

STUDY ON THE GREENHOUSE GAS (GHG) EMISSIONS FROM RICE FIELD UNDER VARIOUS NUTRIENT MANAGEMENT PRACTICES

Abstract

Modernizing traditional farming practices and intensive cultivation on limited land has increased the reliance on fertilizers to maintain soil health. The study was conducted on rice crop from 2022 to 2023. The seven treatment combinations in which recommended dose of nitrogen applied through nano coated urea (NCU) and nano urea, viz., T₁:Control (No nitrogen), T₂: 1/3rd as (NCU) as basal) + 1/3rd NCU at active tillering (AT)) + 1/3rdNCU at panicle initiation (PI)), T₃: 1/3rd NCU as basal + 1/3rd NCU at AT + 2sprays of NU at maximum tillering -MT and PI) @ 2 ml / litre), T₄: 1/3rd NCU as basal + 1/3rd NCU at AT + 1 spray of nano-urea at PI @ 4 ml / litre), T₅: 1/4 NCU as basal + 1/4 NCU at AT +2 sprays of nano-urea (at MT and PI) @ 2 ml / litre), T₆: 1/3rd NCU as basal + 2 sprays of nano-urea (at AT& PI) @ 2 ml / litre), and T₇: 1/3rd NCU as basal + 3 sprays of nano-urea (at AT, PI, and heading) @ 2 ml / litre). The study revealed significant differences in GHG emissions, particularly nitrous oxide (N₂O) and carbon dioxide (CO₂), among the different fertilizer management practices. The highest (p=??) N₂O emissions were observed in the T₂ treatment {1/3rd RDN (NCU as basal) + 1/3rd RDN (NCU at active tillering) + 1/3rd RDN (NCU at panicle initiation)} at 352 kgCO₂eha⁻¹, while the lowest emissions were recorded in the T₁ treatment (Control – without nitrogen) at 88.4 kgCO₂eha⁻¹. Similarly, CO₂ emissions were also the highest in the T₂ treatment at 1376 kgCO₂eha⁻¹, with the control (T₁) recording the lowest at 1165 kgCO₂eha⁻¹. Methane emissions, mainly influenced by water regimes, remained consistent across all treatments, each contributing 2112.3 kgCO₂eha⁻¹, due to similar water management across all treatments. Overall, total GHG emissions were significantly higher in fertilized treatments, with the T₂ treatment exhibiting the highest total emissions of 3841 kgCO₂eha⁻¹, while the control had the lowest at 3366 kgCO₂eha⁻¹. These findings highlighted the complex trade-offs between enhancing rice yields through improved nutrient management and the associated increase in GHG emissions, emphasizing the need for strategies that balance productivity with environmental sustainability.

Keyword: Nano urea, transplanting, GHG emissions, nitrous oxide, carbon dioxide, methane, yield

1. INTRODUCTION

Climate change is a critical environmental challenge of the 21st century, with far-reaching consequences for food security, economic stability, and human well-being. The impacts are particularly severe in developing countries like India, where agriculture plays a vital role in sustaining the livelihoods of millions [1]. Changes in temperature and precipitation directly affect crop yields, threatening food production and overall food security [2]. Rice (*Oryza sativa* L.), a staple food for more than half of the global population, is particularly sensitive to climate change. Traditional rice farming practices are significant sources of greenhouse gas (GHG) emissions, especially methane. Rice cultivation contributes approximately 10% of global methane emissions due to the anaerobic conditions in flooded paddy fields, which favor methane production by methanogenic bacteria [3]. The rise in temperature is mostly due to the increase in greenhouse gases in the atmosphere, resulting in fluctuating climatic circumstances that impact the growth and development cycles of agricultural crops, consequently jeopardizing the sustainability of agricultural output. Rice is a primary staple crop globally and is crucial for food security, especially in developing nations. Rice is acknowledged as a contribution to greenhouse gas emissions in the agricultural industry. Consequently, fertilizer and irrigation management may be one of the agricultural strategies in rice cultivation that has the ability to diminish greenhouse gas emissions from rice fields without significantly impacting rice productivity.

In modern agriculture use of fertilizer, mainly nitrogen, is essential, particularly for high-yielding crops like rice. Urea, the most commonly used nitrogen fertilizer, is preferred for its high nitrogen content and cost-effectiveness [4]. However, the application of conventional urea is often inefficient, with significant nitrogen losses occurring through volatilization, leaching, and denitrification. Besides, excessive nutrient use, particularly nitrogen (N), beyond crop requirements, leads to environmental losses and significant greenhouse gas (GHG) emissions, negatively impacting the environment [5]. Specifically, rice fields contribute approximately 30% of global agricultural methane emissions and 11% of nitrous oxide (N₂O) emissions [6]. These losses reduce nitrogen use efficiency (NUE) and contribute to environmental issues, including water eutrophication [7]. These inefficiencies highlight the need for more effective fertilization methods, leading to the development of innovative solutions such as nano-urea.

