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Comparative Effects of Neem-coated Urea, Agrotain Urea and Nano Nitrogen on Nutrient Uptake of Paddy Crop

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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

Aims: To evaluate the impact of innovative nitrogen management strategies, including neem-coated urea (NCU), nano fertilizers, and Agrotain urea, on nutrient use efficiency (NUE), NPK uptake, and rice productivity in the Southern Telangana Zone.

Study Design: Randomized block design with 3 replications, including traditional and innovative nitrogen formulations combined with foliar-applied nano nitrogen sprays.

Place and Duration of Study: Agricultural Research Institute, Rajendranagar, during the *Kharif* season of 2021&2022.

Methodology: The experiment was conducted on the JGL 24423 rice variety. Treatments included varying nitrogen rates (100%, 50%, and 33% recommended dose of nitrogen [RDN]) applied as NCU (Neem Coated Urea), Agrotain UG (urea granules), or combinations with nano nitrogen sprays. Nitrogen was applied in three splits (transplanting, tillering, and panicle initiation). Nutrient uptake (NPK) was analyzed using standard laboratory methods, and statistical analysis was performed using ANOVA to assess treatment effects.

Results: The 100% RDN-STCR (Soil Test Crop Response)-based NCU treatment demonstrated the highest mean nitrogen uptake (66.8 kg ha^{-1} in grain, 53.7 kg ha^{-1} in straw), phosphorus uptake (18.7 kg ha^{-1} in grain, 9.5 kg ha^{-1} in straw), and potassium uptake (37.7 kg ha^{-1} in grain, 120.9 kg ha^{-1} in straw). Reduced nitrogen treatments with nano nitrogen sprays showed moderate nutrient uptake.The control and nano nitrogen sprays alone had the lowest uptake levels.

Conclusion: Nitrogen management strategies, particularly 100% RDN-STCR-based NCU, significantly enhanced NUE, nutrient uptake, and rice productivity, demonstrating their potential for sustainable rice cultivation.

Keywords: Paddy; NPK uptake; nano nitrogen; agrotain urea; RDN levels.

1. INTRODUCTION

The Green Revolution of the 1970s transformed agriculture through high-yielding rice and wheat varieties, extensive irrigation, and increased use of fertilizers and agrochemicals. While this approach boosted food grains production, it also caused environmental pollution, reduced input use efficiency, deteriorated soil health, diminished food quality, and increased resistance in pests and weeds. Nutrient imbalance further led to micronutrient deficiencies and reduced major nutrient uptake, adversely affecting crop productivity and soil fertility. Fertilizer consumption in India rose from 69.8 thousand tonnes in 1950–51 to 12.9 lakh metric tonnes in 2022–23. Per-hectare application rates increased from 12.4 kg in 1969 to 175 kg in 2018, with Telangana consuming 245.3 kg per hectare in 2018–19. Despite higher usage, nutrient use efficiency (NUE) remains low: nitrogen (N) at 20–50%, phosphorus (P) at 18–20%, and potassium (K) at 35–40%. Losses due to leaching, volatilization, and runoff reduce productivity and increase environmental pollution.

Innovative fertilizers like neem-coated urea (NCU), nano fertilizers, and Agrotain urea aim to improve nutrient management. NCU enhances NUE by 10%, reduces urea consumption, and minimizes nitrogen losses. Studies by Singh and Singh (1986) and Reddy and Mishra (1983) confirmed reduced nitrogen losses with neem products. Prasad et al. (2002) and Chaudhari and Biswas (2020) and Mohanty et al. (2021) emphasized NCU’s role in improving NPK uptake and mitigating environmental impact, boosting yields. Nano fertilizers, with particle sizes under 100 nm, release nutrients controlled by environmental factors like temperature and moisture, improving nutrient uptake efficiency. Umesha et al. (2017) and Salama (2012) reported that nano nitrogen could reduce urea use by 50%, offering a sustainable alternative. These fertilizers address nutrient deficiencies effectively due to their higher solubility and efficiency.

