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RESEARCH ARTICLE

Effect of nano urea on greenhouse gas emissions in transplanted rice (*Oryza sativa* L.) ecosystems

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Abstract

The application of conventional nitrogen fertilizer (urea) to improve rice crop yield has a significant influence on soil methane (CH_4) and nitrous oxide (N_2O) emissions. An experiment was conducted at Tamil Nadu Agricultural University, Coimbatore, wetlands farm, during the summer of 2023. A Randomized Block Design (RBD) was used with 8 treatments and 3 replications to evaluate the impact of different nitrogen application strategies on greenhouse gas emissions, specifically methane and nitrous oxide in transplanted rice, including the varying nitrogen levels. The study aimed to improve rice growth and yield through foliar application of nano urea, focusing on the rice variety CO55 with a recommended dose of NPK (150:50:50 NPK kg/ha). The results indicated that applying 75 kg nitrogen/ha (50% of the recommended dose) as basal through conventional urea, along with 3 nano urea foliar sprays at 20, 40 and 60 days after transplanting (T_5), resulted in significantly lower methane and nitrous oxide emissions compared with 100% of the recommended nitrogen dose i.e. 150 kg nitrogen/ha applied through conventional urea, with 25% used at basal, active tillering, panicle initiation and heading stage (T_1) and 150 kg nitrogen/ha i.e. 100% recommended dose of nitrogen applied through conventional urea, with 50% as basal and 2 top dressings of 25% of the recommended dose of nitrogen (RDN) each at active tillering and panicle initiation (T_2).

Keywords

greenhouse gas emissions; foliar application; nano urea; transplanted rice

Introduction

Rice is a critical staple food widely consumed by many global populations (1, 2). With a history of cultivation spanning thousands of years, it has become deeply ingrained in numerous countries' dietary habits and cultural traditions, especially in Asia. India is the largest rice-growing country, with rice cultivation spanning 46.27 million hectares. India is the worlds' second-largest producer and exporter of rice. The production increased from 84.98 million tonnes in 2000-01 to 137.83 million tonnes with an average yield of 2882 kg/ha in 2023-24 (3). India is a critical player in rice production and consumption, ranking second globally as a significant producer of this essential crop (4, 5). Nutrient management is crucial in rice production, directly affecting crop growth, yield, quality, and sustainability. Proper nutrient management strategies like nano urea technology at critical growth stages ensure that the rice plant receives the required nutrients at the right time and in the right amounts, optimizing its growth and development. Adequate nutrient supply is essential for achieving higher rice yields. Nitrogen is one of the major plant nutrients required for plant growth. Maximizing the yield of rice is a critical component in rice farming.

Nitrogen use efficiency (NUE) in agricultural systems is generally low worldwide, with more than 50 % of the nitrogen (N) applied to agricultural soils potentially lost into the environment. The rice cropping systems' NUE of urea fertilizer is very low (30-35%). Rice is a critical staple food widely used by many global populations (1, 2).

Nano urea liquid as foliar application during critical crop growth stages of rice plants effectively meets its nitrogen requirement, resulting in higher crop productivity and quality than conventional urea (6, 7). Nano-urea liquid has the potential to reduce these losses by providing a controlled and slow-release nitrogen supply, thereby improving the overall nitrogen use efficiency and minimizing the negative environmental impacts (8). The improved absorption of nano urea is primarily due to its nanoparticle size, with increased surface area, and allows easier uptake through plant leaf pores and root systems. This size advantage enables rapid diffusion and transport within plant cells. Studies showed that nano-sized urea particles are more readily absorbed by plants, resulting in enhanced nitrogen uptake (9, 10). This improved nutrient uptake can lead to better plant growth, higher grain yields, and increased nitrogen use efficiency, which is especially important in rice cultivation (11, 12). Liquid nano urea has an absorption efficiency of 85-90%. Since conventional urea is frequently sprayed incorrectly and loses various amounts via irrigation and other processes, it does not have the desired effect on crops. Nano urea has a more positive impact on the quality of underground water, a very significant reduction in global warming with an effect on climate change and sustainable development (13, 14). Nano urea reduces the need for traditional urea by at least half while enhancing crop yields, soil health, and the nutritional quality of produce without affecting soil productivity. It is also more affordable than conventional urea, lowering input costs for farmers and increasing their profits (15).

