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Optimizing nano urea for enhancing economic of rice, nutrient acquisition and nitrogen use efficiency in the Chhattisgarh plains

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Abstract

The experiment was conducted during *Kharif*-2025 at the Instructional Cum Research Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur to optimize the nano urea for enhancing rice productivity, nutrient acquisition and nitrogen use efficiency in the Chhattisgarh plains. The experiment was laid out in a Randomized Block Design (RBD) with three replications. Different treatments also had a significant effect on nitrogen, phosphorus and potassium uptake by the rice crop. The highest nitrogen, phosphorus and potassium uptake were recorded under 100% NPK +2 spray of Nano Urea Plus (@0.4%) at 45-50 DAT and 60-65 DAT (T₁₂), while the lowest in the control. Nitrogen use efficiency was highest (49.62%) in the treatment with 75% N, 100% P and K +2 foliar sprays of Nano Urea Plus (@0.4%) at 45-50 and 60-65 DAT (T₁₀). Agronomical efficiency (AE) ranged from 28.53 to 43.76 kg kg⁻¹, physiological efficiency (PE) from 142.18 to 198.68 kg kg⁻¹, agro-physiological efficiency (APE) from 65.06 to 90.19 kg kg⁻¹, apparent recovery efficiency (ARE) from 38.66 to 49.63%, and utilization efficiency (EU) from 61.80 to 96.41 kg kg⁻¹. The treatment comprising 50% N and 100% P and K + two foliar sprays of Nano Urea Plus (@0.4%) at 45-50 and 60-65 DAT (T₆) recorded the highest AE (43.76 kg kg⁻¹), PE (198.68 kg kg⁻¹), APE (90.19 kg kg⁻¹) and EU (96.41 kg kg⁻¹). The highest ARE (49.63%) was recorded with 75% N and 100% P and K + two sprays of Nano Urea Plus (@0.4%) at 45-50 and 60-65 DAT (T₁₀), followed by T₆ and T₈ (50% N/67% N and 100% P & K + two Nano Urea Plus sprays). The lowest AE (28.53 kg kg⁻¹) and ARE (38.66%) were observed under 100% N, P and K (T₅), while the lowest PE and APE were recorded under 50% N and 100% P and K (T₂) and the lowest EU (61.80 kg kg⁻¹) under 100% N, P and K with one Nano Urea Plus spray at 60-65 DAT (T₁₁). The maximum benefit-cost ratio was achieved with 100% NPK + 1 spray of Nano Urea Plus (@0.4%) at 60-65 DAT (T₁₁), which found almost similar to 75% NPK + 1 or 2 spray of nano urea plus (@0.4%) at 45-50 DAT and 60-65 DAT, whereas lowest under control (T₁).

Keywords: Nano urea, rice, productivity, nutrient use efficiency, economic

Introduction

Rice yield mostly relies on soil conditions and further more on the supply of the accessible nutrients like nitrogen, phosphorus, potassium, sulphur and zinc [18]. Rice plants require large amounts of mineral nutrients including nitrogen for their growth, development and grain production [17]. After carbon, hydrogen and oxygen, nitrogen is one of the important elements in plants because of its key part in chlorophyll production, which is basic for the photosynthesis process. Also, nitrogen is part of different enzymatic proteins that catalyze and regulate plant development processes [28].

Nitrogen plays a vital role in plant nutrition, being a key element of chlorophyll, which gives plants their green colour, and also an essential part of plant proteins. Over the past five decades, the global increase in crop yields has largely been driven by the extensive use of nitrogen fertilizers combined with improved agricultural practices [30]. As cereal crops require more nitrogen than other crops for optimal growth, development and grain production. Despite this need, rice growing soils are often nitrogen deficient [26]. The high productivity of irrigated rice today is mainly due to the heavy application of nitrogen fertilizers [4]. Nitrogen is considered the most limiting nutrient in irrigated rice systems worldwide [27]. In lowland rice, nitrogen comes from soil reserves,

biological nitrogen fixation and fertilizer input. However, a significant portion of soil nitrogen is lost through processes like plant uptake, denitrification, leaching and volatilization. These losses not only reduce nitrogen availability to crops but also pose environmental concerns. Therefore, enhancing nitrogen use efficiency remains a major challenge in sustainable rice production.

