



Nitrogen source's effect on yield protein content, and nitrogen use efficiency of scented rice (*Oryza sativa*) under irrigated conditions

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) season of 2023 and 2024 at IFTM University, Moradabad, Uttar Pradesh, to study the effect of different nitrogen sources and management practices on nutrient content, quality parameters, yield, and nitrogen use efficiency of scented rice (*Oryza sativa* L.) under irrigated conditions. The experiment was laid out in a split-plot design (SPD) with three scented rice varieties (Pusa Basmati 1718, Pusa Basmati 1847, and Pusa Basmati 1886) in the main plots and six nitrogen management practices in subplots, viz. control, 100% N through prilled urea, 50% N through prilled urea + two foliar sprays of nano urea, 50% N through prilled urea + green manuring + one foliar spray of nano urea, 75% N through prilled urea + two foliar sprays of nano urea, and 75% N through prilled urea + green manuring + one foliar spray of nano urea. Results indicated that Pusa Basmati 1847 recorded significantly higher grain protein content, protein yield, total nitrogen uptake, and grain yield (5.62–5.64 t/ha) compared with other varieties. Among nitrogen treatments, 75% N through prilled urea + green manuring + one foliar spray of nano urea produced the highest protein content (8.1–9.1%), protein yield (429.93–482.18 kg/ha), total nitrogen uptake (84.48–84.64 kg/ha), and nitrogen recovery (45.26–68.33%), along with maximum grain yield (5.28–5.29 t/ha). The study highlights the potential of integrating prilled urea, nano urea, and green manuring to improve grain quality, nutrient uptake, and nitrogen use efficiency in scented rice under irrigated conditions.

Keywords: Basmati rice, Green manuring, Grain quality, Nano urea, Nitrogen recovery, Nutrient uptake

Scented rice (*Oryza sativa* L.), particularly Basmati varieties, plays a vital role in India's agricultural export sector due to its distinctive aroma, long slender grains, and exceptional cooking quality (Seth *et al.* 2022). As the world's leading exporter of basmati rice, India is responsible for over 70% of global exports, with cultivation predominantly centered in the fertile Indo-Gangetic plains (APEDA 2025). The economic importance of Basmati rice is underscored by its significant nutrient requirements, particularly concerning nitrogen (N). Nitrogen is essential for optimizing yield, enhancing grain quality, and maximizing market value (Shahane and Shivay 2021). Despite its advantages, the cultivation of Basmati rice often suffers from poor nitrogen management practices. This inefficiency typically results in low nitrogen use efficiency (NUE), which negatively impacts both production costs and environmental sustainability. Excessive nitrogen application can lead to detrimental effects such as nutrient leaching and emissions of nitrous oxide, a potent greenhouse gas. Therefore, improving nitrogen

management practices is crucial not only for boosting economic returns for farmers but also for minimizing environmental repercussions. Innovative strategies, such as precision agriculture and integrated nutrient management, could enhance NUE, ensuring sustainable production of this prized rice variety while safeguarding natural resources for future generations.

The conventional application methods of nitrogen (N) primarily through prilled urea is often hindered by suboptimal recovery rates and misalignment with crop nitrogen demand, challenging its efficacy in agricultural systems (Govindasamy *et al.* 2023). To enhance nutrient management practices, recent innovations have introduced nano urea, a liquid formulation featuring ultrafine particles optimized for foliar application. This approach promotes better absorption by the leaves, potentially diminishing reliance on traditional bulk chemical fertilizers (Singh *et al.* 2025). Furthermore, the incorporation of green manuring crops, such as *Sesbania aculeata*, into rice-based cropping systems offers significant advantages. These legumes not only contribute nitrogen through biological fixation but also enhance soil organic matter, improve soil structure, and boost microbial activity, thereby fostering long-term soil health and fertility (Kumawat *et al.* 2025). Collectively,

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these strategies represent a shift towards more sustainable and efficient nutrient management in agriculture.

