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. This study, conducted from 2022 to 2023 at the Experimental Farm of ICAR-National Rice Research Institute-Regional Rainfed Lowland Rice Research Station (ICAR-NRRI-RRLRRS) in Gerua, Assam, focused on evaluating the impact of various fertilizer management practices on rice cultivation. 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 evaluation covered several parameters, including growth and yield attributes, nutrient uptake, and efficiencies, as well as the environmental impact, particularly greenhouse gas (GHG) emissions.

The study revealed significant differences in GHG emissions, particularly nitrous oxide (N_2O) and carbon dioxide (CO_2), among the different fertilizer management practices. The highest N_2O emissions were observed in the T_2 treatment {1/3rd RDN (NCU as basal) + 1/3rd RDN (NCU at active tillering) + 1/3rd RDN (NCU at panicle initiation)} at 352 $kgCO_2eha^{-1}$, while the lowest emissions were recorded in the T_1 treatment (Control – without nitrogen) at 88.4 $kgCO_2eha^{-1}$. Similarly, CO_2 emissions were also the highest in the T_2 treatment at 1376 $kgCO_2eha^{-1}$, with the control (T_1) recording the lowest at 1165 $kgCO_2eha^{-1}$. Methane (CH_4) emissions, mainly influenced by water regimes, remained consistent across all treatments, each contributing 2112.3 $kgCO_2eha^{-1}$ due to similar water management across all treatments.

Overall, total GHG emissions were significantly higher in fertilized treatments, with the T_2 treatment exhibiting the highest total emissions of 3841 $kgCO_2eha^{-1}$, while the control had the lowest at 3366 $kgCO_2eha^{-1}$. These findings highlight 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.

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.

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

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 (Llones and Suwanmaneepong, 2021). Changes in temperature and precipitation directly affect crop yields, threatening food production and overall food security (Chauhan et al., 2014). 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 (CH_4). 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 (Prasad et al., 2017a).

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 (Masum et al., 2013). 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 (Gupta et al., 2021). Specifically, rice fields contribute approximately 30% of global agricultural methane (CH_4) emissions and 11% of nitrous oxide (N_2O) emissions (Ramesh et al., 2020). These losses reduce nitrogen use efficiency (NUE) and contribute to environmental issues, including water eutrophication (Zebarth et al., 2009). 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 (Kumar et al., 2021). 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 (Kumar et al., 2021).

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-RRLRRS) in Gerua, Assam, located at 26.25° N latitude and 91.56° E longitude, in the Lower Brahmaputra Valley Zone, characterized by a humid sub-tropical climate with hot summers and cold winters. 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., T_1: Control (No nitrogen), T_2: 1/3rd RDN (NCU as basal) + 1/3rd RDN (NCU at active tillering -AT) + 1/3rd RDN (NCU at panicle initiation -PI), T_3: 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), T_4: 1/3rd RDN (NCU as basal) + 1/3rd RDN (NCU at AT) + 1 spray of nano-urea at PI @ 4 ml / litre), T_5: 1/4 RDN (NCU as basal) + 1/4 RDN (NCU at AT) +2 sprays of nano-urea (at MT and PI) @ 2 ml / litre), T_6 : 1/3rd RDN (NCU as basal) + 2 sprays of nano-urea (at AT & PI) @ 2 ml / litre), and T_7: 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 P_2O_5 and 40 kg K_2O/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. 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, in clouding 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 N_2O 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 (CO_2), methane (CH_4), and nitrous oxide (N_2O), 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.

RESULTS AND DISCUSSION

This section presents the results of the greenhouse gas (GHG) emissions measured in terms of nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) emissions across different treatment groups. The total GHG emissions are calculated as the sum of these individual gases, expressed in kg CO_2 equivalents per hectare ($kgCO_2eha^{-1}$). The data provides insights into the effectiveness of different treatments in reducing GHG emissions from rice fields.

