



Effect of Foliar Nitrogen and Basal Phosphorus Fertilization on Growth and Nutrient Uptake of Soybean in Vertisols of the Mewar Region

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The soybean plant frequently suffers substantial losses of flowers and immature pods, with fewer than one-quarter of the flowers ultimately developing into pods. Soybean gives higher positive response to applied nitrogen over symbiotically fixed atmospheric nitrogen through its roots alone which proves that nitrogen fixed by soybean roots is not enough for its growth and development. The present study aimed to determine the effect of Foliar Nitrogen and Basal Phosphorus Fertilization on Growth, Yield, and Nutrient Uptake of Soybean in Vertisols of the Mewar Region. The investigation was carried out at Instructional Farm, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture & Technology, Udaipur. This experiment was conducted in split plot design with foliar nitrogen application and basal phosphorus with 24 treatment combinations. The significantly higher chlorophyll content, leaf area index, biological yield and nutrients uptake (nitrogen, phosphorus and potassium) was obtained under 2.5% nitrogen through urea foliar fertilization in the main plots and 100% recommended dose of phosphorus through single super phosphate in subplots over rest of the treatments. highest phosphorus uptake by soybean was recorded with the foliar application of nitrogen through urea (2.5%), which was foliar application of nitrogen through urea (1.5 and 1.0%) and control but remained statistically at par with the foliar application of nitrogen through urea (2.0 and 3.0%). The improvement in phosphorus uptake can be indirectly linked to better nitrogen availability, which enhances root growth and improves phosphorus uptake by stimulating the activity of phosphate-solubilizing enzymes and root exudates. The harvest index, physical properties of soil *i.e.*, density, porosity, water holding capacity, physico-chemical properties *i.e.*, pH, EC, organic carbon didn't influence significantly with various doses of foliar fertilization of nitrogen and basal phosphorus application. The lowest parameters *i.e.*, chlorophyll content, leaf area index, biological yield and nutrients uptake was obtained control treatments. Based on the findings, it is recommended that foliar fertilization with 2.5% urea along with 100% basal phosphorus should be adopted for enhancing soybean productivity and nutrient use efficiency without adversely affecting soil health.

Keywords: Chlorophyll content; leaf area index; nutrient uptake; physico-chemical properties.

1. INTRODUCTION

Indiscriminate use of nitrogenous fertilizers causes environmental as well as soil pollution. So, the present investigation was carried out to know the effects of foliar fertilization on growth and yield of soybean. Soybean (*Glycine max* L.) is a member of the *Leguminosae* family, renowned for its rich nutrient content and its role as a key nutrient storage crop. Beyond being an important oilseed, soybeans serve a variety of purposes (Modgil et al., 2020). As a major protein and oil crop, soybean is critical to global agriculture, with their oil comprising the largest portion of the world's edible oils. Soybean seed contain 18-22% oil and 40-48% protein, and soybeans contribute to 30% of global edible oil production. They are also a significant ingredient in over 50% of the world's high-protein meals. Additionally, soybean have notable industrial applications due to their nutraceutical and pharmaceutical benefits (Mishra et al., 2024). In India, soybean is grown across 13.5 m ha, producing 12.5 mt with a productivity rate of 980 kg/ha. Maharashtra accounts for 6.9 million tonnes which is nearly 48.77 % of this

production, Rajasthan having 1.13 million hectare of area, 1.41 million tonnes of production with a productivity of 1248 kg/ha, in which Jhalawar is a major producer district followed by Kota, Bundi and Pratapgarh as leading major soybean producing districts of Rajasthan (Anonymous 2024). The soybean plant frequently suffers substantial losses of flowers and immature pods, with fewer than one-quarter of the flowers ultimately developing into pods (Li et al., 2025). This high rate of reproductive abscission significantly restricts yield potential, as the number of retained flowers directly affects seed yield through the pods they form. Soybean yield is positively correlated with flower production, while the number of pods is inversely related to flower and pod abortion rates (Li et al., 2025). Therefore, it is essential to explore strategies to reduce reproductive abscission in order to maximize yields. Reproductive abscission in soybean is influenced by several factors, both individually and interactively, including temperature, photoperiod, solar radiation, moisture stress, deficiencies in assimilates and mineral nutrients especially nitrogen, inadequate fertilization, and hormonal

induction (Staniak et al., 2023). Evaluating the effect of applied mineral nutrients on abscission levels under rain-fed conditions may offer particular benefits. Recent approaches have concentrated on foliar application of essential nutrients during soybean's reproductive stages. This method aims to reduce nutrient depletion from the leaves and minimize reductions in photosynthesis during this critical growth period (Dass et al., 2022).