Various studies have investigated the impact of individual nitrogen sources on the yield and quality of rice; however, comprehensive research on integrated nitrogen management strategies, specifically combining prilled urea, nano urea, and green manuring in scented rice is limited. Additionally, there is a lack of detailed information regarding how these approaches affect nutrient content, quality parameters, and nitrogen use efficiency across multiple Basmati varieties, particularly in the context of irrigated conditions in western Uttar Pradesh. Therefore, this study aims to evaluate the influence of different nitrogen sources and integrated management practices on essential indicators such as nutrient content, grain quality, overall yield, and nitrogen use efficiency of scented rice. By addressing this research gap, the investigation seeks to provide valuable insights into optimizing nitrogen management for improved rice production in this region, ultimately contributing to better agronomic practices and enhanced sustainability in rice cultivation.

MATERIALS AND METHODS

A field experiment was conducted during the rainy (*khari*) season of 2023 and 2024 at IFTM University, Moradabad, Uttar Pradesh. The region experiences a subtropical climate, characterized by elevated summer temperatures and mild winters, along with an average annual precipitation ranging from 900–1,000 mm (Fig. 1). The soil at the experimental site was classified as sandy loam, exhibiting slightly alkaline properties with a pH of 7.7. It presented low organic carbon content of 0.43%, while the levels of phosphorus and potassium were recorded at 18.4 kg/ha and 208.3 kg/ha, respectively. Additionally, the available nitrogen in the soil was estimated 186.7 kg/ha, providing a suitable nutrient base for crop production in the experimental setup.

The experiment was laid out in a split-plot design (SPD) with three distinct scented rice varieties: Pusa Basmati 1718 (V_1), Pusa Basmati 1847 (V_2), and Pusa Basmati 1886 (V_3) allocated to the main plots due to larger management requirements and to minimize experimental error. The subplots consisted of six varying nitrogen management strategies aimed at enhancing crop performance for efficient comparison of fertilizer responses. The treatments included N_0 (Control), N_1 (100% prilled urea), N_2 (50% prilled urea + two foliar application of nano urea), N_3 (50% prilled urea + 25% green manure + 25% (one foliar application of nano urea)), N_4 (75% prilled urea + 25% two foliar application of nano urea), and N_5 (75% prilled urea + 25% combination of green manure and one foliar application of nano urea). Adequate spacing between plots was maintained to avoid lateral movement of applied nutrients and ensure treatment integrity.

The selection of rice varieties was based on their regional importance, grain quality characteristics and differential response to nitrogen fertilization. Pusa Basmati

1847 and other tested scented rice cultivars are widely cultivated in north-western Indo-Gangetic plains and are known for superior grain aroma, elongation ratio and market value. Nitrogen is the most limiting nutrient in irrigated rice ecosystems, and its optimum requirement varies with soil fertility status, genotype and climatic conditions. Recommended nitrogen doses for transplanted rice in western Uttar Pradesh generally range between 120–150 kg/ha. Therefore, graded nitrogen levels were included in the present study to identify the optimum dose that maximizes productivity and nitrogen use efficiency without causing environmental losses.

Twenty-one-day-old seedlings were transplanted manually at a spacing of 20 cm × 15 cm. *Sesbania aculeata* was incorporated into the soil to enhance soil fertility, green manure, 10 days prior to transplanting. The estimated green biomass added to the soil was approximately 5.5–6.0 t/ha, contributing around 60–65 kg N/ha. The incorporated biomass contained approximately 3.5% nitrogen, 0.55% phosphorus and 1.6% potassium on a dry weight basis, contributing to initial soil nutrient availability. Nitrogen was supplied through prilled urea, applied in three equal splits: at the basal stage, during maximum tillering, and at panicle initiation. Additionally, a foliar application of nano urea at a concentration of 4% was administered during key growth phases as per the experiment details. Phosphorus and potassium were applied uniformly @60 kg P_2O_5 /ha and 40 kg K_2O /ha, respectively. Subsequently, soil and plant samples were collected for nitrogen content analysis using standardized methods. To assess protein content, the nitrogen values obtained were multiplied by a factor of 5.95, reflecting a comprehensive approach to nutrient management in this study. NUE and recovery efficiency were computed using the following formulas:

$$\text{Nitrogen use efficiency (NUE)} = \frac{\text{Grain yield of treated plot (kg/ha)} - \text{Grain yield of control plot (kg/ha)}}{\text{Amount of N applied (kg/ha)}} \quad (1)$$

$$\text{Recovery efficiency (RE)} = \frac{\text{N uptake in treated plot (kg/ha)} - \text{N uptake in control plot (kg/ha)}}{\text{Amount of N applied (kg/ha)}} \quad (2)$$