Materials and Methods

Site description

The experimental study was conducted during the summer of 2023 at the wetland farm of TNAU, Coimbatore, Tamil Nadu, located at 11.0168° N and 76.9558° E longitude at 426.7(MSL). The soil samples were collected from 0-15 cm depths, dried, and grounded through a 2 mm sieve for analysis. The soil type of the experimental site is clay loam soil, with a slightly alkaline pH (8.1), an EC of 0.42 Ds/m, and organic carbon (OC) of 0.63%. The availability of nutrients in the soil shows lower nitrogen (260 kg/ha), medium phosphorus (19.5 kg/ha), and higher potassium (440 kg/ha).

Experimental description

The research experiment was carried out using the conventional method of rice cultivation during the summer of 2023. The experiment was designed in a randomized block design (RBD) involving eight treatments and three replications with a plot size of 7.0 m × 3.6 m. The varied dose of nitrogen, along with a foliar spray of nano urea, was applied. The treatments imposed are listed in Table 1.

Table 1. List of treatments used in this research study

Treatment number	Treatments
T_1	100% recommended dose of nitrogen, i.e. 150 kg nitrogen/ha through conventional urea (25% each at basal, Active Tillering, Panicle Initiation and heading stage)
T_2	100% recommended dose of nitrogen, i.e. 150 kg nitrogen/ha, 50% of is as basal dose through conventional urea + 25% of it as top dressing each at Active Tillering & Panicle Initiation
T_3	50% recommended dose of nitrogen, i.e. 75 kg nitrogen/ha as basal application through conventional urea
T_4	50% recommended dose of nitrogen, i.e. 75 kg nitrogen/ha, through conventional urea 75 kg of nitrogen is applied as basal dose + 2 nano urea foliar sprays at 20 & 40 days following transplanting
T_5	50% standard nitrogen rate, i.e. 75 kg nitrogen/ha, through conventional urea 75 kg of nitrogen is basal application only + 3 nano urea foliar sprays at 20, 40 & 60 days after transplanting
T_6	25% optimal nitrogen level (37.5 kg nitrogen/ha) through conventional urea, the full 25% of the recommended dose of nitrogen is applied as initial dose only + 3 nano urea foliar sprays at 20, 40 & 60 days after transplanting
T_7	3 nano urea foliar sprays at 20, 40 & 60 days after transplanting (no basal application)
T_8	Control (0% N)

The recommended dose of fertilizer for rice crops was 150:50:50 kg NPK/ha (16). Phosphorus was applied as a base alone. Four splits of potassium were used at baseline, vigorous shoot development, head formation, and blooming stages. Nitrogen was administered according to the treatment plan. The variety chosen for the study was CO 55. Transplanting was done on 21 DAS (days after sowing) with a spacing of 20 cm × 15 cm. Nano urea spray was given as per the treatment at 20, 40, and 60 days after transplanting.

Weed management

Pre-emergence herbicide application of Pretilachlor @ 1.0 kg a.i/ ha was applied three days after transplanting, followed by one-hand weeding done 40 days after transplanting.

Irrigation

The alternate wetting and drying irrigation method was adopted during the crop growth period.A 5 cm water level was maintained throughout the crop period until water withdrawal before harvest. Irrigation was stopped 10 days before harvest.

Biometric observations

Five plants were tagged randomly within the net plot area, and observations were recorded on active tillering, panicle initiation, flowering, and harvest stage. The data on growth parameters *viz.,* root length, root volume, root dry weight and dry matter production and physiological parameters *viz.*, net assimilation rate, crop growth rate, relative growth rate, and chlorophyll content and yield attributes *viz.,* number of productive tillers m^{-2}, number of filled per panicle and number of unfilled grains per panicle, grain conversion efficiency, grain yield, and straw yield were recorded. The agronomic use efficiency and economics were calculated.