Nano-urea represents a significant advancement in fertilizer technology, developed to address the inefficiencies associated with conventional fertilizers. Nano-urea is characterized by its ultra-small particle size (<100 nm) which enhances its physical and chemical properties compared to traditional urea. The

increased surface area/volume ratio of nano-urea improves nitrogen availability and absorption by plants, reducing nutrient losses and enhancing crop growth [8]. The use of nano-urea in agriculture has shown promising results, including improved NUE, reduced environmental pollution, and mitigated GHG emissions. By providing a more controlled and sustained release of nitrogen, nano-urea can potentially minimize volatilization and leaching losses, which are common with traditional urea [8]. Rice is the only crop grown in predominantly flooded fields, and the subsequent anaerobic soil conditions stimulate the production of methane (CH₄), a potent greenhouse gas (GHG) [9, 10, 11, 12]. CH₄ emissions from rice cultivation contribute substantially to the national GHG budgets of Asian countries [13, 4, 15]. Compiled available data in the literature on N₂O emissions from fertilized rice fields and reported that the fertilizer-induced N₂O emission factors for CF, midseason drainage, and all water regimes were 0.22, 0.37, and 0.31%, respectively. In the loamy soils of the N₂O emissions were minimized by keeping soil flooded after N fertilizer application as shown in a study by [16, 17], conducted a long-term (20 years) model simulation to estimate the effect of prolonged mid-season drainage on CH₄ emission reduction across nine sites in Japan and found that the simulated mean effect (20.1% reduction compared to normal mid-season drainage) was lower than the observed effect in the 2-year field experiment (30.5%;) [18].

A study was designed to assess the effects of newly invented nano fertilizers on GHG emissions in rice crop and their impact on rice productivity.

2. MATERIALS AND METHODS

A two-year study was conducted during two consecutive *kharif* seasons (2022 and 2023) at the experimental farm of ICAR-National Rice Research Institute-Regional Rainfed Lowland Rice Research Station (ICAR-NRRI-RLLRRS) in Gerua, Assam, India, located at 26.25° N latitude and 91.56° E longitude, in the Lower Brahmaputra Valley Zone, characterized by a humid subtropical climate with hot summers and cold winters. The soil of the experimental field was medium in nitrogen (245.4 kg/ha), organic carbon (0.62%) and potassium (195.8 kg/ha) whereas, high in phosphorus (53.8 kg/ha), with adequate zinc content (0.995 ppm) and slightly acidic (pH 5.6) in reaction.

A medium-duration rice variety CR Dhan 311 was taken for experimentation and transplanting was done manually keeping 20 cm row distance. The experiment was laid out in a randomized block design, replicating three times with seven treatment combinations, viz., T₁:Control (No

nitrogen), T₂: 1/3rd RDN (NCU as basal) + 1/3rd RDN (NCU at active tillering -AT) + 1/3rd RDN (NCU at panicle initiation -PI), T₃: 1/3rd RDN (NCU as basal) + 1/3rd RDN (NCU at AT) + 2sprays of nano-urea (at maximum tillering -MT and PI) @ 2 ml / litre), T₄: 1/3rd RDN (NCU as basal) + 1/3rd RDN (NCU at AT) + 1 spray of nano-urea at PI @ 4 ml / litre), T₅: 1/4 RDN (NCU as basal) + 1/4 RDN (NCU at AT) +2 sprays of nano-urea (at MT and PI) @ 2 ml / litre), T₆:1/3rd RDN (NCU as basal) + 2 sprays of nano-urea (at AT& PI) @ 2 ml / litre), and T₇: 1/3rd RDN (NCU as basal) + 3 sprays of nano-urea (at AT, PI, and heading) @ 2 ml / litre). At the time of field preparation, before transplanting, a uniform dose of 20 kg P₂O₅ and 40 kg K₂O/ha were applied through single super phosphate and muriate of potash, respectively, and incorporated in the soil. The soil of the experimental field was medium in nitrogen (245.4 kg/ha), organic carbon (0.62%) and potassium (195.8 kg/ha) and high in phosphorus (53.8 kg/ha), with adequate zinc content (0.995 ppm) and slightly acidic (pH 5.6) in reaction.