The data collected were subjected to statistical analysis employing ANOVA as described by Gomez and Gomez (1984), specifically within a split-plot design (SPD) framework. To further evaluate the differences between the treatment means, Tukey's test was utilized, maintaining a significance level of 5%. This rigorous statistical approach allowed for a comprehensive understanding of the data relationships, effectively identifying significant differences among the treatments while ensuring robust and reliable results throughout the analysis. Statistical analysis was performed using OPSTAT statistical software.

RESULTS AND DISCUSSION

The experimental results indicated consistently higher growth and yield parameters during 2024 compared with

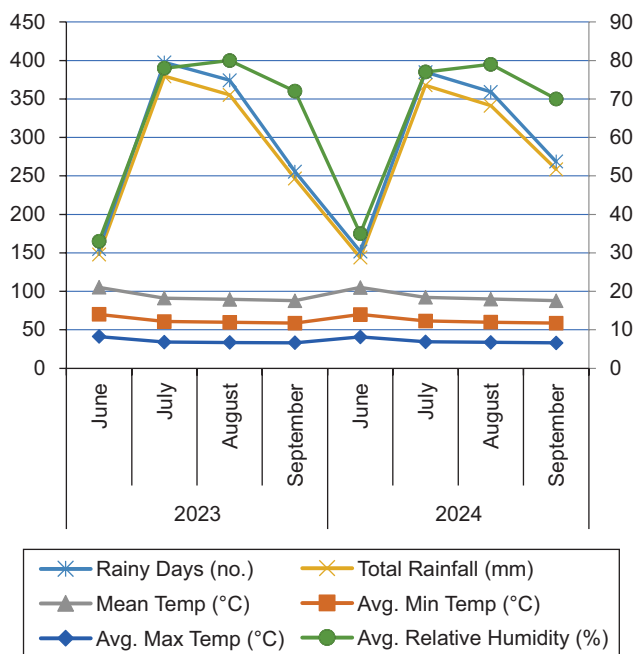


Fig. 1 Monthly rainfall, temperature and relative humidity data for 2023 and 2024 (IMD Data Service Portal).

2023. This variation may be attributed to more favourable weather conditions, particularly improved rainfall distribution, moderate temperature regime and reduced abiotic stress during critical crop growth stages in 2024, which enhanced nutrient uptake and biomass accumulation.

Nitrogen content, available nitrogen, and nitrogen use

efficiency: The nitrogen content in both the grains and straw of various rice varieties demonstrated significant variations. Over the two years of experimentation, Pusa Basmati 1847 consistently stood out by showing the highest nitrogen levels. Following closely were Pusa Basmati 1718 and Pusa Basmati 1886, as detailed in Table 1. It's intriguing to note that despite the observed differences in nitrogen content among these rice varieties, the available nitrogen levels in the soil after harvest remained relatively uniform across the different types. These findings implied that the rate at which nitrogen was depleted from the soil was consistent among the tested rice varieties, indicating similar patterns in soil nutrient dynamics. The superior performance of Pusa Basmati 1847 may be associated with its efficient root system, higher nitrogen uptake capacity, improved assimilate translocation and better tolerance to biotic and abiotic stresses. Genetic potential for higher grain filling and nutrient use efficiency in this variety has also been reported in earlier studies, supporting the present findings. Consequently, it reflects that while specific rice varieties may have higher nutrient accumulation, the overall soil nutrient profile after harvest tends not to vary significantly, potentially impacting fertility management practices for rice cultivation. This reinforces the necessity for tailored soil management strategies in rice farming.