Methane emission

The chamber method recorded methane emissions in experimental plots (17). Glass chambers were placed in all treatments. The initial gas samples from the gas chamber at the active tillering stage and the final gas sample from the gas chamber were collected with the help of a syringe, and the samples were injected into a 20 ml HS flat bottom vial. Separate samples were collected in separate HS flat-bottom vials, and the method used individual HS flat-bottom vials for each treatment (18). Gas analysis was performed using gas chromatography (19, 20).

Nitrous oxide emission

The chamber method was followed for the collection of gas samples. Gas samples were collected from the chambers at regular intervals. The sampling frequency depended on the time scale of nitrous oxide emission fluctuations. Measurements are commonly taken hourly during specific periods (e.g., daytime, nighttime, or throughout the growing season) (21). Gas analysis was done using gas chromatography to measure nitrous oxide concentrations (22).

The recorded parameters were analyzed statistically through standard procedures (23). The critical difference (CD) was determined at a 5% probability level. The SPSS statistical software tools are used for analysis.

Results and Discussion

Methane emission (CH_4)

The adoption of varied levels of nitrogen in conventional urea and applying nano urea as foliar spray significantly influenced the growth, yield attributes, and lesser greenhouse gas emissions in rice fields. The results of methane emission during vigorous shoot growth, heading, and blooming stages are presented in Table 1. Among all the treatments, during the active tillering stage, the lower methane emission was recorded significantly in nano urea applied treatment (T_4 to T_7) compared to conventional urea application treatment (T_1 and T_2). The nano urea applied treatments recorded methane emission of 6.86, 6.74, 6.53, and 6.43 mg m^2/day in T_4, T_5, T_6, and T_7, respectively, at the active tillering stage as compared to other treatments (7.51, 7.22 and 6.98 mg m^2/day with treatment T_1, T_2, and T_3, respectively). However, the lowest methane gas emission was noticed under control (0% N) treatment with a value of 6.32 mg/m^2/day at the active tillering stage, and similar trends were obtained at the panicle initiation stage with a value of 10.10 mg/m^2/day concerning methane gas emission during summer, 2023.

Data recorded at the flowering stage showed lower methane emission in nano urea applied treatment than in active tillering and panicle initiation stages. The nano urea applied treatment recorded methane emissions of 5.72, 5.58, 5.51, and 5.42 mg/m^2/day in T_4, T_5, T_6, and T_7, respectively. The research was conducted on excavated methane emissions from rice fields, specifically emphasizing crop establishment techniques and nutrient "management(24)" and (25). The efficacy of nano urea spray in reducing methane emissions varies based on product formulation, application practices, and environmental conditions (26). However, the potential for decreased one of the many benefits of using nano urea in agriculture is reduced methane emission (27). Methane emission during the active tillering stage shows nano urea spray reduced the methane emission compared to conventional urea (28).

Nitrous oxide (N_2O)

Among various treatments, comparatively lower nitrous oxide was recorded in nano urea applied treatment compared to basal urea application treatment at all crop growth stages. The results of nitrous oxide emission during active tillering, panicle initiation, and flowering stages are presented in Table 2. The nano urea applied treatments registered nitrous oxide of 4.47, 4.49, 4.34 and 4.11 mg/m^2/day with T_4, T_5, T_6, and T_7 treated plots, respectively, as comparable with the conventional method of fertilizer application (T_1 to T_3). Invariably, the least nitrous oxide gas emission was obtained with control (3.97 mg m^2/day) during an active tillering stage in the summer of 2023. At the panicle initiation stage, data about nitrous oxide emissions followed similar outcomes as nitrous oxide at the active tillering stage. At the flowering stage, lower nitrous oxide emissions were recorded in nano urea applied treatment than in conventional urea alone applied plot. The nano urea applied treatment recorded nitrous oxide of 5.11, 4.89, 4.73, and 4.52 mg/m^2/day in T_4, T_5, T_6, and T_7 treated plots at the flowering stage in summer 2023. Excessive application of N fertilizers beyond crop demand has resulted in undesirable consequences of degradation of soil, water, and air quality. These include soil acidification, N leaching in groundwater, and nitrous oxide emissions, a potent greenhouse gas contributing to global warming (6, 29).