The monsoon typically begins in June and lasts until September, with pre-monsoon showers starting in mid-March. Rainfall intensity peaks in August and diminishes from October, reaching its lowest levels in December and January. Weekly meteorological data during the study period were recorded at the Meteorological Observatory of ICAR-NRRI-RRLRRS, Gerua, Assam. The total rainfall received during the crop growing period (2 July-31 December) was 397 mm in 2022 and 472 mm in 2023. In the year 2022 mean monthly maximum and minimum temperatures ranged from 22.7°C to 26.1°C and 32.1°C to 35.1°C, respectively. While in 2023, the corresponding maximum and minimum temperature ranges were 13.5°C to 25°C and 36.0°C to 37.5°C. The mean relative humidity in the morning and evening varied from 80.1% to 84.2% and 78% to 82% in 2022, and 87.8% to 92.5% and 58.7% to 82.4% in 2023.

To estimate GHG emissions, the Cool Farm Tool (CFT), a farm-level greenhouse gas (GHG) emissions calculator specifically designed to help farmers measure and reduce their carbon footprint, was used. This involves several steps and incorporates various scientific models and data inputs, including farm information (geographical location, soil type, and crop type) management practices (tillage, fertilizer use, irrigation, and crop rotation), resource use (fuel, electricity, and water are also included), emission factors (specific to the type of input or activity), fertilizer application (has a certain emission factor for N₂O emissions, which is based on the amount and type of fertilizer used, as well as soil and climate conditions), carbon sequestration (particularly in soil and biomass, which offsets some of the emissions).

The GHG calculation models included Intergovernmental Panel on Climate Change (IPCC) guidelines including (Tier 1, Tier 2, and sometimes Tier 3 approaches, depending on data availability and complexity), biogeochemical models (simulating the cycling of carbon, nitrogen, and other elements in the farm system to estimate GHG emissions), empirical models for certain activities, the tool uses empirical models that are based on field studies and experiments to predict emissions. The tool calculates the total GHG emissions from various sources, including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), provides a breakdown of emissions by source (e.g., soil management, livestock, fertilizer use) and we can compare their emissions with benchmarks or industry averages to identify areas for improvement. The tool allows users to model different scenarios, such as changes in farming practices, to see how these would impact emissions.

The collected data was subjected was statistically analyzed by using the Statistical tool for Agriculture Research STAR software.

3. RESULTS

This section presents the results of the greenhouse gas (GHG) emissions measured in terms of nitrous oxide (N₂O), carbon dioxide (CO₂), and methane (CH₄) emissions across different treatment groups. The total GHG emissions are calculated as the sum of these individual gases, expressed in kgCO₂ equivalents per hectare (kgCO₂eha⁻¹). The data provides insights into the effectiveness of different treatments in reducing GHG emissions from rice fields.

3.1 Nitrous Oxide (N₂O) Emissions

Nitrous oxide is a potent greenhouse gas with a global warming potential approximately 298 times greater than CO₂ over a 100-year period. The treatments showed significant variations in N₂O emissions, T₂ exhibiting the highest N₂O emissions at 352 kgCO₂eha⁻¹, was the least efficient nitrogen management, leading to increased losses through denitrification. T₁ recorded the lowest N₂O emissions at 88.4 kgCO₂eha⁻¹, indicating more effective nitrogen use, likely due to optimized application rates or controlled release mechanisms. T₃, T₄, T₅, T₆, and T₇ demonstrated moderate N₂O emissions, with values ranging from 177 to 264 kgCO₂eha⁻¹. These treatments appear to have similar efficiencies in nitrogen management, although they performed better than T₂.

3.2 Carbon Dioxide (CO₂) Emissions

Carbon dioxide emissions are a direct result of soil respiration and other biological activities. T₂ had the highest CO₂ emissions at 1376 kgCO₂eha⁻¹, indicating that this treatment may have

stimulated microbial activity or accelerated organic matter decomposition, leading to higher CO₂ flux. T₁ recorded the lowest CO₂ emissions at 1165 kgCO₂eha⁻¹, suggesting a less intensive biological activity or more stable soil organic carbon content under this treatment. The treatments T₃, T₄, T₅, T₆, and T₇ exhibited CO₂ emissions between 1236 and 1306 kgCO₂eha⁻¹, reflecting a relatively uniform impact on soil CO₂ production across these treatments, with a slight variation depending on the specific management practices employed.