Nitrous Oxide (N_2O) Emissions

Nitrous oxide is a potent greenhouse gas with a global warming potential approximately 298 times greater than CO_2 over a 100-year period. The treatments showed significant variations in N_2O emissions, T_2 exhibiting the highest N_2O emissions at 352 $kgCO_2eha^{-1}$, was the least efficient nitrogen management, leading to increased losses through denitrification. T_1 recorded the lowest N_2O emissions at 88.4 $kgCO_2eha^{-1}$, indicating more effective nitrogen use, likely due to optimized application rates or controlled release mechanisms. T_3, T_4, T_5, T_6, and T_7 demonstrated moderate N_2O emissions, with values ranging from 177 to 264 $kgCO_2eha^{-1}$. These treatments appear to have similar efficiencies in nitrogen management, although they performed better than T_2.

Carbon Dioxide (CO_2) Emissions

Carbon dioxide emissions are a direct result of soil respiration and other biological activities. T_2 had the highest CO_2 emissions at 1376 $kgCO_2eha^{-1}$, indicating that this treatment may have stimulated microbial activity or accelerated organic matter decomposition, leading to higher CO_2 flux. T_1 recorded the lowest CO_2 emissions at 1165 $kgCO_2eha^{-1}$, suggesting a less intensive biological activity or more stable soil organic carbon content under this treatment. The treatments T_3, T_4, T_5, T_6, and T_7 exhibited CO_2 emissions between 1236 and 1306 $kgCO_2eha^{-1}$, reflecting a relatively uniform impact on soil CO_2 production across these treatments, with a slight variation depending on the specific management practices employed.

Methane (CH_4) Emissions

Methane emissions are primarily produced under anaerobic conditions in flooded rice paddies. All treatments exhibited identical CH_4 emissions of 2112 $kgCO_2eha^{-1}$, suggesting that the treatments did not significantly alter the anaerobic conditions in the soil or the methanogenic microbial activity responsible for CH_4 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.

Total Greenhouse Gas Emissions

The total GHG emissions combine the contributions from N_2O, CO_2, and CH_4 to provide an overall assessment of each treatment's environmental impact. The treatment T_2 had the highest total GHG emissions at 3841 $kgCO_2eha^{-1}$, indicating it as the least environmentally friendly treatment, with high emissions from both N_2O and CO_2. T_1 produced the lowest total GHG emissions at 3366 kg CO_2eha^{-1}, making it the most sustainable option in terms of minimizing overall GHG output. The treatment T_3, T_4, T_5, T_6, and T_7 showed intermediate total GHG emissions, ranging from 3525 to 3682 kgCO$_2$eha^{-1}. Among these, T_6 and T_7 were particularly effective, achieving lower total emissions compared to the others, indicating more efficient nitrogen use and reduced CO$_2$ output.