Agrotain urea, containing the urease inhibitor N-butyl thiophosphoric triamide (NBPT), reduces ammonia volatilization and enhances NUE. Rogers et al. (2015) demonstrated reduced nitrogen losses and improved nitrogen availability with Agrotain urea, enhancing crop performance and NPK balance. India’s goal of producing 300 million tons of food grains by 2025 requires addressing the gap between nutrient demand and consumption, which rose from 27 kg NPK per hectare in the 1970s to 109 kg per hectare in 2008. Neem-coated urea, nano fertilizers, and

Agrotain urea provide viable solutions to enhance nitrogen efficiency, improve nutrient uptake, and promote sustainable agriculture. This study evaluates nano nitrogen, Agrotain urea, and neem-coated urea in rice cultivation in the Southern Telangana Zone, aiming to improve nitrogen management, enhance NPK uptake, increase yields, and ensure agricultural sustainability.

2. MATERIALS AND METHODS

The present study was conducted at the Agricultural Research Institute, Rajendranagar, during the Kharif seasons of 2021–2022 and 2022–2023 to evaluate the impact of nitrogen (N) management strategies on nutrient efficiency and rice (*Oryza sativa L.*) productivity. The experimental site, situated at 17°19'29.21" N latitude and 78°23'48.59" E longitude, was selected to examine the response of the JGL 24423 rice variety under varied nitrogen treatments. The study employed a randomized block design (RBD) with 11 treatments, encompassing traditional and innovative nitrogen formulations, along with foliar-applied Nano N sprays. The soil was sandy loam in texture with 16% clay; 32% silt and 52% sand with a pH of 7.75 and EC of 0.831 dSm^{-1}, available nitrogen of 165 kg ha^{-1}, available P_2O_5 of 66 kg ha^{-1} and available K_2O of 299 kg ha^{-1}. The treatments included: T1 (control, no nitrogen), T2 (three Nano N sprays at 15 DAT, maximum tillering, and panicle initiation), T3 (100% recommended dose of nitrogen [RDN] as neem-coated urea [NCU]), T4 (100% RDN-STCR-based NCU), T5 (100% RDN as Agrotain urea granules [UG]), T6 (50% RDN-NCU + two Nano N sprays), T7 (50% RDN-STCR NCU + two Nano N sprays), T8 (50% RDN-Agrotain UG + two Nano N sprays), T9 (33% RDN-NCU + two Nano N sprays), T10 (33% RDN-STCR NCU + two Nano N sprays), and T11 (33% RDN-Agrotain UG + two Nano N sprays). These treatments aimed to investigate the effectiveness of reduced nitrogen rates combined with Nano N sprays in improving nutrient uptake and crop performance. Soil samples were collected from a 0–15 cm depth before the experiment to assess the site's baseline fertility and guide nitrogen application strategies. A precautionary trial was conducted with IFFCO Nano nitrogen (1250 mL ha^{-1}) to ensure crop safety. Fertilizer application followed the recommended doses: 120:60:40 kg N:P:K for *Kharif*. Nitrogen was applied in three splits—at transplanting, tillering, and panicle initiation stages—while phosphorus as basal dose and potassium in two splits were applied during transplanting. Grain and straw samples were collected at harvest stage, dried and processed to analyze nitrogen, phosphorus, and potassium content using standard laboratory techniques. Nitrogen was estimated via the modified Kjeldahl method (Jackson, 1973) using Automatic kelplus distillation unit after digesting the plant sample in conc. H_2SO_4 and H_2O_2, phosphorus through diacid digestion and spectrophotometry, and potassium using flame photometry. Total nutrient uptake was calculated as:

$$Nitrogen\ uptake\ (kg\ ha^{-1}) = \frac{Nitrogen\ content\ (\%)}{100} \times Dry\ matter\ (kg\ ha^{-1})$$

Statistical analysis was performed using analysis of variance (ANOVA) following Gomez and Gomez (1984) for randomized block designs. Treatment means were compared using the least significant difference (LSD) at a 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Grain and Straw Yield of Paddy