Table 2. Effect of nutrient management practices on methane emission (mg m²/day) of transplanted rice

Treatments		CH_4 (mg m²/day)		
		Active tillering Stage	Panicle initiation stage	Flowering stage
T_1	100% RDN (25% each at basal, AT, PI and heading stage)	7.22	10.99	5.89
T_2	100% RDN (50% as basal+25% each at AT and PI)	7.51	12.15	5.95
T_3	50% RDN (basal only)	6.98	10.85	5.85
T_4	50% RDN (basal)+foliar spray of nano urea at 20 and 40 DAT	6.86	10.79	5.72
T_5	50% RDN (basal)+foliar spray of nano urea at 20, 40 and 60 DAT	6.74	10.62	5.58
T_6	25% RDN (basal)+foliar spray of nano urea at 20, 40 and 60 DAT	6.53	10.42	5.51
T_7	Foliar spray of nano urea at 20, 40 and 60 DAT	6.43	10.22	5.42
T_8	Control (0% N)	6.32	10.10	5.32
SEd.		0.38	0.60	0.31
CD (P=0.05)		1.06	1.65	0.87

AT- Active tillering stage; **PI**- Panicle initiation; **DAT**- Days after transplanting; **RDN**- Recommended dose of nitrogen

Grain yield

The results of grain yield observed in different treatments are presented in Table 3 and Fig. 1. Among the treatments, 75 kg of nitrogen/ha i.e. 50% recommended dose of nitrogen, applied as a basal dose through conventional urea along with 3 nano urea foliar sprays each at 20, 40, and 60

Table 3. Effect of nutrient management practices on nitrous oxide (mg/m²/day) of transplanted rice

Treatments		N_2O (mg/m²/day)		
		Active tillering Stage	Panicle initiation stage	Flowering stage
T_1	100% RDN (25% each at basal, AT, PI and heading stage)	4.78	7.98	5.24
T_2	100% RDN (50% as basal+25% each at AT and PI)	4.59	7.51	5.13
T_3	50% RDN (basal only)	4.22	7.06	4.67
T_4	50% RDN (basal)+foliar spray of nano urea at 20 and 40 DAT	4.47	7.44	5.11
T_5	50% RDN (basal)+foliar spray of nano urea at 20, 40 and 60 DAT	4.49	7.24	4.89
T_6	25% RDN (basal)+foliar spray of nano urea at 20, 40 and 60 DAT	4.34	7.10	4.73
T_7	Foliar spray of nano urea at 20, 40 and 60 DAT	4.11	6.84	4.52
T_8	Control (0% N)	3.97	6.40	4.43
SEd.		0.24	0.38	0.27
CD (P=0.05)		0.66	1.06	0.75

AT- Active tillering stage; **PI**- Panicle initiation; **DAT**- Days after transplanting; **RDN**- Recommended dose of nitrogen.

