Original Research Article

Enhancing Mungbean (*Vigna radiata* L.) Performance with Optimized Nitrogen and Sulphur Levels

ABSTRACT

An experiment was conducted to study the impact of nitrogen and sulphur levels on the performance of mungbean. The experiment consisted of two factors *viz*. nitrogen levels and sulphur levels. The nitrogen application included four levels viz., N_1: RDN @ 30 kg N ha^{-1}; N_2: Foliar application of Nano-urea @ 2 ml/L of water at 20-25 DAS; N_3: Foliar application of Nano-urea @ 2 ml/L of water at 40-45 DAS and N_4: Foliar application Nano-Urea @ 2 ml/L of water at 60-65 DAS whereas Sulphur application included three levels viz., S_0: 0 kg ha^{-1}; S_1:15 kg ha^{-1} and S_2: 30 kg ha^{-1} which was applied through Gypsum. The results showed that application of N_3 resulted in higher performance of Mungbean in terms of growth parameters viz., plant height, DMA and LAI, yield attributes and yield. This indicates the importance of applying nano urea at the optimal growth stage to meet the crop's nutrient demands during critical periods of development. Likewise, increasing sulphur levels from S_0 to S_2 showed a positive effect on crop performance, with the highest results observed at 30 kg sulphur ha^{-1} S_2.

Keywords: *Nano-urea; DMA; LAI; nitrogen and sulphur*

1. INTRODUCTION

Mungbean (*Vigna radiata*L.), also known as the green gram is the third most consumed pulse crop in India (Chakarborty*et al*., 2015; Mishra *et al*., 2018). It is quite a versatile crop grown for seeds, green manure and forage, as mixed for sole crop either on the residual moisture of the previous crop or as a catch crop to make use of the land left idle between two main season crops. It makes a good green manure if incorporated into the soil. Further, it enriches the soil by atmospheric nitrogen fixation through root nodules.The amino acid profile of mungbean, similar to other beans is complementary to cereal grains. Unlike other Pulses, it does not produce heaviness or flatulence and can be easily digestible among pulses. Mungbean has more proteinaceous content and better digestibility than any other pulse crop.

With the growing population of the world in general and the developing countries in particular, demands are overwhelmed for enhanced food production. The increasing global demand for food production necessitates innovative agricultural practices to ensure sustainable crop yields. Pulses continue to be an important ingredient of human diet, especially for the large vegetarian population in the country. In the era of Green Revolution with major focus on staple food like rice and wheat, pulses were relegated to the marginal lands with least inputs. This coupled with the increasing population, resulted in reducing per capita availability of pulses to the masses. Besides emphasizing on main crops and vegetables, pulses play a crucial role to satisfy the growing human food demands. It has been estimated that India's population would reach 1.68 billion by 2030 from the present level of 1.21 billion. Accordingly, the projected pulse requirement for the year 2030 is 32 million tons with an anticipated required growth rate of 4.2% (IIPR Vision 2030). India has to produce not only enough pulses but also remain competitive to protect the indigenous pulse production. In view of this, India has to develop and adopt more efficient crop production technologies along with favourable policies to encourage farmers to bring more area under pulses. India ranks first in the world in terms of pulse production (25% of total worlds production) (FAOSTAT 2010). Among various pulses grown in India, Mungbean is weighed as an important pulse crop after chickpea and pigeonpea (Kumari *et al.,* 2023; Tutlani *et al.,* 2023& 2024). Mungbean is one of the important pulse crops of India cultivated over a wide range of agro-climatic zones of the country.

Currently, soil health has emerged as a critical concern for sustainable agricultural production in the new millennium. Mungbean crop plays a significant role to sustain the soil fertility through biological nitrogen fixation. It stabilizes the atmospheric nitrogen and increases the soil fertility (Kaisher*et al.,* 2010**)**.Fertilizers greatly influence the crop production. The recommendation of fertilizer for soils and crops is a dynamic process and the management of fertilizers is one of the important crop production factors that greatly affect the growth, development and yield of mungbean (Rafiqul Hoque *et al.,* 2004; Singh *et al.,* 2013). Nanotechnology is one of the promising methods in improving the fertilizer use efficiency of fertilizers. An advance in foliar fertilization is the use of nanotechnology which emerges as an alternative to achieve the optimal development of plants in a sustainable and precise way because of its less cost, more profit, better environment and soil health (Singh *et al.,* 2017). So nano urea increases crop productivity and reduces the requirement of conventional urea. Sulphur is an important macro nutrient element, next to NPK that has a profound effect on pulse crops. Sulphur has a great role in N-fixation by influencing active nodulation in legume. It is a part of nitrogenase enzyme, promotes nodulation in legumes, which enhances biological N-fixation (BNF) and the productivity of pulses may drastically be reduced by an inadequate supply of sulphur. It is also necessary for chlorophyll formation and helps in biosynthesis of oil and metabolism of carbohydrates, proteins and fats. In broad sense, the functions of nitrogen and sulphur are similar and they are synergistic.