Grain yield (6188 kg ha^{-1}) and straw yield (7422 kg ha^{-1}) were the highest for 100% RDN-STCR-based NCU (T4), followed by 100% RDN-Agrotain UG (T5) with 5666 and 6799 kg $ha^{-1}$and 100% RDN-NCU (T3) with 5542 and 6540 kg ha^{-1}, according to the pooled mean data. STCR NCU (T7) reported 4989 and 5787 kg ha^{-1} at 50% RDN, surpassing Agrotain UG (T8: 4727 and 5247 kg ha^{-1}) and NCU (T6: 4651 and 5143 kg ha^{-1}). Following Agrotain UG (T11: 4196 and 4096 kg ha^{-1}) and NCU (T9: 4141 and 3997 kg ha^{-1}), STCR-NCU (T10) attained 4433 and 4623 kg ha^{-1}at 33% RDN. These findings highlight the improved performance of STCR-based treatments at all nitrogen levels. The reduced yields were registerd in foliar sprays exclusively because of no basal dose of nitrogen was applied and it aould not neet the demand of crops as required (Das & Jana, 2015). Overall, Agrotain urea produced higher yields than normal urea, validating the findings of Liu et al. (2019). Whereas the controlyields were lower due to an imbalanced distribution of nutrients, these results are consistent with those of Monika et al. (2018) and Mondal et al. (2020). The results were quite deviating from the findings reported by Anushka et al. (2024) and Sandeep et al. (2024).

While the lower yields were recorded with low amount of nitrogen fertilizer application.

Decrease in grain yields of rice with reduced levels of nitrogen application was also reported by Mrudhula and Suneetha (2020) and Maurya et al*.* (2021)

3.2 Nitrogen Uptake

The use of nano-N sprays alone resulted in marginally increased nitrogen uptake by grain and straw at harvest (21.2 and 14.1 kg ha^{-1}), compared to the control (19.7 and 12.8 kg ha^{-1}). This shows that Nano-N sprays may not be an effective substitute for conventional nitrogen fertilization in sustaining crop nitrogen levels (Table 1). Khalil et al. (2019), Midde et al. (2021) discovered that employing Nano N sprays alone wasn't enough to meet the crop's nitrogen requirements. The maximal mean nitrogen uptake with 100% RDN-STCR-based N-NCU was 66.2 kg ha^{-1} and 38.6 kg ha^{-1} in straw, respectively. Increase in nitrogen levels might have improved the root growth and leaf area thus promoting the increased nitrogen uptake. Similar findings were also reported by Uddin et al. (2013) and Javeed et al. (2017).

Nitrogen uptake rates in grain and straw were 43.9 kg ha^{-1} and 25.5 kg ha^{-1}, respectively, under 50% RDN-STCR-based N-NCU with two Nano-N sprays. Increase in Nitrogen uptake was registered with increased doses of nitrogen level and this findings were also inline with Meena et al. (2003) and Panday et al. (2007). Furthermore, the grain absorbed 31.9 kg ha^{-1} of nitrogen and the straw 18.5 kg ha^{-1}, which was comparable to the other two sources (NCU and Agrotain UG) of 33% nitrogen given to the crop. The application of STCR-based N-NCU in various combinations to rice crops significantly boosted nitrogen uptake by grain and straw throughout the *Kharif* season 2021&2022 when compared to alternative nitrogen sources. increase in the input source of nitrogen further improved the nitrogen uptake. These results were in confirmity with Diwedi et al. (2024) and Nagabovanalli et al. (2021).

Percent increase in nitrogen uptake by grain for different treatments, along with the pooled mean values for Kharif 2021 and 2022. The highest yield improvement was observed in the 100% RDN-STCR based N-NCU treatment (T4), which showed a 236% increase, followed by 100% RDN-NCU (T3) at 167%, and 100% RDN-Agrotain UG (T5) at 188%. Treatments combining reduced nitrogen (RDN) with nano-nitrogen sprays also resulted in improvements, though the 33% RDN treatments had the smallest gains, ranging from 41% to 62%. Similarly, nitrogen uptake by straw at harvest, varied from 22% to 25%. The highest straw nitrogen uptake was achieved by 100% RDN-STCR based N-NCU (T4) at 202%, followed by 100% RDN-NCU (T3) at 135%, and 100% RDN-Agrotain UG (T5) at 160%. When nano nitrogen sprays were added to 50% RDN treatments (T6, T7, T8), the pooled mean uptakes were 99%, 63%, and 72%, respectively. The percent increase in N uptake's were found to be similar with the findings from Monika et al. (2018), Pradeep et al. (2012) and Choudhary et al. (2011).