As a legume, soybeans can fix atmospheric nitrogen, but this alone does not satisfy the crop's entire nitrogen needs. Generally, soybean requires much more nitrogen for seed production in comparison to other legume crops (Hungria and Mendes, 2015). Soybean gives higher positive response to applied nitrogen over symbiotically fixed atmospheric nitrogen through its roots alone which proves that nitrogen fixed by soybean roots is not enough for its growth and development (Hinson, 1975). Thus, small amounts of combined N may stimulate growth and yield of soybeans (Paradiso et al., 2015). During the pod-filling stage mineral N plus N₂ fixation usually do not meet the N demand of the developing seeds and N is translocated to the seeds from the leaves and other parts. The breakdown of proteins in the leaves causes a decrease in physiological activity and ultimately leaf senescence, thus restricting the period of pod-fill. Soybean a "self-destructive" species and suggested that yield are limited by the restricted duration of pod-fill (Vasilas et al., 1980). Foliar applications of N and other nutrients may be effective in extending the pod-filling period by delaying senescence (Vasilas et al., 1980). The need for these foliar applications of nutrients was suggested to be due either to a decline in root absorption activity (Vasilas et al., 1980).

Phosphorus is essential for nodulation in legumes, and supports chlorophyll formation, growth hormone stimulation, enzymatic activity, and reproductive processes (Mitran et al., 2018). Despite the increased use of chemical fertilizers in India over the years, nutrient use efficiency remains low 40-50% for nitrogen, 10-15% for phosphorus. To improve phosphorus, use efficiency and minimize P fixation in the soil, foliar applications of various sources (Kavitha et al., 2025). Foliar spraying of nutrients is the most rapid method to boost crop growth, delivering readily available nutrients to plants during the critical early stages of growth and development (Ishfaq et al., 2022). Flower senescence and poor pod filling are significant challenges in soybean cultivation that can be effectively managed through foliar nutrient application. So, this experiment was carried out to know the combined effect of foliar nitrogen and phosphorus basal application on growth and nutrients uptake by soybean.

2. MATERIALS AND METHODS

The present investigation was carried out during *Kharif*, 2024 at Instructional Farm, Rajasthan College of Agriculture, Udaipur. The experimental site is located in the south-eastern region of Rajasthan, at an elevation of 579.5 meters above mean sea level, situated at 24°35' N latitude and 74°42' E longitude. The area falls within Agro-Climatic Zone IVA, classified as the Sub-Humid Southern Plain and Aravalli Hills of Rajasthan. The region experiences typical subtropical weather with moderate summer temperature and mild winters. The rainfall occurs with south-west monsoon with 637 mm of yearly average annual precipitation. The experimental soil was clayey in texture. The 24 treatments

Table 1. Treatment details

Treatment	:	Description
Levels of foliar Nitrogen application through urea		
N ₁	:	Control
N ₂	:	1.0%
N ₃	:	1.5%
N ₄	:	2.0%
N ₅	:	2.5%
N ₆	:	3.0%
Doses of Phosphorus application through SSP		
P ₁	:	Control
P ₂	:	100% RDP
P ₃	:	75% RDP
P ₄	:	50% RDP

combination which was carried out in split plot design are existing in Table 1. The cultivar JS – 355 was used for the experiment. The treatments were applied according to treatment details using urea at 1% ,1.5%, 2%, 2.5% and 3% in 500 litre water and recommended dose of phosphorus was applied as basal at the time of sowing. The crop was sown on 24th June, 2024 with seed rate of 80 kg and harvested on October 19, 2024. The critical difference for the comparison of treatments was worked out, wherever, the 'F' test was found significant at 5 per cent level of significance.