2. MATERIALS AND METHODS

2.1 Location and climate

The experimental site is situated in temperate zone of Jammu and Kashmir and lies between 30^{o} 8' N latitude and 74^{o} 83' ″E longitude at an altitude of 1617 meters above mean sea level.Climatically, the experimental site is in mid high-altitude temperate zone characterized by hot summers and severe cold winters. The mean meteorological data for cropping season recorded at Meteorological Observatory located at Shalimar, is depicted in Fig. 1a& Fig. 1b. It is evident from the meteorological data that mean maximum temperature ranged from 24.73 to 32.64 °C and 25 to 33.57 °C, mean minimum temperature ranged from 7.30 to 20.33 °C and 8 to 19.20 °C, mean maximum relative humidity ranged from 75.29 to 88.57 % and 78 to 93.14 %, mean minimum relative humidity ranged from 40.57 to 67.86 % and 38 to 67.14 % during the cropping season of *Kharif* 2022 and 2023 respectively. The total rainfall received during the period of experimentation was 279.80 mm and 311.60 mm during *kharif* 2022 and 2023, respectively.

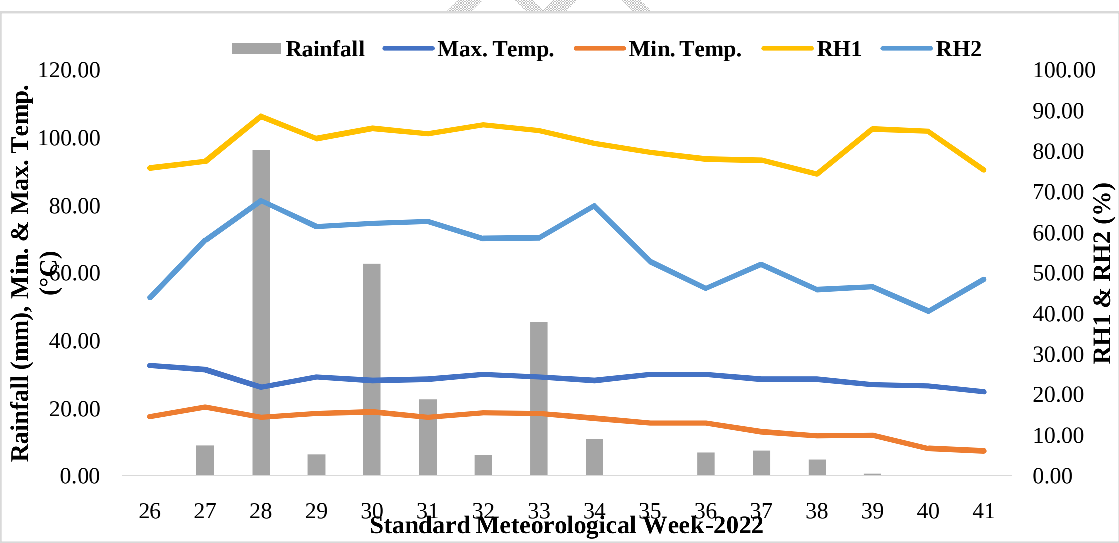

Fig. 1a: Weather condition during crop growing season (*kharif*-2022)