Recent advancements in agriculture, such as the use of nano urea, offer promising improvements in rice cultivation. Nano urea, composed of ultra-small urea particles, enhances nitrogen absorption by plants, leading to better growth, higher yields and improved nitrogen use efficiency. This form of liquid fertilizer is considered a superior alternative to traditional urea for instance, just 500 ml of nano urea can replace a 45 kg bag of conventional urea. Its nano-sized particles (about 30 nm) possess a much greater surface area, enabling efficient nutrient delivery through foliar application during key growth stages. Research by Sharmila and Rahale has shown that nano- clay based formulations like zeolite and montmorillonite can release nitrogen for over 1000 hours, in contrast to less than 500 hours with regular fertilizers. This slow-release mechanism ensures consistent nutrient availability, boosting important yield parameters such as the number of panicles, grain count, test weight and both grain and straw yields. Beyond productivity, nano urea also contributes to environmental benefits reducing nitrate leaching into groundwater, cutting greenhouse gas emissions and supporting climate resilience and sustainable farming practices [3].

Materials and Methods

The field experiment was conducted during the *Kharif* -2025 season at the Instructional- cum-Research Farm, Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, Chhattisgarh (21.232245° N to 81.700344° E). Raipur lies in a dry sub-humid agro- climatic zone and receives an annual rainfall of about 1200–1400 mm, with nearly 88% occurring during the southwest monsoon (June–September). During the crop season, the experimental site received 741.2 mm of well-distributed rainfall, mainly from the third week of July to the second week of November. Maximum temperature ranged from 28.0 to 32.8 °C, minimum temperature from 10.7 to 25.1 °C, while relative

humidity varied from 84–94% (RH-I) and 38–83% (RH-II). The experimental soil was deep black clay (*Kanhar*) with high water-holding capacity. The experiment was laid out in a Randomized Complete Block Design (RBD) with three replications and twelve treatments. Seedlings were transplanted on 24 July 2025 at a spacing of 20 × 10 cm. The recommended fertilizer dose (RDF) of 120:60:40 N:P₂O₅:K₂O kg ha⁻¹ was followed, with nitrogen applied at 50%, 67%, 75% and 100% of the RDF according to treatment (Table 1). Full doses of phosphorus and potassium were applied as SSP and MOP at transplanting. Nitrogen was supplied through urea in three splits (30% basal, 40% at maximum tillering, and 30% at panicle initiation). Nano nitrogen was sprayed twice, at maximum tillering (9 September) and panicle initiation (19 September), as per the treatment schedule. The crop was harvested at full maturity on 13 November 2025 (113 days after transplanting). Border rows were removed before harvesting the net plot area. The harvested produce was sun-dried for seven days, manually threshed on 21–22 November, winnowed and dried further to achieve a grain moisture content of 12–13%.

Soil sampling and analysis

Soil samples were collected from the 0–0.15 m depth before sowing and after completion of the two cropping cycles. The collected samples were air-dried, finely ground, and sieved through a 2 mm (100-mesh) sieve before analysis. Soil pH was determined in a 1:2 soil-to-water suspension using a glass electrode pH meter following the method of Potentiometric [24]. Electrical conductivity (EC) was measured in the soil–water suspension after 24 h of equilibration using a conductimetric method [7]. Soil organic carbon (OC) was estimated by the Walkley and Black method [32]. Available nitrogen (N) was determined using the alkaline permanganate method [30], while available phosphorus (P) was analyzed in 0.5 M sodium bicarbonate extract according to Olsen [21]. Available potassium (K) was extracted with 1.0 N neutral ammonium acetate extractant [25]. Available micronutrients, including Zn, Cu, Fe and Mn, were determined using the 0.005 M DTPA extraction method [16], whereas available boron (B) was estimated by the hot water extraction method [6]. The initial chemical characteristics of the experimental soil are presented in Table 2.

Table 1: Treatment details

Treatment	Details
T ₁	0%N & 100% P & K
T ₂	50% N & 100% P & K
T ₃	67% N & 100% P & K
T ₄	75% N & 100% P & K
T ₅	100% N & 100% P & K
T ₆	T ₂ +2 spray of Nano Urea Plus (@0.4%) at 45-50 DAT and 60-65 DAT
T ₇	T ₃ +1 spray of Nano Urea Plus (@0.4%) at 60-65 DAT
T ₈	T ₃ + 2 spray of Nano Urea Plus (@0.4%) at 45-50 DAT and 60-65 DAT
T ₉	T ₄ +1 spray of Nano Urea Plus (@0.4%) at 60-65 DAT
T ₁₀	T ₄ +2 spray of Nano Urea Plus (@0.4%) at 45-50 DAT and 60-65 DAT
T ₁₁	T ₅ +1 spray of Nano Urea Plus (@0.4%) at 60-65 DAT
T ₁₂	T ₅ +2 spray of Nano Urea Plus (@0.4%) at 45-50 DAT and 60-65 DAT

Table 2: Initial physico-chemical properties of the experimental soil (0-15 cm).