3. RESULTS

3.1 Chlorophyll Content at 45 DAS

A perusal of data (Table 2) that foliar application of nitrogen through urea had a synergistic effect on chlorophyll content in soybean recorded at 45 DAS. The crop receiving 2.5% nitrogen through urea foliar fertilization recorded significantly higher chlorophyll content at 45 DAS as compared to foliar application of 2.0, 1.5, 1.0% nitrogen and control. The magnitude of difference in chlorophyll content at 45 DAS between foliar applications of nitrogen through urea of 2.5-3.0% was not significant. The foliar application of 2.5% nitrogen through urea significantly improved chlorophyll content at 45 DAS to the extent of 5.13, 12.23, 20.87 and 25.30 per cent over foliar application of 2.0, 1.5, 1.0% nitrogen through urea and control, respectively.

Data furnished in Table 2, reveal that chlorophyll content of soybean recorded at 45 DAS was significantly influenced by different levels of phosphorus application through SSP. Highest chlorophyll content (2.96 mg g⁻¹ fresh leaves) at 45 DAS was recorded with application of 100% RDP through SSP which was significantly higher over rest of the treatments. The magnitude of increase in chlorophyll content at 45 DAS was 6.45, 15.79 and 29.66 per cent over application of 75, 50% RDP through SSP and control, respectively.

3.1.1 Leaf area index

Amongst level of nitrogen application, significantly highest leaf area index was recorded with foliar application of 2.5% nitrogen through urea (Table 2). Foliar application of 2.5% nitrogen through urea in soybean crop gave the higher leaf area index was of 3.32, that was 5.01, 6.29, 12.34, 21.52 and 29.32 per cent more than

obtained with foliar application of 2.0, 3.0, 1.5, 1.0% nitrogen through urea and control, respectively.

It is evident from data (Table 3) that there exist significant variations in leaf area index of soybean crop due to phosphorus application through SSP. Highest leaf area index (3.38) was recorded with application of 100% RDP through SSP which was significantly higher over rest of the treatments. The magnitude of increase in leaf area index was 7.84, 18.95 and 35.59 per cent over application of 75, 50% RDP through SSP and control, respectively.

3.1.2 Interaction effect of foliar application of nitrogen and phosphorus basal application

Interaction between foliar application of nitrogen through urea and phosphorus application through SSP was significant on leaf area index (Table 3). Highest leaf area index of soybean was found in foliar application of 2.5% nitrogen through urea with the application of 100% RDP through SSP, which was significantly superior over rest of the levels of nitrogen and phosphorus application but remained at par with foliar application of 2.5% nitrogen through urea with the application of 75% RDP through SSP.

3.1.3 Total yield

Maximum biological yield was recorded under foliar application of 2.5% nitrogen through urea followed by foliar application of 3.0 and 2.0% nitrogen through urea, which was significantly increased over rest of the treatments. It increased the biological yield by a huge margin of 299, 526 and 769 kg ha⁻¹ over foliar application of 1.5, 1.0% nitrogen through urea and control, respectively.

It is evident from data (Table 2) that there exist significant variations in biological yield of soybean crop due to phosphorus application through SSP. Maximum biological yield (2298 kg ha⁻¹) was recorded with application of 100% RDP through SSP which was significantly higher by 5.80, 12.08 and 29.14 per cent over application of 75, 50% RDP through SSP and control, respectively.

3.1.4 Harvest index

An examination of data (Table 2) indicates that foliar application of nitrogen through urea harvest

did not significantly influence in index of soybean crop during investigation. A reference of data (Table 2) showed that harvest index of soybean

crop remained statistically unchanged due to application of various levels of phosphorus application through SSP during experimentation.