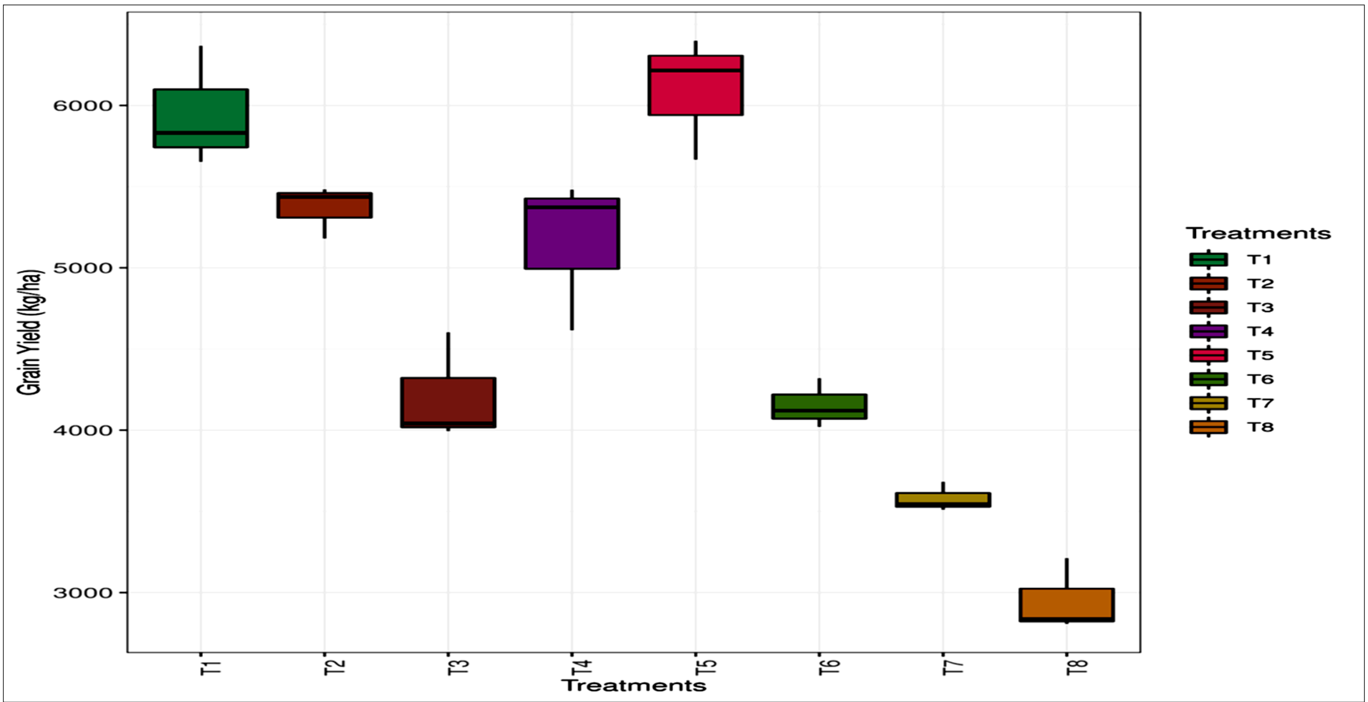

Fig 1. Effect of nutrient management treatments on Grain yield (kg/ha) of transplanted rice.

days after transplanting gave a significantly higher grain yield of 6093 kg/ha (T_5), which was equivalent to the treatment in which 150 kg nitrogen/ha i.e. 100% recommended dose of nitrogen was applied 25% each at initial, vigorous shoot growth, panicle initiation, and heading stage throu gh conventional urea, with the grain yield of 5950 kg/ha (T_1). This was followed by 100% advised nitrogen dosage, i.e. 150 kg nitrogen/ha, in which 50% of it was applied as initial dose coupled with 25% each as top dressing at active tillering and panicle initiation through conventional urea with the grain yield of 5367 kg/ha (T_2), which was balanced with 75 kg nitrogen, i.e., 50% standard nitrogen rate is applied as basal dose through conventional urea coupled with 2 nano urea foliar sprays at 20 and 40 days after transplanting with the yield of 5156 kg/ha (T_4). The nano urea application alone treatment (without urea) recorded a grain yield of 3579 kg/ha (T_7). The lowest grain yield of 2952 kg/ha was observed in the control (T_8). A recent showed that it reduced conventional urea spray use by half of RDN and nano urea foliar spray, improving grain yield (15).