No.	Characteristics of the soil	Value	Rating
1.	Soil pH [(1:2.5), Soil Water Ratio]	7.44	Lightly alkaline
2.	Electrical Conductivity (dS m ⁻¹ at 25°C)	0.39	Normal
3.	Organic Carbon (%)	0.42	Medium
4.	Available Nitrogen (kg ha ⁻¹)	185	Low
5.	Available Phosphorus (kg ha ⁻¹)	18.54	Medium
6.	Available Potassium (kg ha ⁻¹)	470	High
7.	Available zinc (mg kg ⁻¹)	1.79	Sufficient
8.	Available copper (mg kg ⁻¹)	3.67	Sufficient
9.	Available Manganese (mg kg ⁻¹)	16.74	Sufficient
10.	Available Iron (mg kg ⁻¹)	23.66	Sufficient
11.	Available boron (mg kg ⁻¹)	1.4	Sufficient

Element analysis

Grain and straw samples collected at harvest of rice and wheat crops were analyzed for N, P and K content using the Kjeldahl distillation unit^[8], vanado-molybdophosphoric acid color method^[14] and flame photometric methods respectively^[8].

Nutrient uptake

The grain and straw of rice was estimated on a hectare basis (kg ha⁻¹) using their respective dry matter production (kg ha⁻¹). The uptake was calculated according to the following formula^[12]:

Nutrient uptake (kg ha⁻¹) = Nutrient content
% in grain or straw × yield (kg ha⁻¹)

Agronomic efficiency (AE) (kg kg⁻¹)

$$AE = \frac{G_f - G_{uf}}{F}$$

where G_f is the grain yield in the fertilized plot (kg), G_{uf} is the grain yield in the unfertilized plot (kg) and F is the quantity of nutrient applied (kg)

Physiological efficiency (PE) (kg kg⁻¹)

$$PE = \frac{Y_f - Y_{uf}}{N_f - N_{uf}}$$

where Y_f is the total biological yield (grain plus straw) of the fertilized plot (kg), Y_{uf} is the total biological yield in the unfertilized plot (kg), N_f is the nutrient accumulation in the fertilized plot (kg) and N_{uf} is the nutrient accumulation in the unfertilized plot (kg).

Agro-physiological efficiency (APE) (kg kg⁻¹)

$$APE = \frac{Y_f - Y_{uf}}{N_f - N_{uf}}$$

where G_f is the grain yield in the fertilized plot (kg), G_u is the grain yield in the unfertilized plot (kg), N_f is the nutrient accumulation by straw and grains in the fertilized plot (kg), and N_u is the nutrient accumulation by straw and grains in the unfertilized plot (kg).

Apparent recovery efficiency (ARE) (%)

$$ARE = \frac{N_f - N_u}{F} \times 100 = \%$$

where N_f is the nutrient accumulation by the total biological yield (straw plus grain) in the fertilized plot (kg), N_u is the nutrient accumulation by the total biological yield (straw plus grain) in the unfertilized plot (kg) and F is the quantity of nutrient applied (kg).

Utilization efficiency (EU) (kg kg⁻¹)

ARE = PE X ARE

Economics

The economics of cultivation were worked out by considering various variable costs, including expenses incurred on field preparation, seeds, fertilizers and labour, based on the prevailing market rates and expressed in rupees per hectare (Rs ha⁻¹). Gross returns were calculated by multiplying the grain and straw yields by their respective current market prices, as suggested by Perin *et al*^[23], and were expressed in rupees per hectare (Rs ha⁻¹). Net returns per hectare were determined by deducting the total cost of cultivation from the gross returns and expressed in rupees per hectare (Rs ha⁻¹). The net benefit:cost ratio was calculated as the ratio of gross returns to the cost of cultivation using the following formula: Net benefit:cost ratio = Net returns (Rs ha⁻¹) / Cost of cultivation (Rs ha⁻¹).