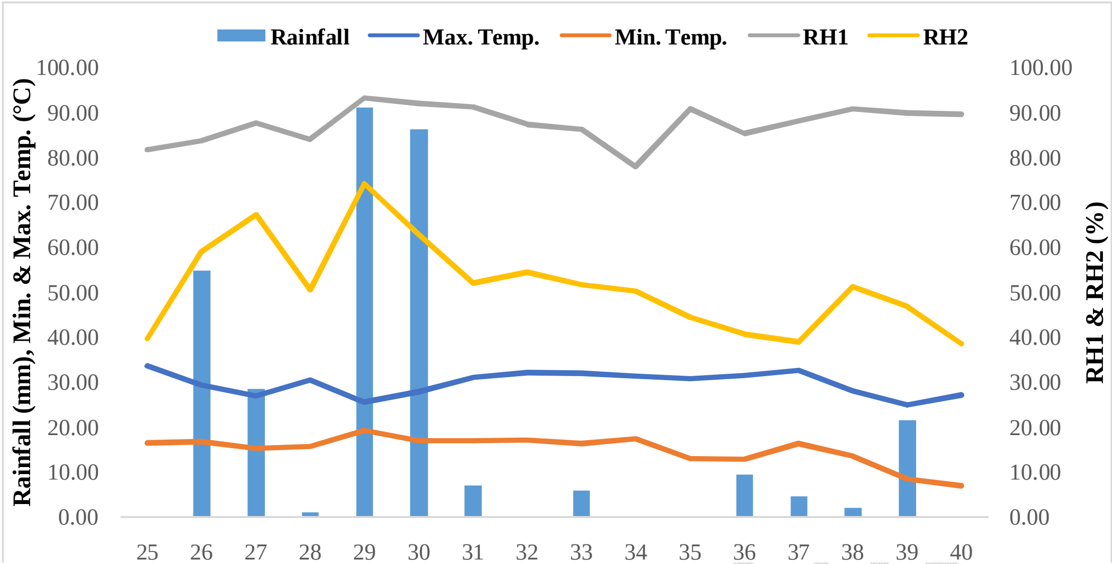

Fig. 1b: Weather condition during crop growing season (*kharif*-2023)

2.2 Experimental details

The experiment was laid out in Randomized Complete Block Design (Factorial). The experiment consisted of two factors viz. nitrogen application and levels of sulphur. The nitrogen application included four levels viz., N_1: RDN @ 30 kg N ha^{-1}; N_2: Foliar application of Nano-Urea @ 2 ml/L of water at 20-25 DAS; N_3: Foliar application of Nano-Urea @ 2ml/L of water at 40-45 DAS and N_4: Foliar application Nano-Urea @2 ml/L of water at 60-65 DAS whereas Sulphur application included three levels viz., S_0: 0 kg ha^{-1}; S_1:15 kg ha^{-1} and S_2: 30 kg ha^{-1} which was applied through Gypsum. The experimental plots were demarcated as per the layout plan of the experimental field. Sowing of mung bean was done by opening a narrow furrow @ 20 kg ha^{-1} at a row distance of 30 cm.

2.3 Observations recorded

The periodic observations on growth and yield of green gram were recorded to assess the effect of different treatments. Randomly five plants were selected and tagged from every plot of each replication and then average for growth parameter was worked out and recorded at 30, 60, 90 DAS and at harvesting stage.

2.4 Statistical analysis

The statistical analysis of experimental data was carried out using the standard method of analysis of variance (ANOVA) technique subjected to Randomized Block design (Factorial). F-test was used to check the significance of treatments at 0.05 level of probability. In case of statistically significant results at ($p \leq 0.05$) least significant differences (LSD) was calculated to compare the effect of different treatments.

3. EXPERIMENTAL FINDINGS

3.1 Growth parameters

Plant height is the reliable index of plant growth and represents the infrastructure build up in plant over the growth period (Table 1). Among the different Nano urea levels, highest plant height was recorded with the application of N_3 showing consistent growth across both years. At harvest, the maximum height was observed as 89.25 cm in year 2022 and 90.42 cm in 2023. However, the lowest plant height at harvest was recorded in N_1 with 72.96cm in year 2022 and 72.46 cm in 2023. Among the Nitrogen Levels treatments, N_3 consistently recorded the highest LAI across all stages and years (Fig.2a and Fig. 2b). At 90 DAS N_3 showed a maximum LAI of 3.56 in 2022 and 3.62 in 2023, indicating its effectiveness in promoting leaf area development. However, the lowest LAI was observed with N_1, which recorded 3.15 in 2022 and 3.16 in 2023 at 90 DAS.

Sulphur application also significantly influenced plant height. The highest plant height at harvest was recorded with S_2, which recorded 86.91 cm in 2023. However, the lowest plant height was observed with $\mathbf{S_0}$, which recorded 75.63 at harvest in 2022.At 90 DAS S_2 achieved a maximum

LAI of 3.41 in year 2022 and 3.48 in 2023. However, control treatment without sulphur (S_0) resulted in the lowest LAI with 3.15in 2022 and 3.16 in 2023 at 90 DAS.