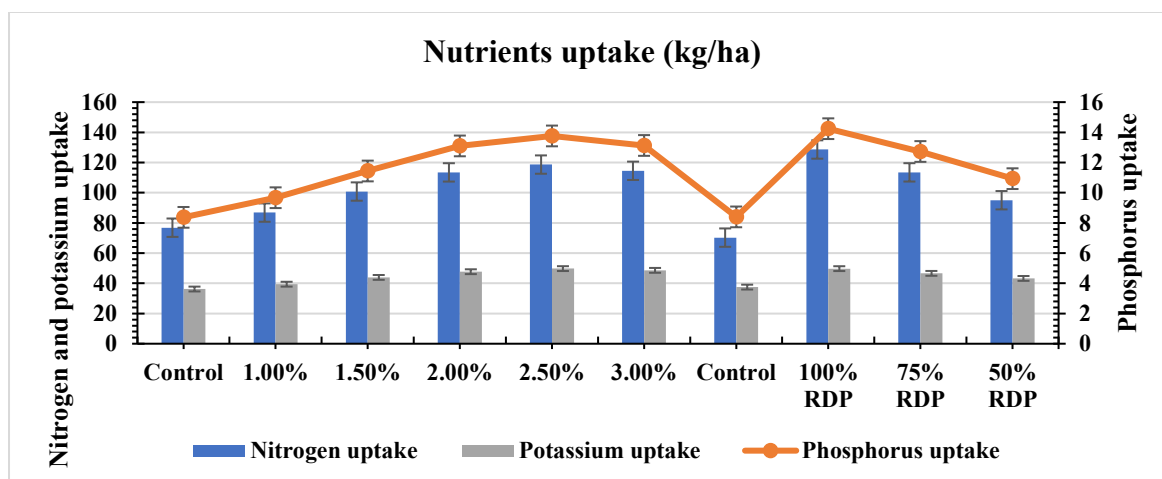


Fig. 1. Effect of nitrogen and phosphorus application on nutrient uptake by soybean

Table 2. Effect of nitrogen and phosphorus application on growth and yield of soybean

Treatments	Chlorophyll content	Leaf area index	Biological yield (kg/ha)	Harvest index (%)
Foliar application of nitrogen through urea				
Control	28.31	2.45	2291	41.35
1.0%	30.85	2.73	2535	41.68
1.5%	33.23	2.96	2762	41.85
2.0%	35.47	3.16	2977	42.14
2.5%	37.29	3.32	3061	42.40
3.0%	36.18	3.13	2977	42.20
SEm±	0.51	0.04	56	0.37
CD (P=0.05)	1.76	0.15	193	NS
Phosphorus application through SSP				
Control	28.96	2.49	1780	41.64
100% RDP	37.55	3.38	2298	41.78
75% RDP	35.28	3.13	2173	42.10
50% RDP	32.43	2.84	2051	42.23
SEm±	0.33	0.03	38	0.27
CD (P=0.05)	0.98	0.08	113	NS
Interaction (N×P)				
SEm±	0.74	0.06	85	0.60
CD (P=0.05)	NS	0.19	NS	NS

Table 3. Interaction effect of nitrogen and phosphorus application on leaf area index

Treatments	Control	100% RDP	75% RDP	50% RDP
Control	1.81	3.08	2.56	2.34
1.0%	2.41	3.20	2.78	2.56
1.5%	2.49	3.30	3.17	2.87
2.0%	2.71	3.47	3.42	3.05
2.5%	2.86	3.71	3.52	3.20
3.0%	2.66	3.51	3.33	3.01
SEm±		0.06		
CD (P=0.05)		0.19		

3.1.5 Nitrogen uptake

Data obtained during the experiment in Fig.1, indicated that the total nitrogen uptake by soybean was significantly influenced by different levels of nitrogen. Foliar application of nitrogen through urea (2.5%) recorded the significantly highest total nitrogen uptake over rest of the treatments except remained statistically at par with the foliar application of 3.0 and 2.0% nitrogen through urea. The increase in total nitrogen uptake due to foliar application of 2.5% nitrogen through urea was to the magnitude of 17.72, 36.59 and 47.65 per cent over foliar application of 1.5, 1.0% nitrogen through urea and control, respectively.

Evaluation of data in (Fig. 1) indicated that total nitrogen uptake by soybean crop did significantly influence due to phosphorus application through SSP during investigation. Application of 100% RDP through SSP recorded highest total nitrogen uptake (129 kg ha^{-1}), which was significantly higher over rest of treatments. Per cent increases in total nitrogen uptake due to application of 100% RDP through SSP were 13.33, 35.36 and 83.03 as compared to application of 75, 50% RDP through SSP and control, respectively.