3.4 Methane (CH₄) Emissions

Methane emissions are primarily produced under anaerobic conditions in flooded rice paddies. All treatments exhibited identical CH₄ emissions of 2112 kgCO₂eha⁻¹, suggesting that the treatments did not significantly alter the anaerobic conditions in the soil or the methanogenic microbial activity responsible for CH₄ production. Therefore, methane production was likely governed by the inherent characteristics of the rice paddies, such as water management and organic matter content, rather than the specific treatments.

3.5 Total Greenhouse Gas Emissions

The total GHG emissions combine the contributions from N₂O, CO₂, and CH₄ to provide an overall assessment of each treatment's environmental impact. The treatment T₂ had the highest total GHG emissions at 3841 kgCO₂eha⁻¹, indicating it as the least environmentally friendly treatment, with high emissions from both N₂O and CO₂. T₁ produced the lowest total GHG emissions at 3366 kg CO₂eha⁻¹, making it the most sustainable option in terms of minimizing overall GHG output. The treatment T₃, T₄, T₅, T₆, and T₇ showed intermediate total GHG emissions, ranging from 3525 to 3682 kgCO₂eha⁻¹. Among these, T₆ and T₇ were particularly effective, achieving lower total emissions compared to the others, indicating more efficient nitrogen use and reduced CO₂ output.

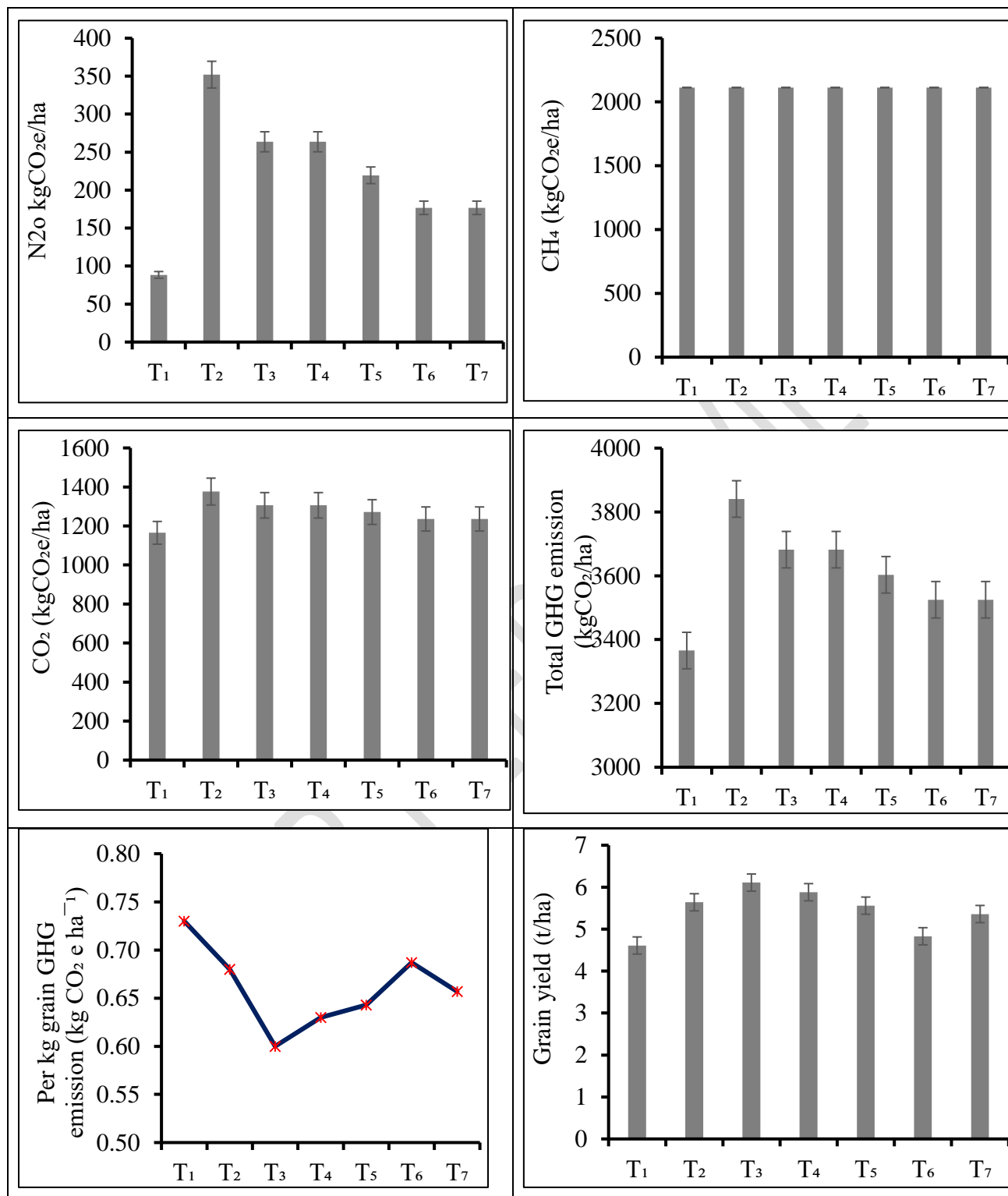


Fig 1: Effect of fertilizer management practices on N_2O , CO_2 , CH_4 , and total GHG emissions (kg CO₂e ha⁻¹) in transplanted *kharif* rice