Dry matter production increased with the advancement in the age of crop irrespective of different treatment combinations and highest increase in dry matter was recorded during 60-90 DAS (Table 2). The application of different nitrogen levels showed a consistent increase in dry matter accumulation in moong bean. The treatment N_3 consistently recorded the highest dry matter accumulation, demonstrating a significant upward trend compared to N_1 i.e. recommended dose of nitrogen. By the harvest, N_3 showed an increase of over 20% in dry matter accumulation compared to N_1, highlighting the substantial impact of nano-urea on the growth and productivity of moong bean. Across all growth stages, the treatment N_3 (applied at 40 DAS) consistently showed the highest dry matter accumulation, suggesting that applying nano-urea at this intermediate growth stage was most beneficial for the plant. Treatment N_2, which was applied earlier at 20 DAS, resulted in relatively lower dry matter accumulation, while N_4 (applied at 60 DAS) also showed a comparatively lower performance than N_3, though still superior to N_2. Likewise, higher sulphur levels yielded better results in terms of dry matter accumulation. The treatment S_2 consistently recorded the highest dry matter accumulation compared to the control (S_0) throughout the growth period. By the harvest, S_2 exhibited an improvement of over 15% in dry matter accumulation relative to S_0, demonstrating the positive impact of higher sulphur levels on plant growth and productivity.

Table 1: Impact of Nitrogen Levels and Sulphur levels on plant height (cm) of Mungbean

Treatments	**30 DAS**		**60 DAS**		**90 DAS**		**At Harvest**	
	2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
Additional vs Rest								
Additional	15.00	14.73	32.07	31.20	59.06	59.65	61.50	62.06
Mean Factorial	17.66	18.22	40.49	41.79	78.68	79.90	80.81	81.60
SE (m±)	**1.32**	**1.41**	**2.20**	**2.41**	**3.95**	**4.08**	**4.09**	**4.23**
CD (P≤0.05)	**3.86**	**4.11**	**6.42**	**7.05**	**11.54**	**11.91**	**11.95**	**12.36**
Nano-urea								
N_1	20.11	20.86	38.91	40.15	70.23	71.79	72.96	72.45
N_2	17.98	18.65	42.02	43.24	76.19	77.21	78.10	78.79
N_3	16.34	16.77	45.05	46.62	86.69	87.86	89.25	90.42
N_4	16.19	16.62	35.99	37.14	81.63	82.73	83.93	84.74
SE (m±)	**0.59**	**0.65**	**0.97**	**0.98**	**1.68**	**1.67**	**1.72**	**1.88**
CD (P≤0.05)	**1.72**	**1.90**	**2.83**	**2.89**	**4.93**	**4.89**	**5.03**	**5.50**
Sulphur Levels								
S_0	15.93	16.35	37.66	38.68	73.70	74.79	75.63	76.60
S_1	17.64	18.27	40.55	41.83	78.76	80.09	81.20	81.29
S_2	19.41	20.05	43.26	44.85	83.59	84.81	86.36	86.91
SE (m±)	**0.51**	**0.56**	**0.84**	**0.85**	**1.46**	**1.44**	**1.49**	**1.62**
CD (P≤0.05)	**1.49**	**1.65**	**2.45**	**2.50**	**4.27**	**4.23**	**4.36**	**4.77**