3.1.6 Phosphorus uptake

Data obtained during the experiment in Fig.1, indicated that the total phosphorus uptake by soybean was significantly influenced by different levels of nitrogen. Foliar application of nitrogen through urea (2.5%) recorded the significantly highest total phosphorus uptake over rest of the treatments except remained statistically at par with the foliar application of 3.0 and 2.0% nitrogen through urea. The increase in total phosphorus uptake due to foliar application of 2.5% nitrogen through urea was to the magnitude of 20.30, 42.25 and 56.50 per cent over foliar application of 1.5, 1.0% nitrogen through urea and control, respectively.

Evaluation of data in (Fig. 1) indicated that total phosphorus uptake by soybean crop did significantly influence due to phosphorus application through SSP during investigation. Application of 100% RDP through SSP recorded highest total phosphorus uptake (14.24 kg ha^{-1}), which was significantly higher over rest of treatments. Per cent increases in total phosphorus uptake due to application of 100% RDP through SSP were 11.79, 30.18 and 69.37

as compared to application of 75, 50% RDP through SSP and control, respectively.

3.1.7 Potassium uptake

Data obtained during the experiment in Fig. 1, indicated that the total potassium uptake by soybean was significantly influenced by different levels of nitrogen. Foliar application of nitrogen through urea (2.5%) recorded the significantly highest total potassium uptake over rest of the treatments except remained statistically at par with the foliar application of 3.0 and 2.0% nitrogen through urea. The increase in total potassium uptake due to foliar application of 2.5% nitrogen through urea was to the magnitude of 13.24, 26.14 and 31.63 per cent over foliar application of 1.5, 1.0% nitrogen through urea and control, respectively.

A critical examination of data (Fig. 1) revealed that total potassium uptake by soybean crop did significantly influence due to phosphorus application through SSP during investigation. Application of 100% RDP through SSP recorded highest total potassium uptake (14.24 kg ha^{-1}), which was significantly higher over rest of treatments. Per cent increases in total potassium uptake due to application of 100% RDP through SSP were 6.71, 15.00 and 32.57 as compared to application of 75, 50% RDP through SSP and control, respectively.

3.2 Physical Properties of Soil

The results related to physical properties viz., bulk density, particle density, porosity and water holding capacity of soil after harvest of soybean as affected by foliar application of nitrogen through urea and phosphorus application through SSP have been summed up in Table 4.

3.2.1 Bulk density

A perusal of data presented in Table 4, shows that application of nitrogen through urea as foliar spray failed to bring about significant variations in bulk density of soil after harvest of soybean. An examination of data indicates that bulk density of soil after harvest of soybean crop did not significantly influenced due to phosphorus application through SSP during investigation.

3.2.2 Particle density

A perusal of data (Table 4) reveals that there exists no significant variation in particle density of

soil after harvest of soybean due to foliar application of nitrogen through urea and phosphorus application through SSP.

3.2.3 Porosity

A perusal of data in Table 4, reveals that foliar application of nitrogen through urea was found non-significant variation in porosity of soil after harvest of soybean crop during investigation. Data that there exist no significant variations in porosity of soil recorded after harvest of soybean crop due to phosphorus application through SSP.

3.2.4 Water holding capacity

Examination of data in Table 4 showed that various level of foliar application of nitrogen through urea failed to bring about significant variations in water holding capacity in soil after harvest of soybean. Data obtained during the experiment indicated that water holding capacity of soil after harvest of soybean crop did not significantly influenced due to different level of phosphorus application through SSP during investigation.

3.3 Physico-chemical Properties of Soil

The results related to physical properties viz., soil pH, EC and organic carbon in soil after harvest of

soybean as affected by foliar application of nitrogen through urea and phosphorus application through SSP have been summed up in Table 5.

3.3.1 Soil pH

Data presented in Table 5, reveal that there exist no significant variations in soil pH after harvest of soybean crop due to different levels of nitrogen and phosphorus application.