3.3 Phosphorus Uptake

100% RDN-STCR based N-NCU maintained its lead in mean P uptake at the harvest stage (Table 2) with 18.7 kg ha-1, whereas 100% RDN-Agrotain-UG (16.8 kg ha^{-1}) and 100% RDN-NCU (15.9 kg ha^{-1}) closely followed in terms of P uptake by rice grain. in comparison to other reduced dose treatments, such as 33% RDN-STCR based N-NCU with 2 Nano-N sprays (12.9 kg ha^{-1}), the 50% RDN-STCR based N-NCU with 2 Nano-N sprays performed noticeably better (14.1 kg ha^{-1}). According to Sathish et al. (2011), Sandhyakanthi et al. (2014) rice uptake of phosphorus (P) was lower in the control treatment compared to nitrogen (N)-applied treatments during critical growth stages. Nitrogen availability frequently has a positive effect on phosphorus uptake because it improves root development and metabolic activity, which in turn improves the plant's ability to absorb and assimilate phosphorus. Higher nitrogen treatments, like 100% STCR-based N-NCU, facilitated greater P uptake. Increase in phoshorus uptake is also registered with the rise in the grain yield. These findings corroborates with Malhotra et al. (2018) and Utami et al. (2020).

As anticipated, the control (8.1 kg ha^{-1}) and three Nano-N sprays (8.8 kg kg ha^{-1}) had the lowest P uptake. Comparable patterns were seen in the straw, where 100% STCR-based N-NCU had the highest mean uptake (9.5 kg ha^{-1}), followed by 100% RDN-Agrotain UG (8.3 kg ha^{-1}) and 100% RDN-NCU (7.8 kg ha^{-1}). treatments with lower N levels, such as 50% and 33% RDN, did reasonably well, although the control (2.6 kg ha^{-1}) had the lowest phosphorus uptake by ricestraw. Similar results were reported by Ghoose et al. (2014) and Srivastava and Singh (2017).

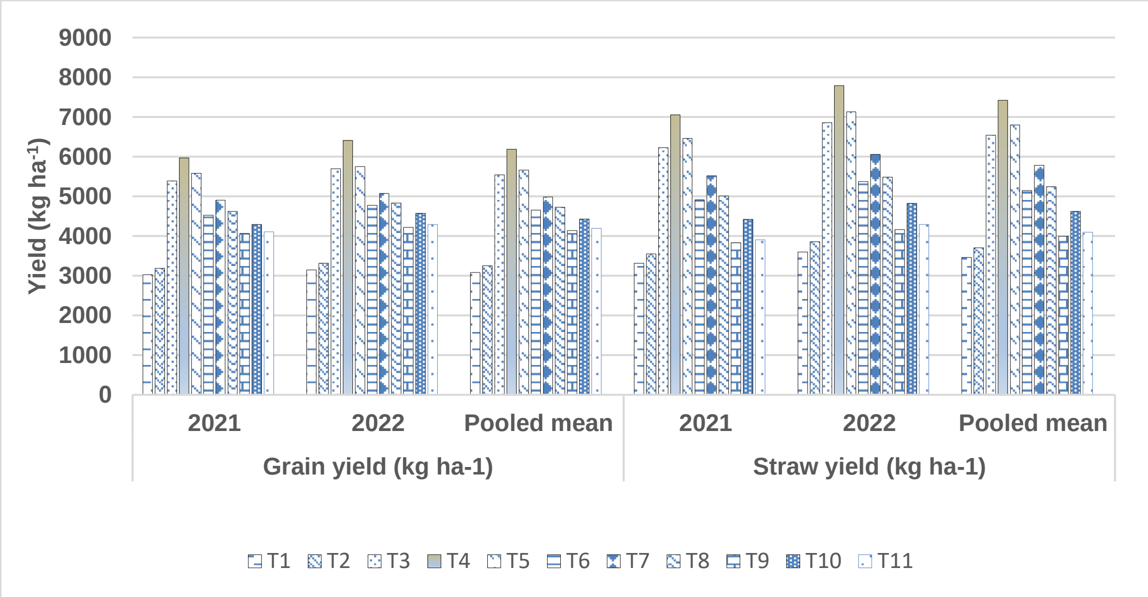

Fig. 1. Grain and Straw Yield of Rice Under Various Levels of Nano Nitrogen, Agrotain, and Neem-Coated Urea During *Kharif* 2021–2022