When evaluating nitrogen management practices in rice, the combination treatment of 75% prilled urea supplemented with one application of foliar nano urea and green manuring (N₅), proved to be the best treatment. The combination consistently recorded the highest nitrogen content in both

Table 1 Effect of different nitrogen levels on available N, nitrogen content in grain and straw and nitrogen use efficiency of scented rice

Treatments	Available N (kg/ha)		Nitrogen content in grain (%)		Nitrogen content in straw (%)		Nitrogen Use Efficiency (%)	
	2023	2024	2023	2024	2023	2024	2023	2024
Varieties (Main plot)								
V ₁	190.2	194.3	1.26	1.36	0.41	0.42	26.81	27.04
V ₂	190.5	194.7	1.31	1.42	0.46	0.47	32.50	31.21
V ₃	189.9	193.7	1.21	1.31	0.42	0.43	25.24	25.95
SEM±	0.79	0.85	0.01	0.01	0.02	0.01	2.79	2.65
CD (p=0.05)	NS	NS	0.04	0.04	0.06	0.03	NS	NS
Nitrogen levels (Sub-plot)								
N ₀	189.3	185.0	1.06	0.93	0.35	0.36	24.22	23.18
N ₁	190.5	196.7	1.31	1.47	0.39	0.38	27.46	27.66
N ₂	189.6	195.0	1.23	1.37	0.38	0.37	28.63	28.44
N ₃	189.4	194.8	1.26	1.40	0.37	0.38	29.34	28.86
N ₄	190.9	196.8	1.33	1.49	0.39	0.40	30.47	29.10
N ₅	191.6	197.3	1.37	1.53	0.42	0.45	32.18	32.33
SEM±	0.89	0.85	0.01	0.01	0.01	0.02	3.12	2.89
CD (p=0.05)	NS	2.45	0.03	0.03	0.03	0.06	9.35	8.54

Treatments details are given under Materials and Methods.

grain (1.37% and 1.53%) and straw (0.42% and 0.45%). Additionally, this treatment demonstrated superior nitrogen use efficiency (NUE) values of 32.18% and 32.33%, compared to the control treatment (N_0) during both years of the study. These findings emphasize the synergistic effects of combining organic inputs with nano urea, which appear to enhance nitrogen assimilation and overall utilization efficiency in rice cultivation. The integration of green manuring helps to sustain soil fertility, while nano urea provides precise and targeted nutrient supply, reducing the potential losses of nitrogen. The implications of this approach highlight the potential of integrating innovative fertilization strategies to optimize crop performance while maintaining soil health. Grain yield increased with successive nitrogen application upto the N_5 level, which closely corresponds to the recommended nitrogen requirement for irrigated rice in the region. Adequate nitrogen availability at this level likely enhanced chlorophyll synthesis, tiller production, photosynthetic activity and grain filling, resulting in higher productivity. Collectively, these results contribute valuable insights into sustainable agricultural practices and long-term soil health that promote efficient and sustainable nutrient management in rice production systems (Sidhu *et al.* 2016, Prasad *et al.* 2019a, Singh *et al.* 2022, Bhardwaj *et al.* 2023, Baral *et al.* 2024).

The higher nitrogen recovery observed at the N_3 level compared with N_5 during 2024 suggests reduced fertilizer use efficiency at excessive nitrogen supply. This may be due to luxury consumption, volatilization losses, leaching or denitrification under flooded soil conditions.

Protein content, protein yield, and nitrogen uptake: The protein content and yield of different rice varieties exhibited significant trends that were closely linked to the nitrogen levels present in the grains (Table 2). Among the varieties evaluated, Pusa Basmati 1847 distinguished itself with notably higher protein yield and total nitrogen uptake across both years of experimentation. This finding underscores its impressive capacity to effectively assimilate nitrogen from the soil, which is crucial for optimal growth and development. The evident correlation between nitrogen content and protein yield implies that optimizing nitrogen fertilization practices could significantly enhance the nutritional quality of rice. This enhancement not only benefits the agricultural output but also contributes to food security and improved dietary options. Consequently, Pusa Basmati 1847 emerges as a particularly favourable selection for cultivation in nitrogen-rich soils, offering both high-quality grains and a sustainable approach to rice production in various farming systems.