Results and Discussion

Nutrient uptake

The data on nitrogen (N), phosphorus (P) and potassium (K) uptake in grain and straw are presented in Figures 1. Application of Nano N significantly influenced the uptake of N, P and K by the rice crop. Total nitrogen uptake ranged from 42.94 to 96.28 kg ha⁻¹, with the highest total N uptake (96.28 kg ha⁻¹) recorded under 100% NPK + 2 sprays of Nano Urea Plus (@ 0.4%) at 45–50 DAT and 60–65 DAT (T_{12}), followed by 100% NPK (T_5) and 75% N + 100% PK + 2 sprays of Nano Urea Plus (@ 0.4%) at 45–50 DAT and 60–65 DAT (T_{10}), which were found to be at par with each other, whereas the lowest N uptake (42.94 kg ha⁻¹) was observed under the control (T_1). Similarly, total phosphorus uptake ranged from 3.93 to 9.83 kg ha⁻¹, with the highest P uptake (9.83 kg ha⁻¹) recorded under 100% NPK + 2 sprays of Nano Urea Plus (@ 0.4%) at 45–50 DAT and 60–65 DAT (T_{12}), followed by 75% N + 100% PK + 2 sprays of Nano Urea Plus (@ 0.4%) at 45–50 DAT and 60–65 DAT (T_{10}) and 100% NPK (T_5), which were found to be at par with each other; the lowest P uptake (3.93 kg ha⁻¹) was recorded under the control (T_1). Total potassium uptake ranged from 49.53 to 130.09 kg ha⁻¹, and the highest K uptake (130.09 kg ha⁻¹) was observed under 100% NPK + 2 sprays of Nano Urea Plus (@ 0.4%) at 45–50 DAT and 60–65 DAT (T_{12}), followed by 100% NPK (T_5) and 75% N + 100% PK + 2 sprays of Nano Urea Plus (@ 0.4%) at 45–50 DAT and 60–65 DAT (T_{10}), which were found to be at par with each other, while the lowest K uptake (49.53 kg ha⁻¹) was recorded under the control (T_1). The higher uptake of N, P, and K under the integrated application of soil-applied fertilizers and foliar Nano Urea Plus may be attributed to the corresponding improvement in grain and straw yield, adequate nutrient availability, and synergistic interactions among N, P and K. Moreover, nano fertilizers possess a larger surface area and nano-sized particles, which facilitate their penetration and absorption into plant tissues, thereby enhancing nutrient uptake. The recommended dose of potassium also ensured an adequate supply of K and maintained proper potassium concentration in the plant, while the combined and synergistic effects of N, P and K contributed to greater nutrient uptake compared with the control treatment^[5, 22, 33].

Nutrient use efficiency in rice crop

Nitrogen fertilizer doses and application methods significantly (table 3) influenced nitrogen use efficiency indices in rice, including Agronomic Efficiency (AE), Physiological Efficiency (PE), Agro- Physiological Efficiency (APE), Apparent Recovery Efficiency (ARE) and Utilization Efficiency (EU). AE ranged from 28.53 to 43.76 kg kg⁻¹, PE from 142.18 to 198.68 kg kg⁻¹, APE from 65.06 to 90.19 kg kg⁻¹, ARE from 38.66 to 49.63%, and EU from 61.80 to 96.41 kg kg⁻¹. The treatment comprising 50% N and 100% P and K + two foliar sprays of Nano Urea Plus (@0.4%) at 45–50 and 60–65 DAT (T₆) recorded the highest AE (43.76 kg kg⁻¹), PE (198.68 kg kg⁻¹), APE (90.19 kg kg⁻¹) and EU (96.41 kg kg⁻¹). The highest ARE (49.63%) was recorded with 75% N and 100% P and K + two sprays of Nano Urea Plus (@0.4%) at 45–50 and 60–65 DAT (T₁₀), followed by T₆ and T₈ (50% N/67% N and 100% P & K + two Nano Urea Plus sprays). The lowest AE (28.53 kg kg⁻¹) and ARE (38.66%) were observed under 100% N, P and K (T₅), while the lowest PE and APE were recorded under 50% N and 100% P and K (T₂) and the lowest EU (61.80 kg kg⁻¹) under 100% N, P and K with one Nano Urea Plus spray at 60–65 DAT (T₁₁). Overall, foliar application of Nano Urea Plus improved nitrogen use efficiency compared with conventional nitrogen application by enhancing nutrient absorption, reducing nitrogen losses and increasing rice grain yield [2, 28, 19, 32].