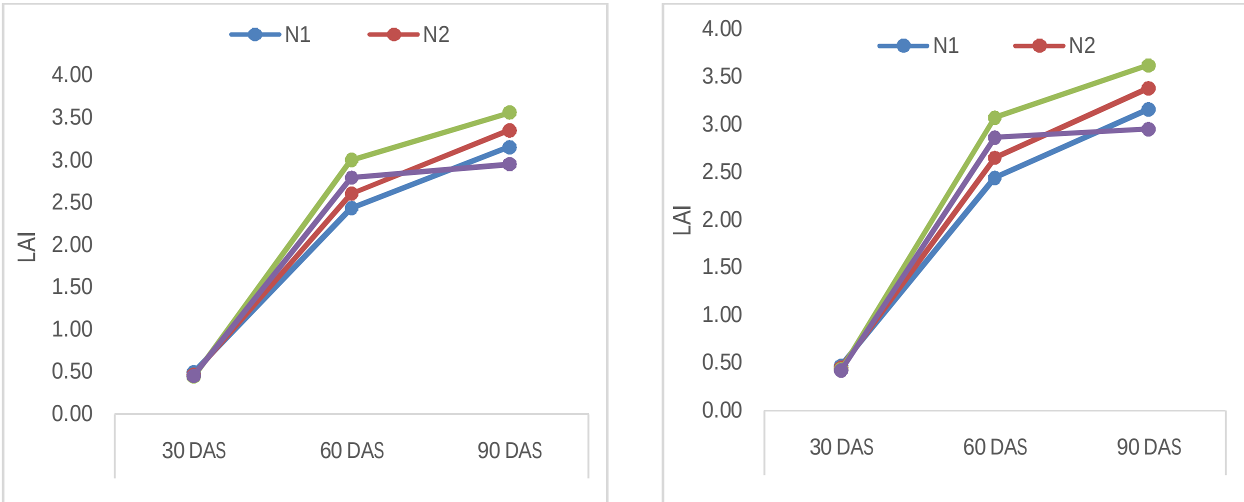

Fig. 2a: Impact of Nitrogen Levels on LAI of Mungbean

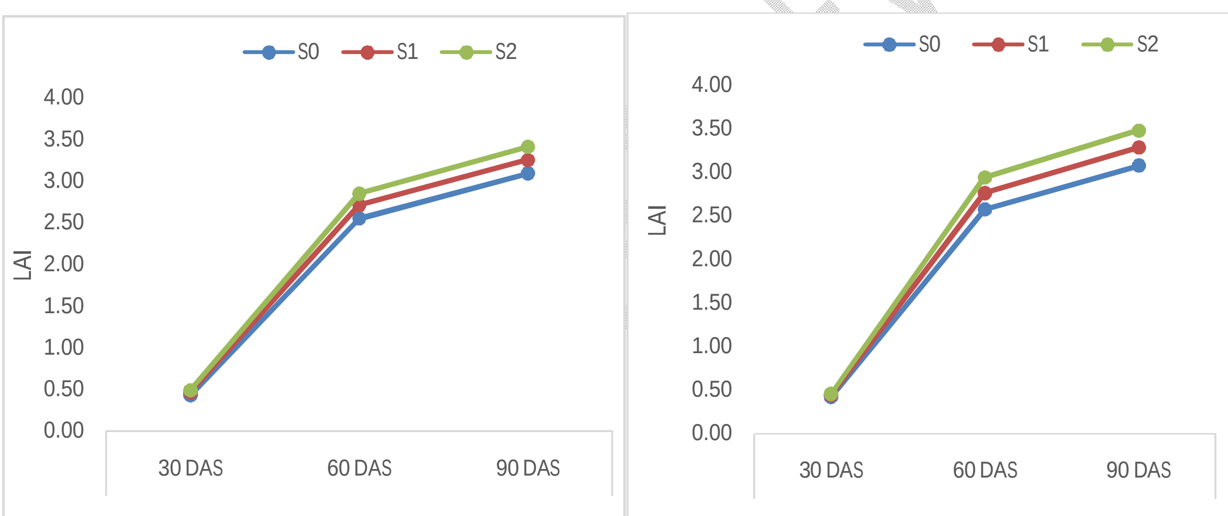

Fig. 2b: Impact of Sulphur levels on LAI of Mungbean

Table 2: Impact of Nitrogen Levels and Sulphur levels on dry matter accumulation (q ha^{-1}) of Mungbean

Treatments	30 DAS		60 DAS		90 DAS		At Harvest	
	2022	2023	2022	2023	2022	2023	2022	2023
Additional vs Rest								
Additional	1.63	1.63	5.28	5.82	12.65	13.43	14.5	14.8
Mean Factorial	1.82	2.00	7.78	7.90	16.57	17.55	18.57	19.4
SE (m±)	**0.14**	**0.13**	**0.54**	**0.48**	**0.85**	**0.82**	**0.82**	**0.96**
CD (P≤0.05)	**0.42**	**0.38**	**1.57**	**1.39**	**2.49**	**2.40**	**2.39**	**2.80**
Nitrogen Levels								
N_1	2.04	2.32	7.47	7.57	14.90	15.94	16.83	17.52
N_2	1.83	2.04	8.07	8.21	15.92	16.96	17.96	18.78
N_3	1.74	1.85	8.70	8.89	18.41	19.24	20.26	21.26
N_4	1.67	1.79	6.89	6.95	17.07	18.04	19.22	20.04
SE (m±)	**0.04**	**0.05**	**0.19**	**0.20**	**0.31**	**0.34**	**0.36**	**0.38**
CD (P≤0.05)	**0.12**	**0.14**	**0.55**	**0.59**	**0.91**	**0.99**	**1.04**	**1.13**
Sulphur Levels								
S_0	1.58	1.81	6.98	7.25	15.37	16.32	17.52	18.32
S_1	1.85	2.01	7.86	7.93	16.60	17.67	18.60	19.44
S_2	2.03	2.18	8.50	8.53	17.75	18.66	19.58	20.45
SE (m±)	**0.03**	**0.04**	**0.16**	**0.17**	**0.27**	**0.29**	**0.31**	**0.33**
CD (P≤0.05)	**0.10**	**0.12**	**0.48**	**0.51**	**0.79**	**0.86**	**0.90**	**0.98**