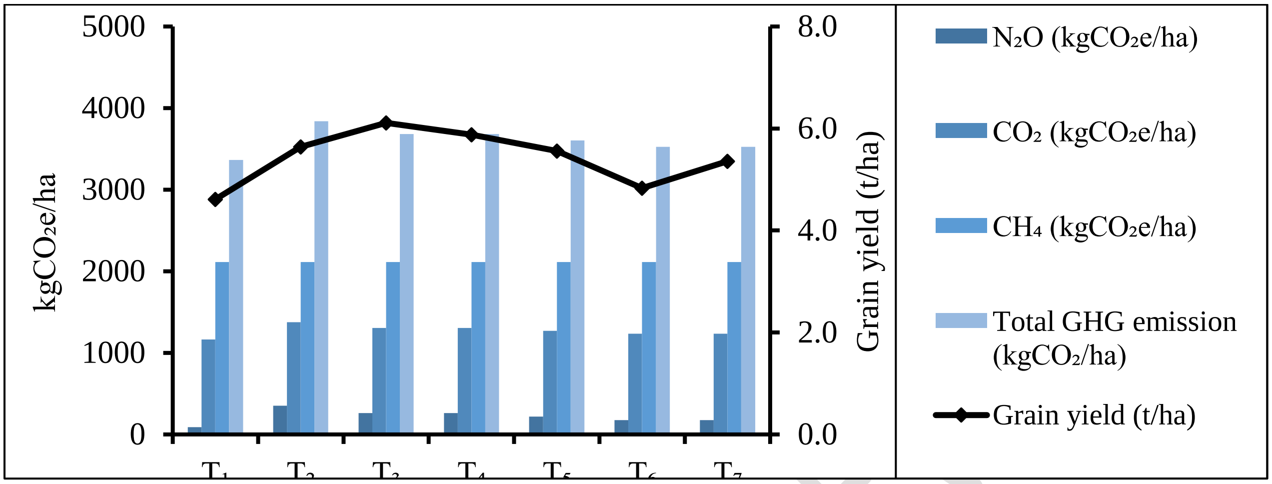

Fig 1: Effect of fertilizer management practices on N$_2$O, CO$_2$, CH$_4$, and total GHG emissions (kg CO$_2$eha^{-1}) in transplanted *kharif* rice

The highest total GHG emission was observed in T_2 (3841 kgCO$_2$eha^{-1}), while T_1 recorded the lowest emissions (3366 kgCO$_2$eha^{-1}). The variation in total emissions is primarily influenced by differences in N$_2$O and CO$_2$ emissions, as CH$_4$ emissions remain constant across all treatments. T_3 achieved the highest grain yield (6.11 t/ha), closely followed by T_4 (5.88 t/ha). T_1 recorded the lowest grain yield (4.61 t/ha).

The efficiency of GHG emissions per kg of grain produced was the highest in T_3 (0.60 kgCO$_2$eha^{-1} per kg grain) and the lowest in both T_1 and T_6 (0.73 kgCO$_2$eha^{-1} per kg grain). This indicates that T_3, despite having relatively high total emissions, is more efficient in terms of emissions per unit of grain produced.

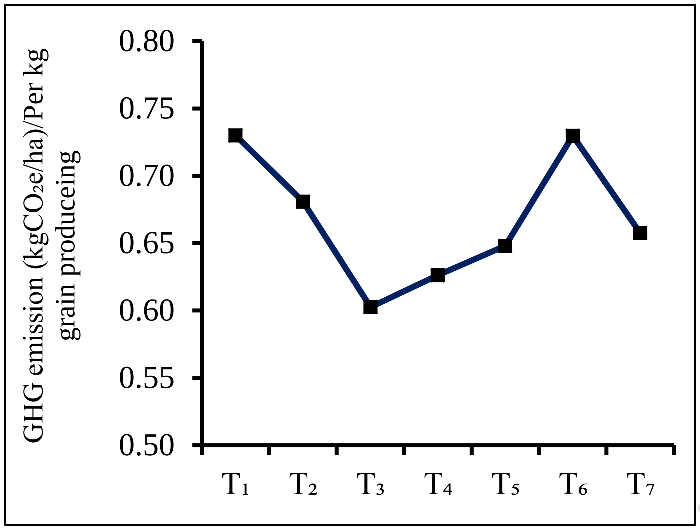

Fig 2 : Graphical presentation showing GHG emission rate

CONCLUSION

The two-year study reveals that T_3 (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) is recommended as the most efficient option for farmers seeking to maximize grain yield while minimizing GHG emissions per unit of grain produced. This treatment achieves the highest grain yield (6.11 t/ha) with the lowest per kg grain GHG emission (0.60 $kgCO_2eha^{-1}$) 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 T_3. While T_2 (application of recommended dose of N (60 kg N/ha) in three equal instalments – at transplanting (basal), active tillering, and PI through NCU) also provides high yield and relatively low GHG emission per kg grain, and its higher total GHG emissions make it less favorable than T_3. Conversely, although T_1 (Control – without nitrogen) has the lowest total GHG emissions, its lower grain yield and higher GHG emissions per kg of grain produced indicate it may not be as efficient for maximizing both productivity and sustainability. Therefore, it is recommended to focus on optimizing practices that align with T_3 to achieve the best balance between high yield and low environmental impact.