Straw yield

The results of straw yield observed in different treatments are presented in Table 3 and Fig. 2. From this observation, 50% recommended dose of nitrogen, i.e. 75 kg nitrogen/ha through conventional urea as the basal application only + 3 nano urea foliar sprays at 20, 40, and 60 days after transplanting (T_5), had a profound influence on straw yield of transplanted rice (7681 kg/ha) which was on par with 100% recommended dose of nitrogen i.e. 150 kg nitrogen/ha applied through conventional urea in which 25% each applied at basal, active tillering, panicle initiation, and heading stage with the straw yield of 7538 kg/ha (T_1). This was followed by a 100% recommended dose of nitrogen, i.e. 150 kg nitrogen/ha, in which 50% of it was applied as basal dose through conventional urea + 25% each as top dressing at active tillering and panicle initiation through conventional urea with the straw yield of 6627 kg/ha (T_2), which was on par with 50% recommended dose of nitrogen, i.e., 75 kg nitrogen/ha through conventional urea as the basal application only + 2 nano urea foliar sprays at 20 and 40 days after transplanting with the yield of 6537 kg/ha (T_4). The lowest straw yield of 3947 kg/ha was recorded with control (T_8). These exhibit efficacy when nano nitrogen is administered as a foliar spray during the active tillering stage, alongside soil treatments involving a total NPK or a combination of 75% N and 100 % PK, resulting in higher grain and straw yield (30).

Economics

The cost of cultivation, gross return, net return, and B : C ratio were worked out from different rice nutrition management practices are presented in Fig. 3. Application of 50% recommended dose of nitrogen, i.e. 75 kg nitrogen/ha applied through conventional urea as basal only + nano urea foliar spray at 20, 40, and 60 days after transplanting (T_5) received higher B: C ratio of 2.19. The maximum gross returns (96,159 ₹/ha) and net returns (52,310 ₹/ha) were observed in T_5, followed by T_1. Applying the recommended dose of nitrogen with nano urea resulted in significant improvements in economic and by-product yields, resulting in better economics than other treatments. Higher grain yield and straw yield resulted in more gross income, net income, and B: C ratio in the T_5 combination. Due to the complete absence of application of nitrogen in control (T_8), the resulting lower gross income, net income, and B : C ratio were reflected in lesser grain yield and straw yield. It is concluded that a lesser dose of conventional urea, 50% of the recommended dose of nitrogen, along with 3 times