3.2 Yield attributes

The number of pods per plantand seeds per pod of mungbean were significantly influenced by nitrogen levels and sulphur levels (Table 3). The timing of nano-urea application played a key role in determining yield attributes. Among the Nitrogen levels, N_3 significantly recorded the highest values for all parameters across both years followed by N_2 and N_1.However, $N_1$with no nano-urea application, recorded the lowest values for all parameters. Among the sulphur treatments, significantly higher number of pods per plant and seeds per podwere recorded under treatment S_2 outperforming S_1 and S_0. The test weightof mungbean was significantly influenced by nitrogen and sulphur levels. Among the nitrogen levels, higher test weightwas recorded in N_3 which was at par with N_4 and varied significantly from N_2 and N_1. Among sulphur treatments, treatment S_2 recorded significantly highest test weight, with 33.87 g in 2022 and 34.25 g in 2023 whereas control treatment without sulphur (**S_0**) recorded the lowest test weight of 32.46 g in 2022 and 33.07 g in 2023. 34.28

3.3 Seed yield

The seed yield of mungbean was significantly influenced by nano urea and sulphur levels (Table 3). The seed yield of mungbean was significantly influenced by nitrogen and sulphur levels with notable increments observed in response to higher levels and optimized timing of application. Among the treatments, significantly higher seed yieldwas recorded in N_3 followed by N_4 and N_2. Treatment N_3 recorded seed yield of 12.53 q ha^{-1} in 2022 and 13.02 q ha^{-1} in 2023 which represented an increment of 61.85% in 2022 and 53.50% in 2023 compared to N_1 (7.74 q ha^{-1} in 2022 and 8.48 q ha^{-1} in 2023). Among sulphur treatments, sulphur application significantly enhanced seed yield, with S_2 consistently recording the highest values of 11.44 q ha^{-1} in 2022 and 12.02 q ha^{-1} in 2023. This represented an improvement of 30.12% in 2022 and 29.81% in 2023 compared to the control (S_0), which recorded the lowest seed yields (8.79 q ha^{-1} in 2022 and 9.26 q ha^{-1} in 2023). Treatment S_1 performed moderately, indicating that higher sulphur levels positively influence seed yield in moong bean.

Table 3: Impact of Nitrogen levels and Sulphur levels on yield attributes and seed yield of Mungbean.

Treatments	No. of Pods/plant		No. of Seeds/pod		Test Weight (g)		Seed Yield (q ha^{-1})	
	2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
Additional vs Rest								
Additional	6.86	6.93	8.27	7.88	26.93	27.45	5.02	4.76
Mean factorial	9.65	10.26	10.18	10.41	33.16	33.68	10.11	10.65
SE (m±)	**0.65**	**0.65**	**0.55**	**0.61**	**0.68**	**0.50**	**0.84**	**0.88**
CD (P≤0.05)	**1.90**	**1.91**	**1.60**	**1.77**	**2.00**	**1.46**	**2.46**	**2.57**
Nano-urea								
N_1	8.26	8.89	8.96	9.07	32.06	32.62	7.74	8.48
N_2	9.22	9.81	9.78	9.97	32.75	33.34	9.27	9.80
N_3	10.99	11.62	11.38	11.71	34.28	34.69	12.53	13.02
N_4	10.12	10.71	10.59	10.87	33.53	34.06	10.89	11.29
SE (m±)	**0.28**	**0.30**	**0.26**	**0.28**	**0.26**	**0.24**	**0.28**	**0.29**
CD (P≤0.05)	**0.83**	**0.89**	**0.76**	**0.83**	**0.77**	**0.69**	**0.82**	**0.87**
Sulphur levels								
S_0	8.86	9.43	9.48	9.67	32.46	33.07	8.79	9.26
S_1	9.66	10.24	10.18	10.41	33.14	33.71	10.10	10.66
S_2	10.42	11.10	10.87	11.14	33.87	34.25	11.44	12.02
SE (m±)	**0.24**	**0.26**	**0.23**	**0.24**	**0.23**	**0.20**	**0.24**	**0.26**
CD (P≤0.05)	**0.72**	**0.77**	**0.66**	**0.71**	**0.66**	**0.60**	**0.71**	**0.75**

3.4 Protein content and yield

The protein content and protein yield of mungbean were significantly influenced by nitrogen and sulphur levels (Table 4). Among the nitrogen levels, N1 (RDN) recorded the lowest protein content (19.64% in 2022 and 19.59% in 2023) and protein yield (152.81 kg/ha in 2022 and 166.46 kg/ha in 2023). The application of treatment N2 improved both protein content (20.56% in 2022 and 20.54% in 2023) and protein yield (191.10 kg/ha in 2022 and 202.60 kg/ha in 2023). However, the application of N3 resulted in significantly highest protein content (21.98% in both years) and protein yield (276.36 kg/ha in 2022 and 288.08 kg/ha in 2023) followed by N_4. Among sulphur treatments, the application of 30 kg sulphur ha-1 (S2) significantly increased protein content (21.57% in 2022 and 21.61% in 2023) and protein yield (248.06 kg/ha in 2022 and 261.36 kg/ha in 2023) which was followed by application of 15 kg sulphur ha-1 (S1) resulted in protein content (20.82% in 2022 and 20.79% in 2023) and protein yield (211.90 kg/ha in 2022 and 222.48 kg/ha in 2023).