Table 1. Effect of different levels of Nano nitrogen, Agrotain and Neem coated urea on nitrogen uptake (kg ha^{-1}) at harvest of rice during *Kharif,* 2021&2022

Trt. No	Treatments	Grain			Straw		
		2021	2022	Pooled mean	2021	2022	Pooled mean
T_1	Control (No N)	18.7	20.8	19.7	12.0	13.7	12.8
T_2	3 Nano N sprays (15DAT, MT&PI)	19.8	22.6	21.2	12.8	15.4	14.1
T_3	100% RDN-NCU	50.1	55.2	52.6	28.0	32.2	30.1
T_4	100% RDN- STCR based N-NCU	62.7	69.8	66.2	34.6	42.9	38.6
T_5	100% RDN- Agrotain UG	55.2	58.1	56.7	31.0	35.7	33.3
T_6	50% RDN-NCU+2 Nano N sprays	35.3	38.2	36.7	19.1	22.6	20.8
T_7	50% RDN-STCR based N-NCU+2 Nano N sprays	42.7	45.2	43.9	23.2	27.9	25.5

Trt. No	Treatments	Grain			Straw		
		2021	2022	Pooled mean	2021	2022	Pooled mean
T_8	50% RDN-Agrotain UG + 2 Nano N sprays	37.0	41.0	39.0	20.0	24.1	22.0
T_9	33% RDN-NCU+2 Nano N sprays	26.4	29.1	27.7	14.2	17.1	15.6
T_{10}	33% RDN-STCR based N-NCU+2 Nano N sprays	29.6	34.3	31.9	17.2	19.8	18.5
T_{11}	33% RDN-Agrotain UG +2 Nano N sprays	27.1	30.4	28.7	14.8	17.2	16.0
	Mean	**36.8**	**40.4**	**38.6**	**20.6**	**24.4**	**22.5**
	SEm±	**1.22**	**1.28**	**1.25**	**0.68**	**0.81**	**0.71**
	CD@5%	**3.3**	**3.6**	**3.5**	**1.9**	**2.2**	**2.0**

Table 2. Effect of different levels of Nano Nitrogen, Agrotain and Neem coated urea on phosphorus uptake (kg ha^{-1}) at harvest stage of rice during *kharif*, 2021&2022

Trt. No	Treatments	Grain			Straw		
		2021	2022	Pooled mean	2021	2022	Pooled mean
T_1	Control (No N)	7.5	8.8	8.1	2.7	2.5	2.6
T_2	3 Nano N sprays (15DAT, MT&PI)	8.0	9.6	8.8	3.0	3.1	3.1
T_3	100% RDN-NCU	15.0	16.9	15.9	6.7	8.8	7.8
T_4	100% RDN- STCR based N-NCU	17.3	20.2	18.7	8.1	10.9	9.5
T_5	100% RDN- Agrotain UG	15.8	17.9	16.8	7.2	9.4	8.3
T_6	50% RDN-NCU+2 Nano N sprays	12.2	13.8	13.0	4.8	6.0	5.4
T_7	50% RDN-STCR based N-NCU+2 Nano N sprays	13.4	14.8	14.1	5.7	7.5	6.6
T_8	50% RDN-Agrotain UG + 2 Nano N sprays	12.5	13.9	13.2	5.0	6.3	5.6
T_9	33% RDN-NCU+2 Nano N sprays	10.5	11.9	11.2	3.4	4.1	3.8
T_{10}	33% RDN-STCR based N-NCU+2 Nano N sprays	11.4	13.2	12.3	4.2	5.2	4.7
T_{11}	33% RDN-Agrotain UG +2 Nano N sprays	10.6	12.2	11.4	3.6	4.4	4.0
	Mean	**12.2**	**13.9**	**13.1**	**4.9**	**6.2**	**5.6**
	SEm±	**0.6**	**0.6**	**0.5**	**0.2**	**0.3**	**0.2**
	CD@5%	**1.7**	**1.6**	**1.5**	**0.5**	**0.8**	**0.6**