3.3.2 Organic carbon

Data (Table 5) showed that the organic carbon in soil after harvest of soybean crop remained statistically unchanged due to application of various levels of nitrogen and phosphorus during experimentation.

3.3.3 Electrical conductivity

Foliar application of nitrogen through urea and phosphorus application through SSP could not bring significant variation in electrical conductivity in soil after harvest of soybean crop during present investigation (Table 5).

Table 4. Effect of nitrogen and phosphorus application on physical properties of soil

Treatments	Bulk density (Mg m ⁻³)	Particle density (Mg m ⁻³)	Porosity (%)	WHC (%)
Foliar application of nitrogen through urea				
Control	1.33	2.65	49.74	41.11
1.0%	1.32	2.63	49.62	41.01
1.5%	1.33	2.64	49.85	41.20
2.0%	1.32	2.64	49.97	41.30
2.5%	1.33	2.65	49.87	41.21
3.0%	1.33	2.66	50.16	41.45
SEm±	0.01	0.02	0.29	0.24
CD (P=0.05)	NS	NS	NS	NS
Phosphorus application through SSP				
Control	1.32	2.64	49.90	41.24
100% RDP	1.32	2.65	49.96	41.29
75% RDP	1.32	2.63	49.76	41.12
50% RDP	1.34	2.67	49.85	41.20
SEm±	0.01	0.03	0.16	0.14
CD (P=0.05)	NS	NS	NS	NS
Interaction (N×P)				
SEm±	0.03	0.06	0.37	0.30
CD (P=0.05)	NS	NS	NS	NS

Table 5. Effect of nitrogen and phosphorus application on physico-chemical properties

Treatments	pH	Electrical conductivity (dS m ⁻¹)	Organic carbon (%)
Foliar application of nitrogen through urea			
Control	8.07	0.672	0.678
1.0%	8.08	0.673	0.678
1.5%	8.10	0.675	0.681
2.0%	8.08	0.673	0.678
2.5%	8.11	0.676	0.681
3.0%	8.11	0.674	0.680
SEm±	0.06	0.005	0.005
CD (P=0.05)	NS	NS	NS
Phosphorus application through SSP			
Control	8.05	0.670	0.675
100% RDP	8.06	0.672	0.677
75% RDP	8.08	0.673	0.679
50% RDP	8.17	0.681	0.686
SEm±	0.09	0.006	0.006
CD (P=0.05)	NS	NS	NS
Interaction (N×P)			
SEm±	0.19	0.01	0.01
CD (P=0.05)	NS	NS	NS

4. DISCUSSION

Nitrogen plays a vital role in chlorophyll synthesis, which directly influences photosynthetic efficiency and biomass production (Kumar et al., 2021). The enhanced chlorophyll content at 45 DAS under 2.5% N suggests better nitrogen assimilation, leading to improved photosynthetic performance and plant vigor. Moreover, adequate nitrogen supply is essential for the initiation and development of root nodules, which are responsible for biological nitrogen fixation. The higher number of effective nodules observed at 45 DAS under the 2.5% N treatment implies that this dose possibly created a more favourable environment for rhizobia colonization and nodule functionality, as reported by Yadav et al. (2022).

Similarly, the increase in leaf area index reflects improved vegetative growth and canopy expansion, which are positively influenced by nitrogen application due to enhanced cell division and elongation processes (Patel et al., 2023). The taller plants recorded under 2.5% N application could be due to the cumulative effects of better nitrogen uptake, efficient photosynthesis, and stronger root development, all of which are interlinked with higher nitrogen availability.

Excessive nitrogen, however, beyond the threshold level can lead to luxury consumption and lodging, but in this study, 2.5% N remained

within the optimal range, promoting balanced growth without adverse effects. The results corroborate with findings from recent studies that suggest foliar application of nitrogen at appropriate concentrations can effectively supplement soil N supply, particularly under nutrient-deficient conditions (Choudhary et al., 2021; Meena et al., 2024).

Maximum biological yield was recorded under foliar application of 2.5% nitrogen through urea followed by foliar application of 3.0 and 2.0% nitrogen through urea, which was significantly increased over rest of the treatments. This enhanced biological yield under 2.5% N treatment can be attributed to the synergistic improvement in both seed and haulm yield, reflecting overall better growth and productivity (Yadav et al., 2021).