Table 4: Impact of Nano-Urea and Sulphur levels on protein content and protein yield of Mungbean

Treatments	Protein content (%)		Protein yield (kg ha^{-1})	
	2022	**2023**	**2022**	**2023**
Additional vs Rest				
Additional	16.77	18.61	83.89	88.75
Mean factorial	20.80	20.79	212.55	223.76
SE (m±)	**0.64**	**0.64**	**21.91**	**22.89**
CD (P≤0.05)	**1.87**	**1.86**	**63.95**	**66.80**

Nano urea				
N_1	19.64	19.59	152.81	166.46
N_2	20.56	20.54	191.10	202.60
N_3	21.98	21.98	276.36	288.08
N_4	21.03	21.05	229.96	237.92
SE (m±)	**0.29**	**0.30**	**6.27**	**6.90**
CD (P≤0.05)	**0.85**	**0.89**	**18.39**	**20.24**
Sulphur Levels				
S_0	20.01	19.96	177.70	187.45
S_1	20.82	20.79	211.90	222.48
S_2	21.57	21.61	248.06	261.36
SE (m±)	**0.25**	**0.26**	**5.43**	**5.98**
CD (P≤0.05)	**0.73**	**0.77**	**15.92**	**17.53**

4. DISCUSSION

4.1 Effect of nitrogen levels

4.1.1 Crop growth attributes

The different growth parameters *viz.,* plant height, leaf area index and dry matter accumulation of Mungbean were significantly affected due to different nitrogen treatments. The highest plant height and dry matter accumulation was recorded with the application of N_3,with the lower growth parameters recorded in N_1. The increase in traits above may be due to the rapid arrival of nutrients added by foliar spraying through stomata or cuts and scratches in the leaves to the cells faster, which helps in the speed and continuity of the supply of nutrients necessary for plant metabolic processes, increasing the rate of photosynthesis and producing more dry matter (Rajaseker*et al*., 2017). And its role in stimulating enzymes involved in the influence of these traits by increasing the activity of chemical reactions and reduce the impact of free radicals that negatively affect the efficiency of the work of some organelles in the plant (Sorooshzadah*et al*., 2012 and Morteza*et al*., 2013). The results of this experiment agreed with Kandil and Marie (2017), Burhan and Al-Hassan (2019), who confirmed a significant increase in vegetative growth traits due the use of nanofertilizer.

The increasing levels of sulphur could have increased the ferridoxin content which is responsible for nodulation activity. Ferridoxin are rich in sulphur and contain Fe-S clusters which play vital role in N_2 fixation. These nodulations encourage the activity of rhizhosphere region increases the nutrient retention in root zone which in turn increased the nutrient absorption and translocation from assimilate to shoot encourage the growth parameters. By supplying sulphur in an easily available SO_4^{2-} form, gypsum ensures that the plant has sufficient sulphur for optimal chlorophyll synthesis, leading to more extensive leaf growth. Besides sulphur plays an important role on improving the vegetative growth by activating certain proteolytic and co-enzymes. Our results are in line with earlier findings of Kaisher*et al*., (2010),Varun *et al*. (2011) and Akter*et al.* (2013).

The higher plant height, LAI and dry matter accumulation recorded with the application of S_2 may be attributed to the fact that application of sulphur improved not only availability of S but other nutrients too which are considered vitally important for growth and development of plants. The application of S through gypsum which contains S in readily available form (SO_4^{2-}) enhanced the concentration of S in soil solution for plant absorption. Besides, it also lowers the soil pH which was responsible for greater availability and mobility of nutrients. Thus, the overall nutritional environment of rhizosphere improved due to application of sulphur which resulted in greater availability and uptake of nutrients vitally important for various metabolic process of the plant. The application of sulphur accelerated photosynthesis because it boosted protein synthesis and maintained a high chlorophyll concentration (Ahmad and Abedin, 2000). Similar findings were also observed by Yadav (2004), Dhaker*et al.* (2010) and Varun *et al*. (2011).