Table 3. Effect of different levels of Nano nitrogen, Agrotain and Neem coated urea on potassium uptake (kg ha^{-1}) at harvest stage of rice during *Kharif,* 2021&2022

Trt. No	Treatments	Grain			Straw		
		2021	2022	Pooled mean	2021	2022	Pooled mean
T_1	Control (No N)	14.5	16.6	15.6	36.8	41.4	39.1
T_2	3 Nano N sprays (15DAT, MT&PI)	16.0	17.9	16.9	39.5	46.5	43.0
T_3	100% RDN-NCU	31.3	34.3	32.8	92.7	109.6	101.2
T_4	100% RDN- STCR based N-NCU	36.4	39.1	37.7	113.0	128.7	120.9
T_5	100% RDN- Agrotain UG	32.9	34.3	33.6	98.8	116.2	107.5
T_6	50% RDN-NCU+2 Nano N sprays	24.9	26.4	25.6	63.8	74.7	69.2
T_7	50% RDN-STCR based N-NCU+2 Nano N sprays	28.0	29.5	28.8	74.4	87.8	81.1
T_8	50% RDN-Agrotain UG + 2 Nano N sprays	25.9	27.7	26.8	66.5	77.2	71.9
T_9	33% RDN-NCU+2 Nano N sprays	21.4	22.8	22.1	43.2	49.8	46.5
T_{10}	33% RDN-STCR based N-NCU+2 Nano N sprays	23.2	25.2	24.2	50.8	60.2	55.5
T_{11}	33% RDN-Agrotain UG +2 Nano N sprays	21.8	23.4	22.6	44.1	52.5	48.3
	Mean	**25.1**	**27.0**	**26.1**	**65.8**	**76.8**	**71.3**
	SEm±	**1.0**	**1.0**	**1.0**	**2.5**	**3.1**	**2.8**
	CD@5%	**3.0**	**3.0**	**2.9**	**7.5**	**9.1**	**8.2**

3.4 Potassium Uptake

With 100% RDN-STCR-based NCU, the maximum mean potassium uptake was seen at harvest (Table 3), with 37.7 kg ha^{-1} in grain and 120.9 kg ha^{-1} in straw. Agrotain UG (33.6 kg ha^{-1} in straw) were the next two 100% RDNs.

The 50% RDN-STCR-based N-NCU with two nano nitrogen sprays demonstrated the highest uptake among the decreased N treatments (28.8 kg ha^{-1} in grain and 81.1 kg ha^{-1} in straw). The lowest uptakeobserved in the control group (15.6 and 39.1 kg ha^{-1}), whereas the 33% RDN treatments, specifically with two nano sprays, reported 24.2 kg ha^{-1} in grain and 55.5 kg ha^{-1} in straw. The study found that 100% RDN-STCR-based NCU outperformed other NCUs in terms of potassium uptake. Reduced N level treatments, notably 50% RDN-STCR with nano nitrogen sprays, showed promising results for rice crop K uptake. These findings support the findings of Ramalakshmi et al. (2012), Roohi et al. (2024) and Sepheya et al. (2012).

4. CONCLUSION

The study highlights the efficacy of innovative nitrogen management strategies in enhancing rice productivity and nutrient uptake. Among the various treatments, 100% RDN-STCR-based NCU consistently outperformed other nitrogen sources, achieving the highest grain and straw yields, as well as superior nitrogen, phosphorus, and potassium uptake. This treatment demonstrated significant improvements in nitrogen efficiency and crop performance, supporting the findings of previous studies on nutrient management. Nano nitrogen sprays, when combined with reduced nitrogen doses, contributed to modest improvements in nitrogen uptake, but did not fully substitute the need for conventional nitrogen fertilizers. The reduced nitrogen treatments, particularly those combining 50% RDN with Nano-N sprays, showed promising results in improving nutrient uptake without compromising crop yield significantly. Overall, the application of STCR-based NCU at full nitrogen doses offers a sustainable approach to optimizing nutrient management in rice cultivation, enhancing yield and nutrient use efficiency while minimizing environmental impacts. The findings of this study underscore the importance of integrated nutrient management for sustainable agricultural practices and highlight the potential of advanced fertilizers like neem-coated urea, nano fertilizers, and Agrotain urea in improving rice production systems.

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 writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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