In terms of nitrogen management strategies, the treatment N_5 , which comprised 75% prilled urea along with one application of foliar nano urea and incorporation of green manuring, appeared to be the most beneficial. This treatment consistently recorded the highest observed protein yield, achieving values of 429.39 kg/ha and 482.18 kg/ha during both years of experimentation. This treatment also led to maximum total nitrogen uptake, with values of 84.48 kg/ha and 84.64 kg/ha, indicating its effectiveness in enhancing soil fertility and crop nutrient assimilation. These results highlight the synergistic role of combining conventional

Table 2 Effect of different nitrogen levels on protein, protein yield, total N uptake and recovery percentage of scented rice

Treatments	Protein (%)		Protein yield (kg/ha)		Total N uptake (kg/ha)		Nitrogen recovery (%)	
	2023	2024	2023	2024	2023	2024	2023	2024
Varieties (Main plot)								
V ₁	7.5	8.1	344.23	378.88	73.28	74.08	28.28	49.57
V ₂	7.8	8.5	440.24	481.91	89.92	90.24	30.39	51.43
V ₃	7.2	7.8	318.35	350.47	70.08	70.88	35.62	54.48
SEM±	0.06	0.05	4.51	5.57	3.24	3.36	6.29	5.94
CD ($p=0.05$)	0.23	0.21	17.69	21.87	9.87	10.12	NS	NS
Nitrogen levels (Sub-plot)								
N_0	6.3	5.5	266.99	235.33	66.88	66.88	0.00	0.00
N_1	7.8	8.7	397.47	446.89	81.28	81.6	27.51	43.97
N_2	7.3	8.2	344.09	393.97	75.2	76.96	34.58	64.80
N_3	7.5	8.3	360.36	404.57	76.8	77.44	41.49	71.93
N_4	7.9	8.8	406.81	459.59	81.92	82.88	39.73	61.94
N_5	8.1	9.1	429.93	482.18	84.48	84.64	45.26	68.33
SEM±	0.07	0.07	5.43	5.14	3.12	3.25	6.56	6.23
CD ($p=0.05$)	0.21	0.2	15.67	14.85	9.38	9.73	20.32	19.65

Treatment details are given under Materials and Methods.

nitrogen fertilizers with innovative technologies and organic amendments to achieve sustainable improvements in crop performance.

Following N₅, the nitrogen management treatments N₄ (75% prilled urea paired with two applications of foliar nano urea) and N₁ (100% prilled urea) also showed significant improvement in protein yield and nitrogen uptake compared to the control treatment. In stark contrast, the control plots, which did not receive any nitrogen management interventions, reported the lowest protein yields of 266.99 kg/ha and 235.33 kg/ha, as well as total nitrogen uptake of 66.88 kg/ha in both years. These findings emphasize the critical role of integrated nitrogen management practices with modern approaches in promoting grain quality and enhancing the nutritional profile of the crop (Akhtar *et al.* 2022, Yadav *et al.* 2023, Singh *et al.* 2024).

Grain yield, straw yield, and harvest index: Grain yield, straw yield, and overall biological yield were found to be significantly affected by both the rice variety under cultivation and the levels of nitrogen applied (Table 3). The interaction between these two factors clearly demonstrated that appropriate nitrogen management, combined with the choice of variety, plays a crucial role in determining crop productivity, highlighting the importance of integrated approaches for achieving higher yields in rice cultivation.

