrated nitrogen management practices (38).

Conclusion

The experimental results clearly indicate that basal application of 100 % and 80 % RDN in combination with foliar fertilization of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter produced almost parallel results on all aspects of growth, physiology, yield and quality parameters of green gram. Hence, basal application of 80 % RDN integrated with foliar nutrition of nano urea @ 4 ml litre^{-1} of water at FI stage and 15 days thereafter could be a viable nutrient management approach to augment the plant growth, boost up the physiological activities, enhance the yield and to improve the quality of green gram under summer irrigated conditions.

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Authors' contributions

VS conducted the field & lab experiments and prepared the manuscript. MS formulated the research work, monitored and evaluated the research work as a chairman. GP monitored the progress of research work and provided valuable technical advice in agronomic aspects as a primary advisory committee member. VBRP assisted in physiological aspects of the research work as a secondary advisory committee member. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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