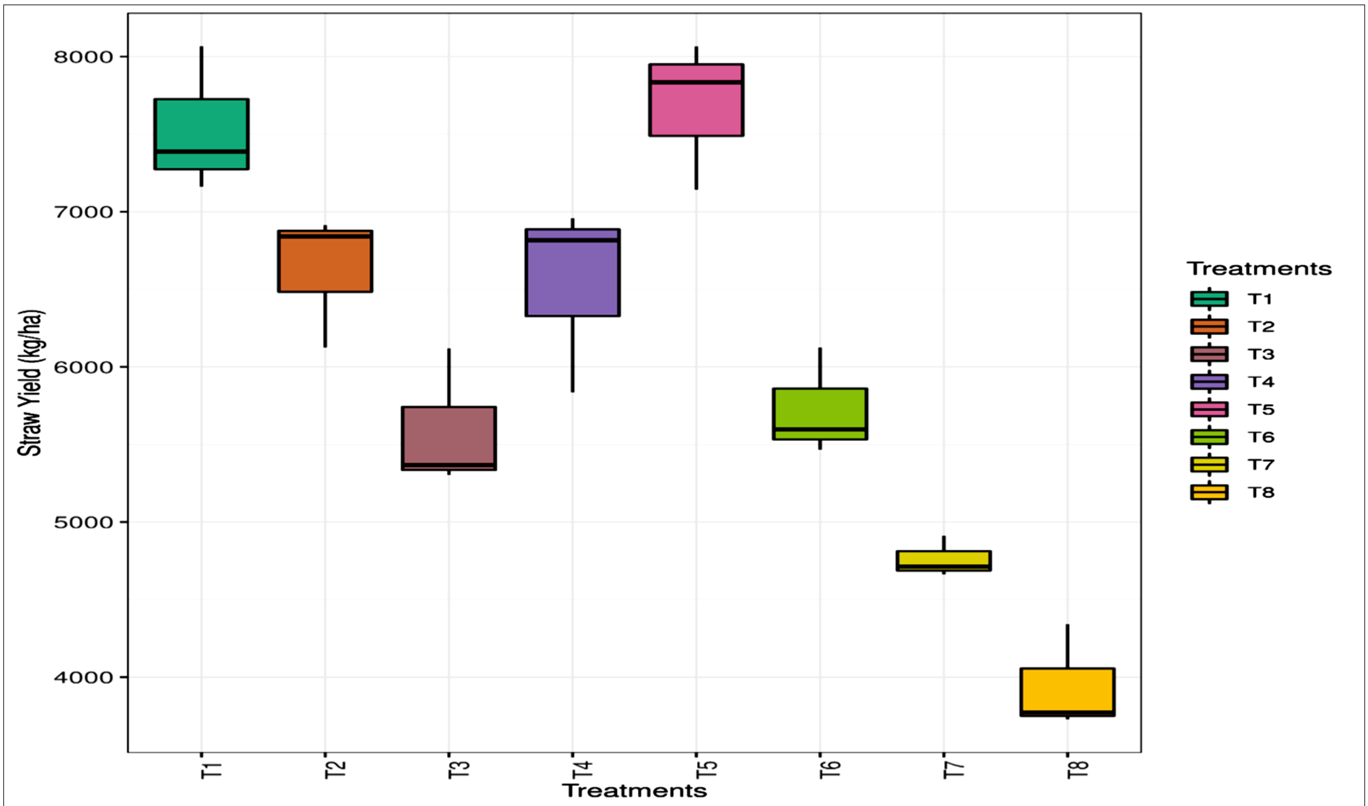

Fig 2. Effect of nutrient management treatments on straw yield (kg/ha) of transplanted rice.