Pusa Basmati 1847 achieved the highest grain yields of 5.62 and 5.64 t/ha, along with impressive biological yields of 12.01 and 12.07 t/ha. Additionally, it exhibited a remarkable harvest index of 46.8 and 46.7. These outstanding results can be attributed to the variety's superior sink capacity,

which enhances its ability to produce and store grains, as well as its high nutrient use efficiency, allowing for optimal growth and yield potential under various agricultural conditions. Among the various nitrogen treatments tested, the combination N₅, consisting of 75% prilled urea, one foliar application of nano urea, and green manuring, achieved the highest grain yields of 5.28 and 5.29 t/ha. Additionally, it recorded maximum biological yields of 11.88 and 11.97 t/ha. Similarly, the treatment labeled N₄, which included 75% prilled urea along with two foliar applications of nano urea, consistently outperformed other treatments across both years. This highlights the effectiveness of integrating organic sources with nano urea for enhanced crop performance.

The harvest index showed no significant differences across the various nitrogen levels, indicating that both grain yield and straw yield responded in a proportional manner to nitrogen application. This trend suggested that while nitrogen supplementation enhances total productivity, it does not markedly influence the balance of assimilate partitioning between economic yield (grain) and vegetative biomass (straw). These results are consistent with earlier reports which emphasized the role of integrated nitrogen management in improving yield performance, particularly in aromatic and high-value rice cultivars (Oo *et al.* 2007, Sharma *et al.* 2021, Patel *et al.* 2022, Kumar *et al.* 2023, Gawdiya *et al.* 2023). The absence of variation in the harvest index highlights that nitrogen contributes more to overall biomass accumulation rather than altering resource allocation efficiency. Such findings underline the significance of adopting efficient nitrogen strategies that enhance total

Table 3 Effect of different nitrogen levels on grain yield, straw yield, biological yield and harvest index of scented rice

Treatments	Grain yield (t/ha)		Straw yield (t/ha)		Biological yield (t/ha)		Harvest Index (%)	
	2023	2024	2023	2024	2023	2024	2023	2024
Varieties (Main plot)								
V ₁	4.58	4.63	6.11	6.15	10.69	10.78	42.8	42.9
V ₂	5.62	5.64	6.39	6.43	12.01	12.07	46.8	46.7
V ₃	4.38	4.43	5.90	5.91	10.28	10.34	42.5	42.8
SEM±	0.04	0.06	0.04	0.05	0.08	0.10	0.11	0.23
CD (p=0.05)	0.16	0.23	0.16	0.20	0.31	0.39	0.45	0.91
Nitrogen levels (Sub-plot)								
N ₀	4.18	4.18	5.32	5.29	9.50	9.47	43.8	43.9
N ₁	5.08	5.10	6.35	6.42	11.43	11.52	44.3	44.2
N ₂	4.70	4.81	5.97	5.97	10.67	10.78	43.9	44.5
N ₃	4.80	4.84	6.08	6.13	10.88	10.97	44.0	43.9
N ₄	5.12	5.18	6.48	6.49	11.61	11.68	44.0	44.3
N ₅	5.28	5.29	6.61	6.67	11.88	11.97	44.3	44.1
SEM±	0.05	0.06	0.07	0.07	0.12	0.12	0.15	0.20
CD (p=0.05)	0.16	0.16	0.21	0.20	0.35	0.34	NS	NS

Treatment details are given under Materials and Methods.

yield, maintain grain quality, and ensure economic viability for farmers cultivating scented rice. Future investigations may focus on fine-tuning nitrogen scheduling and complementary practices to maximize productivity while safeguarding sustainability.

The current study emphasizes the exceptional performance of Pusa Basmati 1847 when evaluated for protein content, nitrogen uptake, and use efficiency in comparison to alternative rice varieties. The research demonstrates that a well-structured nitrogen management strategy is crucial; specifically, the combination of 75% prilled urea alongside green manuring and a single foliar application of nano urea consistently leads to the highest yield outcomes in terms of both quality and nitrogen use efficiency. This sustainable approach not only reduces dependence on synthetic fertilizers but also contributes positively to soil health, fertility and sustainability. By establishing an effective methodology for cultivating Basmati rice in the Indo-Gangetic plains, this research promotes environmentally sustainable agricultural practices and offers valuable insights into how to enhance productivity while caring for the ecosystem.

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