Gross return, Net return, total cost of cultivation and Benefit cost ratio

The data on the gross returns of rice are presented in the figure 2. The economic analysis of rice cultivation clearly indicated that

fertilizer management combined with Nano Urea Plus sprays significantly influenced returns and profitability. The treatment with 100% NPK +1 foliar spray of Nano Urea Plus (@0.4%) at 60–65 DAT (T₁₁) recorded the highest gross return (₹1, 33, 304ha⁻¹) and net return (₹87, 398ha⁻¹) and also achieved the maximum B:C ratio (1.90), making it the most profitable option. Treatments 100% NPK + 2 sprays of Nano Urea Plus (@0.4%) at 45–50 and 60–65 DAT (T₁₂) and 75% N and 100% P & K + 2 sprays of Nano Urea Plus (@0.4%) at 45–50 DAT and 60–65 DAT (T₁₀) also produced comparably high gross returns of ₹1, 32, 744ha⁻¹ and ₹1, 30, 639 ha⁻¹, respectively, with 100% NPK + 2 sprays of Nano Urea Plus (@0.4%) at 45–50 and 60–65 DAT (T₁₂) and 75% N and 100% P and K + 2 spray of Nano Urea Plus (@0.4%) at 45–50 DAT and 60–65 DAT (T₁₀), following 100% NPK + 1 spray of Nano Urea Plus (@0.4%) at 60–65 DAT (T₁₁) in net returns (₹85, 933ha⁻¹ and ₹84, 213 ha⁻¹). However, the total cost of cultivation (₹46, 811ha⁻¹) was highest in 100% NPK + 2 sprays of Nano Urea Plus (@0.4%) at 45–50 and 60–65 DAT (T₁₂) followed by 75% N and 100% P & K + 2 sprays of Nano Urea Plus (@0.4%) at 45–50 DAT and 60–65 DAT (T₁₀) and 67% N and 100% P & K + 2 sprays of Nano Urea Plus (@0.4%) at 45–50 DAT and 60–65 DAT (T₈), whereas the lowest cost (₹37, 080ha⁻¹) was observed in the control (T₁), which also recorded the lowest gross return (₹49, 457ha⁻¹), net return (₹12, 377ha⁻¹) and B:C ratio (0.33). Overall, the results demonstrate that the application of recommended fertilizer dose 100% NPK + 1 spray of Nano Urea Plus (@0.4%) at 60–65 DAT (T₁₁) is economically most viable, yielding higher returns and better cost efficiency compared to other treatments [1, 33].

Table 3: Effect of Nano N on the nutrient use efficiency (NUE) of rice crop

S. No.	Agronomic efficiency (kg kg ⁻¹)	Physiological efficiency (kg kg ⁻¹)	Agro- physiological efficiency (kg kg ⁻¹)	Apparent recovery efficiency (%)	Utilization efficiency (kg kg ⁻¹)
T ₁	-	-	-	-	-
T ₂	29.42	142.18	65.06	45.21	64.28
T ₃	31.57	156.30	70.72	44.65	69.78
T ₄	33.05	172.26	79.27	41.70	71.82
T ₅	28.53	164.21	73.80	38.66	63.48
T ₆	43.76	198.68	90.19	48.52	96.41
T ₇	37.19	172.51	80.86	46.00	79.35
T ₈	38.47	178.11	80.42	47.84	85.21
T ₉	37.12	174.68	78.97	47.00	82.11
T ₁₀	38.07	164.74	76.70	49.64	81.77
T ₁₁	29.49	141.59	67.56	43.65	61.80

T₁: 0% N & 100% P, K, T₂: 50% N & 100% P&K, T₃: 67% N & 100% P&K, T₄: 75%N & 100% P&K, T₅: 100% NPK, T₆: T₂+2 spray of Nano Urea Plus (@0.4%) at 45-50 DAT and 60- 65 DAT, T₇: T₃+1 spray of Nano Urea Plus (@0.4%) at 60-65 DAT, T₈: T₃ + 2 spray of Nano Urea Plus (@0.4%) at 45-50 DAT and 60-65 DAT, T₉: T₄+1 spray of Nano Urea Plus (@0.4%) at 60-65 DAT, T₁₀: T₄+2 spray of Nano Urea Plus (@0.4%) at 45-50 DAT and 60-65 DAT, T₁₁: T₅+1 spray of Nano Urea Plus (@0.4%) at 60-65 DAT, T₁₂: T₅+2 spray of Nano Urea Plus (@0.4%) at 45-50 DAT and 60-65 DAT.