Biological yield, a sum of economic (seed) and vegetative (haulm) output, serves as a comprehensive indicator of a plant's total biomass production. Foliar nitrogen at 2.5% likely optimized nutrient availability at crucial vegetative and reproductive stages, thereby improving photosynthesis, nitrogen metabolism, and dry matter accumulation. Rapid and direct absorption of nitrogen through foliage leads to increased enzymatic activity, cell division, and chlorophyll synthesis, which collectively enhance biomass production (Kumar et al., 2021; Meena et al., 2024). The biological yield increase under 2.5% N is also consistent with earlier findings,

where balanced nitrogen nutrition improved source-sink dynamics, root activity, and overall plant vigor, ultimately resulting in higher dry matter accumulation (Choudhary et al., 2021; Yadav et al., 2022).

Foliar application of nitrogen through urea (2.5%) recorded the significantly highest nitrogen uptake by soybean over rest of the treatments except remained statistically at par with the foliar application of 3.0 and 2.0% nitrogen through urea. The enhanced nitrogen uptake in plant is attributed to the direct and rapid absorption of foliar-applied nitrogen, which supplements root-based uptake, especially during critical growth phases. This leads to an increase in metabolic activities, protein synthesis, and improved nitrogen assimilation efficiency (Kumar et al., 2021; Meena et al., 2024).

Similarly, highest phosphorus uptake by soybean was recorded with the foliar application of nitrogen through urea (2.5%), which was foliar application of nitrogen through urea (1.5 and 1.0%) and control but remained statistically at par with the foliar application of nitrogen through urea (2.0 and 3.0%). The improvement in phosphorus uptake can be indirectly linked to better nitrogen availability, which enhances root growth and improves phosphorus uptake by stimulating the activity of phosphate-solubilizing enzymes and root exudates (Yadav et al., 2022). Nitrogen-induced root development and rhizosphere activity increase the mobility and acquisition of relatively immobile nutrients like phosphorus in the soil (Patel et al., 2023).

The results related to physical properties viz., bulk density, particle density, porosity and water holding capacity of soil after harvest of soybean as was not affected by foliar application of nitrogen through urea. This lack of significant change can be attributed to the nature of foliar application, which primarily influences plant physiology and growth without direct interaction with the soil matrix. Unlike soil-applied fertilizers, foliar applications deliver nutrients directly to the plant leaves, bypassing the soil environment. As a result, they contribute minimally to changes in soil physical characteristics such as compaction, pore structure, and moisture retention capacity (Kumar et al., 2021). Bulk density and particle density are primarily influenced by long-term organic matter accumulation, tillage practices, and soil texture—factors not significantly altered by short-term foliar nutrient interventions (Meena et al., 2022).

Similarly, soil porosity and water holding capacity are dependent on the soil's structure, organic carbon content, and texture. Since foliar nitrogen applications do not add organic residues or affect microbial biomass significantly in the short term, they do not bring about measurable changes in these parameters (Choudhary et al., 2023). In contrast, practices such as green manuring, compost application, or incorporation of crop residues have been shown to significantly influence these properties over time. Thus, the results align with previous research indicating that foliar nutrient management, while effective for enhancing plant nutrition and yield, does not significantly alter the soil's physical environment in the short term.

5. CONCLUSION

The present study clearly demonstrated that foliar application of nitrogen and basal phosphorus significantly influenced the growth and nutrient uptake of soybean. Among all treatment combinations, foliar application of 2.5% nitrogen through urea, coupled with 100% recommended dose of phosphorus via single super phosphate, resulted in markedly higher chlorophyll content, leaf area index, biological yield, and nutrient uptake (N, P, and K). In contrast, control treatments recorded the lowest values for these parameters. However, soil physical and physico-chemical properties such as bulk density, porosity, water holding capacity, pH, EC, and organic carbon remained unaffected by the treatments. Based on the findings, it is recommended that foliar fertilization with 2.5% urea along with 100% basal phosphorus should be adopted for enhancing soybean productivity and nutrient use efficiency without adversely affecting soil health.

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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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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