Disclaimer (Artificial intelligence)

Option 1:

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 the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

REFERENCES

[1] Adhikari R, Subedi R, Tripathi J K, Pandey SP, Ranjan S (2020). Nano-fertilizers for balanced crop nutrition: A review. Journal of Nanotechnology in Agriculture and Food, 18(4), 341-355.

[2] Zebarth BJ, Drury CF, Tremblay N, Cambouris AN (2009). Opportunities for improved fertilizer nitrogen management in production of arable crops in eastern Canada: A review. Canadian Journal of Soil Science, 89, 113-132.

[3] Chen D, Li Y, Zhang H, et al. (2020), Assessing the impacts of nitrogen application rates on yield and nitrogen use efficiency of summer maize under a drip irrigation system. PLoS One, 15(1): e0228040. doi: 10.1371/journal.pone.0228040

[4] Gong F, Liang Y, Wu X, et al. (2020). Nano-urea fertilizer reduced nitrogen leaching and improved nitrogen use efficiency in a wheat-maize rotation system. Sci. Rep., 10(1):18775. doi:10.1038/s41598-020-75694-2

[5] Gupta K, Kumar R, Baruah KK, Hazarika S, Karmakar S, Bordoloi N (2021). Greenhouse gas emission from rice fields: A review from Indian context. Environ. Sci. Pollut. Res., 28, 30551–30572

[6] Kumar R, Ritesh Kumar Singh, Annusuiya Panda and Sanjay Kumar Singh (2021). Nano Urea: An Efficient Tool for Precision Agriculture and Sustainability, *Vigyan Varta An International E-Magazine for Science Enthusiasts* E-ISSN: 2582-9467 Popular Article.

[7] Kumar Y, Tiwari, KN, Singh T and Raliya R (2021). Nano fertilizers and their role in sustainable agriculture. Annals of Plant and Soil Research, 23, 238-255

[8] Li H, Yu P, Li Y, et al. (2018). Nanotechnology-mediated immunoassays for pesticide residues: state of the art and future prospects. Trends Anal Chem.,103:1-12. doi: 10.1016/j.trac.2018.03.021

[9] Liu X, Zhang Y, Han W, Tang A, Shen J, Cui Z (2013). Enhanced nitrogen deposition over China. Nature, 494(7438),459-462. doi:10.1038/nature11917

[10] Llones C and Suwanmaneepong S (2021). Influence of perceived risks in farmer's decision towards sustainable farm practices. International Journal of Agricultural Technology, 17, 2143-2154.

[11] Chauhan N, Chauhan RP, Joshi M, Agarwal TK, Aggarwal P, Sahoo BK (2014). Study of indoor radon distribution using measurements and CFD modeling. Journal of Environmental Radioactivity, 136, 105-111

[12] Prasad R, Bhattacharyya A, Nguyen QD (2017), Nanotechnology in sustainable agriculture: Recent developments, challenges, and perspectives. Front. Microbiol., 8, 1014.

[13] Prasad R, Kumar V, Prasad KS (2014). Nanotechnology in sustainable agriculture: present concerns and future aspects. Afr. J. Biotechnol., 13(6), 705–713

[14] Ramesh T and Selvaraj R (2020). Evaluation of rice cultivation systems for greenhouse gases emission and productivity. Int. J. Ecol. Environ. Sci., 2, 49–54.

[15] Masum SM, Malek M, Mandal SH, Haque MN and Akther Z (2013). Influence of plant extracted pyroligneous acid on transplanted aman rice. Bangladesh Journal of Experimental Bioscience, 4, 31-34.

[16] Yan X, Jin D, Liu J, et al. (2018). High nitrogen use efficiency by application of slow-release urea with reduced nitrification inhibitor in intensive wheat-maize systems in North China Plain. Field Crop Res., 228, 34-43. doi: 10.1016/j.fcr.2018.08.001