4.1.2 Yield attributes and yield

The nano urea spray had a substantial impact on pods per plant, seeds per pod and 1000 seed weight during the active growth phases of Mungbean. N_3 produced the largest number of pods per plant, 100-seed weight, and seeds per pod which may be due to the more rapid supply of primary mineral nutrients by nanofertilizers through foliar spray through plant openings (stomata or wounds and scratches) in the leaves, which increased the delivery of nutrients for the metabolism of plants. This encourages vegetative and reproductive growth and aids in improving the yield characteristics of mung bean. Our results are in line with the earlier findings of Rajasekar *et al*. (2017) and Abdel-Aziz *et al*. (2018). When there is sufficient nitrogen available, boron has a positive effect on pollen germination, development, anther viability, anthesis, cell division, increased enzymatic activity, and sugar availability, all of which contribute to the formation of more seeds (Shehzad *et al*., 2015). Hassan *et al*. (2019) and Hossain *et al*. (2023) who also reported an increase in growth and yield attributes due to enhanced efficiency of nanofertilizers nutrients through foliar spraying in cereals and pulses, respectively.The seed yieldof Mungbean wassignificantlynitrogen treatments which might be because foliar nano urea treatment encourages plant development and metabolic processes like photosynthesis lead to enhanced photosynthates accumulation and transport to the plant's functional parts. Furthermore, it had a direct impact on energy conversion, the activation of an enzyme involved in carbohydrate metabolism and the increased translocation of photosynthates to vegetative and reproductive parts, all of which improved growth and yield characteristics that affected final yield. Our results are in line with the earlier findings of Khalil *et al.* (2019), Rehab *et al.* (2020), Mahmood and Omer (2021) and Samui *et al.* (2022).

Increasing levels of sulphur upto 30 kg ha^{-1} recorded significant improvement in yield attributes and yield of mungbean. Application of sulphur could have improved the nitrate recovery and diversion of greater proportion of assimilation to developing pods. Besides, S application increases the photosynthetic activity over all growing environment (rhizohsphere region of roots) and greater partitioning of metabolites and adequate translocation of nutrients to developing structure leads to increase the yield attributes. The increase in yield attributes and yield with increasing sulphur level may also be due to synergism between S and most of nutrients which was responsible for higher growth, yield and also leads to encourage the nutrient availability and assimilation. This result was in concurrence with the findings of Dhaker*et al.*(2010), Kaisher *et al*., (2010), Varun *et al*. (2011), and Kokani *et al*. (2014).

4.1.3 Protein content and yield

Nitrogen levels significantly influenced the protein content and protein yield in Mungbean which suggests that applying nano urea during peak nutrient demand periods can enhance nitrogen assimilation, leading to improved protein synthesis and yield. Thus, higher protein content and yield in N_3 treatment can be attributed to more accumulation of nitrogen in grains coupled with higher grain yield. This could be due to the foliar application of nano urea, which caused quick absorption and movement of nitrogen in plant due to tiny particle sizes than the stomatal openings of leaves of plant. These research findings bear coherence with findings of Kumar *et al.* (2015), Pandey *et al.* (2016), and Singh *et al.* (2018) in lentil.

Sulphur application significantly influenced the protein content and protein yield in mungbean. Significantly higher protein content and yield was recorded with S_2 and lowest protein content and yield was recorded with S_0. An increase in protein content with the application of sulphur might be due to increased root activity and translocation of higher nitrogen and sulphur resulting in the synthesis of more sulphur-containing amino acids such as methionine, cysteine and cystine. The synergistic action of nitrogen and sulphur with each other increased their availability in the soil might be attributed to increased N and protein content in mungbean. Enhanced protein content by sulphur application was also documented by Kumar and Singh (2009), Kaisher*et al*., (2010) and Shivay*et al.* (2014).

5. CONCLUSION

The study revealed that both nitrogen application and sulphur levels significantly influenced the key growth parameters, yield attributes, and yield of mungbean across two years (2022 and 2023). Among the nitrogen treatments, the application at N_3 consistently led to better results. This trend indicates that the timing of nano-urea application plays a crucial role, with N_3 being the optimal time for maximizing dry matter accumulation. Therefore, not just the dosage, but also the timing of nano-urea application significantly influences moong bean growth, with a mid-growth application proving to be the most effective. Likewise, increasing the sulphur levels from S_0 to S_3 showed positive impact on growth, yield and quality that emphasizes on the critical role of sulphur in improving the performance of mungbean. Over all the results indicate that application of N_3 i.e., 2 ml nano urea spray at 20-25 DAS with application of 30 kg Sulphur ha^{-1} is an effective strategy for improving growth, yield attributes, and productivity of Mungbean and can be recommended under similar agro-climatic conditions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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