Treatment	N ₂ O (kgCO ₂ e/ha)	CO ₂ (kgCO ₂ e/ha)	CH ₄ (kgCO ₂ e/ha)	Total GHG emission (kgCO ₂ /ha)	Grain yield (t/ha)	Per kg grain GHG emission (kgCO ₂ e/ha)
T1	88	1165	2112	3366	4.61	0.73
T2	352	1376	2112	3841	5.64	0.68
T3	264	1306	2112	3682	6.11	0.60
T4	264	1306	2112	3682	5.88	0.63
T5	219	1271	2112	3603	5.57	0.64
T6	177	1236	2112	3525	5.14	0.69
T7	177	1236	2112	3525	5.36	0.66
C.D.	10.58	8.62	NS	18.95	0.34	0.04

The highest total GHG emission was observed in T₂ (3841 kgCO₂e ha⁻¹), while T₁ recorded the lowest emissions (3366 kgCO₂e ha⁻¹). The variation in total emissions is primarily influenced by differences in N₂O and CO₂ emissions, as CH₄ emissions remain constant across all treatments. T₃ achieved the highest grain yield (6.11 t/ha), closely followed by T₄ (5.88 t/ha). T₁ recorded the lowest grain yield (4.61 t/ha).

The efficiency of GHG emissions per kg of grain produced was the highest in T₃ (0.60 kgCO₂e ha⁻¹ per kg grain) and the lowest in both T₁ and T₆ (0.73 kgCO₂e ha⁻¹ per kg grain). This indicates that T₃, despite having relatively high total emissions, is more efficient in terms of emissions per unit of grain produced.

4. DISCUSSION

Overall, the management approaches, particularly fertilizer application, significantly affect the emission of greenhouse gases (GHGs). The individual gases as well as total GHGs emissions were recorded lowest in the treatment with no nitrogen application (T₁), while a yield penalty was noted. Moreover, the application of Nano fertilizer via foliar spray in treatments T₂-T₇ resulted in comparatively greenhouse gas emissions without compromising yield, likely due to the decreased soil application of nitrogen fertilizer, which in turn reduced nitrogen losses. It was demonstrated that nano fertilizers exhibit high utilization efficiency, resulting in no apparent production decrease (19, 20 & 21).

5. CONCLUSION

The two-year study reveals that T₃ (application of 2/3 of recommended dose of nitrogen through NCU, 1/3 each at transplanting (basal) and active tillering followed by two nano-urea sprays (2ml/litre) at maximum tillering and PI) can be recommended as the most efficient option for

farmers seeking to maximize grain yield while minimizing GHG emissions per unit of grain produced. This treatment achieved the highest grain yield (6.11 t/ha) with the lowest per kg grain GHG emission ($0.60 \text{ kgCO}_2\text{eha}^{-1}$) per kg of grain producing, making it the most sustainable choice in terms of productivity and environmental impact. Farmers aiming to balance yield with environmental sustainability should consider adopting practices similar to those in T₃. While T₂ (application of recommended dose of N (60 kg N/ha) in three equal instalments – at transplanting (basal), active tillering, and PI through NCU) also provided high yield and relatively low GHG emission per kg grain, and its higher total GHG emissions making it less favorable than T₃. Conversely, although T₁ (Control – without nitrogen) had the lowest total GHG emissions, its lower grain yield and higher GHG emissions per kg of grain produced indicate that it may not be as efficient for maximizing both productivity and sustainability. Therefore, it is recommended to focus on optimizing practices that align with T₃ to achieve the best balance between high yield and low environmental impact.

This study's results contribute valuable insights into the relationship between fertilizer use, particularly nano-urea applications, and GHG emissions in rice cultivation. The findings suggest that while advanced fertilizer management can improve yields and economic returns, it may also exacerbate GHG emissions, necessitating further research to optimize these practices for both environmental and economic benefits.

COMPETING INTERESTS: Authors have declared that no competing interests exist.

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