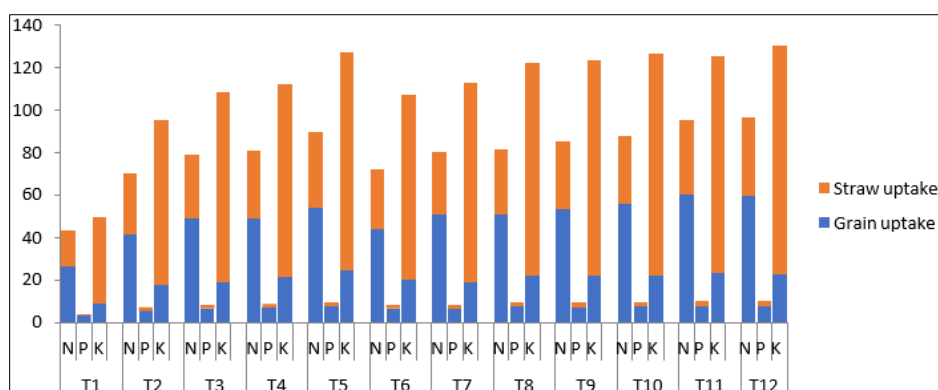


Fig 1: Effect of Nano urea application on NPK uptake by rice crop

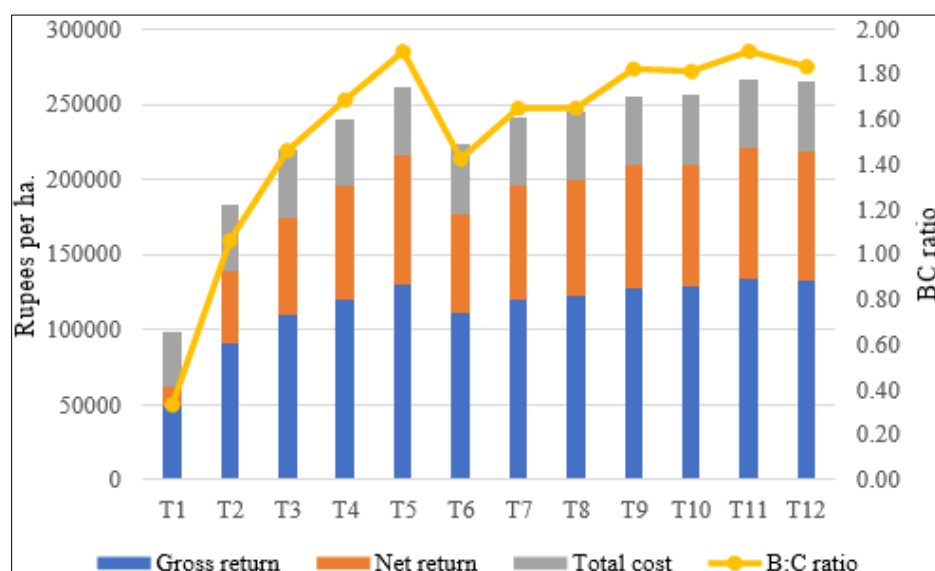


Fig 2: Effect of Nano urea application on gross return, net return, total cost and BC ratio of rice crop

Conclusion

The results indicate that Nano Urea application significantly influenced the uptake of major nutrients (N, P and K) in rice. The highest nitrogen and potassium uptake was recorded under 100% NPK + two sprays of Nano Urea Plus, while the highest phosphorus uptake was observed under 100% NPK. In contrast, the lowest nutrient uptake was recorded in the control treatment. Overall, the integration of Nano Urea with recommended fertilizer doses enhanced nutrient uptake in rice, thereby improving nutrient availability and utilization by the crop. The results also demonstrate that nitrogen dose and application method significantly influenced nitrogen use efficiency in rice. Application of 50% N with 100% P and K along with two foliar sprays of Nano Urea Plus (@0.4%) at 45–50 and 60–65 DAT (T₆) achieved the highest agronomic efficiency, physiological efficiency, agro-physiological efficiency and utilization efficiency, while 75% N with 100% P and K plus two Nano Urea Plus sprays (T₁₀) recorded the highest apparent recovery efficiency. In contrast, the conventional application of 100% recommended N, P and K showed comparatively lower nitrogen use efficiency, indicating that partial substitution of conventional nitrogen with Nano Urea Plus foliar sprays can improve nitrogen use efficiency in rice. Economic analysis showed that Nano Urea combined with recommended fertilizers increased profitability. The results showed that the application of Nano Urea along with 50% NPK, 67% NPK or 75% NPK through inorganic fertilizers resulted in higher gross returns, net returns and B:C ratios. Overall, the integration of Nano Urea was economically beneficial for rice cultivation.

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