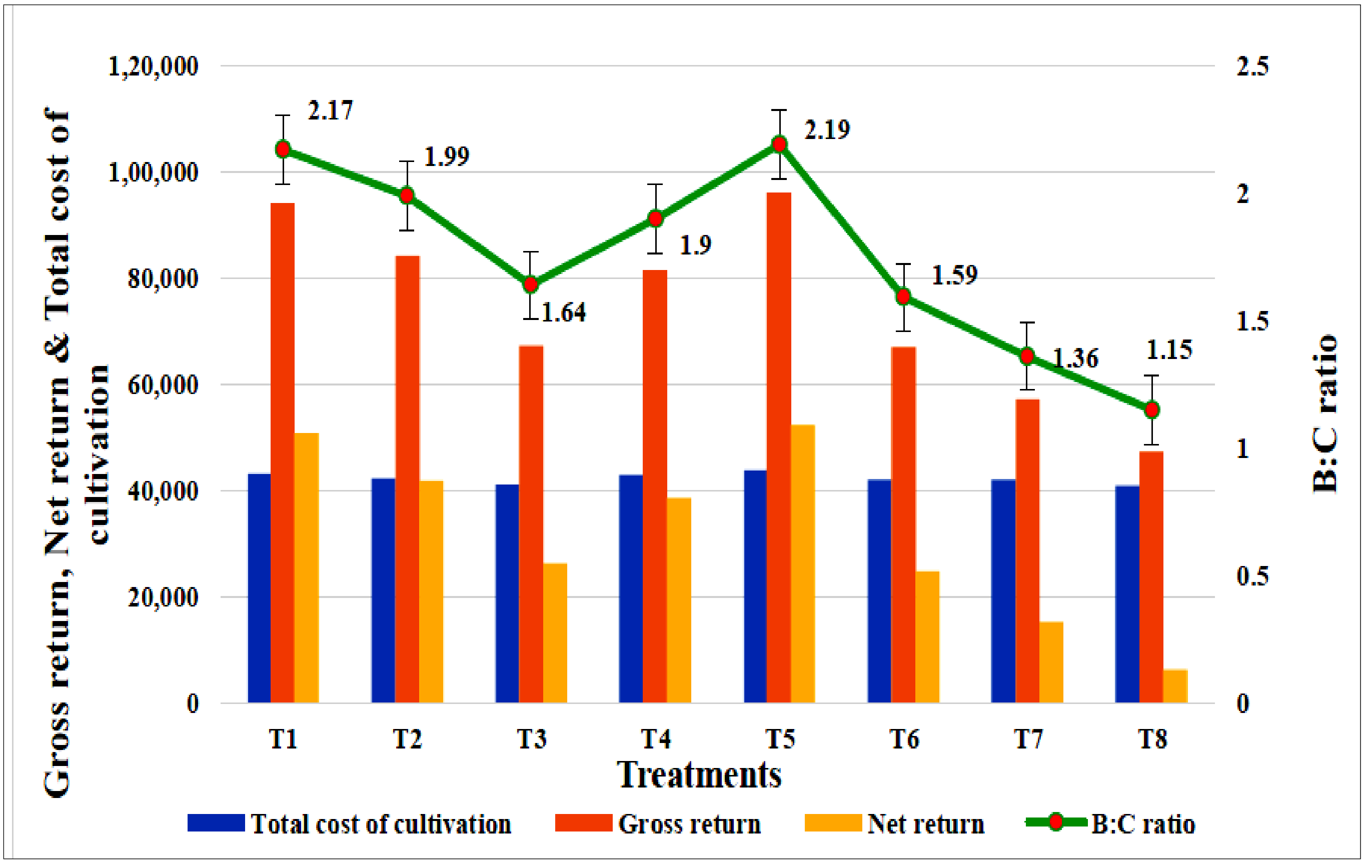

Fig 3. Effect of nutrient management treatments on transplanted rice economics (Rs./ha).

foliar application of nano urea on 20, 40, and 60 days after transplanting resulted in higher net return and Benefit-cost ratio (2.20) when compared to 100% recommended dose of nitrogen through conventional urea application.

Conclusion

To understand its impact on emissions, nano urea uses different crop management practices, such as irrigation methods, planting densities, and soil types. By improving nitrogen efficiency, nano urea may help reduce nitrous oxide emissions, a potent greenhouse gas, while sustaining high crop yields, offering a promising solution for climate-smart agriculture. This study evaluated methane and nitrous oxide emissions from nitrogen application in rice cultivation. The results indicated that the treatment with 50% recommended dose of nitrogen, i.e. 75 kg of nitrogen/ha applied through conventional urea as basal only + 3 nano urea foliar sprays each at 20, 40, and 60 days after transplanting (T_5) recorded the lower emission of both methane and nitrous oxide gases compared to treatment using 100% recommended dose of nitrogen i.e. 150 kg of nitrogen/ha through conventional urea is applied at 25% of dose each at initial, active tillering, panicle initiation and heading stage (T_1) and 100% optimal nitrogen level i.e. 150 kg nitrogen/ha through conventional urea, 50% of it as basal application + 2 top dressing each with 25% of it at active tillering and panicle initiation) (T_2). Since the T_5 treatment combinations generated lower greenhouse gas emissions than one another, The T_5 treatment achieved significant reductions in greenhouse gas emissions and enhanced growth and yield, demonstrating its economic advantages.

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Authors' contributions

Anushka A S: Writing an original draft, Formal analysis, Data curation, and Practical experimental work, Investigation; Design of the experiment; G Senthil Kumar: Research conceptualization, Methodology, Supervision; Nunavath Umilsingh: Editing; Aditya Kamalakar Kanade: Editing; N Sridharan: Editing.

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