Partial substitution of mineral fertilizers with cattle dung compost improves grain yield while reducing greenhouse gas emissions in irrigated lowland rice systems.

ABSTRACT:

The growing dependence on mineral fertilizers in irrigated rice production has raised production costs and increased greenhouse gas emissions, creating a need for more sustainable fertilization practices. This study explored whether part of the mineral fertilizer requirement could be replaced with cattle dung compost without reducing rice productivity or increasing greenhouse gas emissions. To address this objective, twelve fertilization strategies combining different rates of cattle dung compost, NPK fertilizer, and urea were compared under irrigated lowland conditions. Rice grain yield, together with CH_4, CO_2, and N_2O emissions, was monitored throughout the cropping cycle. Pearson's correlation and principal component analyses were then applied to better understand the links between crop performance and greenhouse gas emissions. Fertilization treatments significantly affected grain yield and greenhouse gas emissions ($P < 0.001$). The highest grain yield (9.60 t ha^{-1}) was achieved when 30 t $ha^{-1}$of cattle dung compost was used together with complete substitution of NPK fertilizer and a 67% reduction in urea application. In contrast, conventional mineral fertilization generated the highest emissions of CH_4, CO_2, and N_2O. Most treatments combining compost with mineral fertilizers reduced emissions while maintaining satisfactory rice yields. Although reductions in the three greenhouse gases were positively associated, their relationships with grain yield remained weak and were not statistically significant. Overall, the results suggest that integrating cattle dung compost into fertilization programs offers a practical way to maintain rice productivity while reducing greenhouse gas emissions in irrigated lowland systems.

Keywords:Cattle dung compost, Greenhouse gas mitigation, Organo-mineral fertilization, Rice yield, Lowland rice, Sustainable rice production

INTRODUCTION

Rice cultivation is one of the world's major agricultural activities and provides food for more than half of the global population (Alam et al., 2024). In West Africa, particularly in Côte d'Ivoire, rice plays a key role in food security. However, despite an annual per capita consumption estimated at 80-100 kg, national production remains insufficient to meet domestic demand, resulting in a heavy reliance on rice imports (African Climate Action Partnership, 2024).

In this context, irrigated lowland ecosystems represent a major opportunity for the sustainable intensification of rice production in West Africa. Owing to greater water availability and generally favorable soil conditions, these ecosystems can achieve higher yields than rainfed systems, provided that they are properly developed and managed (Rodenburg et al., 2014). Nevertheless, irrigated rice systems are among the major agricultural sources of greenhouse gas (GHG) emissions. Flooded rice fields promote methane (CH_4) emissions, whereas the intensive use of mineral nitrogen fertilizers, particularly urea, contributes substantially to nitrous oxide (N_2O) emissions, a greenhouse gas with a global warming potential 273 times greater than that of carbon dioxide (CO_2) (Chataut et al., 2023). Irrigated rice production therefore faces a dual challenge of sustainably increasing grain yield while reducing greenhouse gas emissions.

Among the various climate-smart agriculture (CSA) practices, organo-mineral fertilization has received increasing attention because of its potential to reconcile agronomic performance with environmental sustainability. It aims to sustainably improve agricultural productivity, enhance the resilience of production systems, and contribute to the mitigation of greenhouse gas emissions (Lipper et al., 2014). In this context, organo-mineral fertilization, which combines organic and mineral nutrient inputs, represents a promising strategy. Organic materials such as cattle dung are expected to improve the physical, chemical, and biological properties of the soil, stimulate microbial activity, and promote the gradual release of nutrients (Xu et al., 2025). Several studies have shown that well-managed organo-mineral fertilization can maintain or even increase rice yields while reducing CH_4 and N_2Oemissions (Liu et al., 2021; Van Groenigen et al., 2010; Zhou et al., 2017).

To the best of our knowledge, the effects of organo-mineral fertilization on the simultaneous emissions of CH_4, CO_2, and N_2O, as well as on rice yield under irrigated lowland conditions in Côte d'Ivoire, remain poorly documented. This lack of scientific information limits the development of fertilization strategies adapted to the country's agroecological conditions and the requirements of sustainable agriculture.The present study aimed to evaluate the effects of different organo-mineral fertilization treatments on CH_4, CO_2, and N_2Oemissions, as well as on the yield of rice grown in an irrigated lowland in southern Côte d'Ivoire. The relationships among fertilization treatments, greenhouse gas emission reductions, and agronomic performance were also investigated.

MATERIALS AND METHODS

Study site

The study was conducted in southern Côte d'Ivoire on an experimental plot located 1.4 km from Banco Forest and 50 m from a remnant of this forest preserved in its natural state within Nangui ABROGOUA University (UNA). The experiment was carried out in constructed plots designed to simulate irrigated lowland conditions. The study site is located between 5°17′ and 5°31′ N latitude and 3°45′ and 4°22′ W longitude. It is characterized by a deep sandy clay soil and a humid tropical climate with a mean annual temperature of approximately 27 °C. The experimental field had been left fallow for two years before the establishment of the experiment.

Experimental conditions

The study was conducted over two consecutive cropping seasons, from July to November in 2024 and 2025. To reproduce the hydrological conditions characteristic of irrigated lowlands, the experimental plots were designed to allow controlled water supply and maintenance throughout the entire cropping cycle. Following transplanting, a 3-cm water layer was maintained in the plots. The water depth was subsequently increased to 5 cm during the vegetative growth stage and maintained at this level until the beginning of panicle emergence. From panicle emergence onwards, the water level was gradually reduced until grain maturity to promote grain filling and maturation. Before the experiment was established, composite soil samples were collected from the topsoil layer (0-20 cm) to determine the main physicochemical characteristics of the experimental site. Soil analyses were performed according to standard laboratory procedures. The results are presented in Table 1.

Plant material

The plant material used in this study consisted of rice (*Oryza sativa* L.) seeds of the GT11 variety, supplied by the Agency for the Development of the Rice Sector (ADERIZ),Côte d'Ivoire. GT11 is an improved rice variety widely cultivated in Côte d'Ivoire, recognized for its desirable organoleptic characteristics (aroma and taste) and its adaptation to the country's rice production systems.

Experimental design

The experiment was established using a randomized complete block design (RCBD) comprising twelve fertilization treatments and three replicates, for a total of 36 experimental units. The treatments consisted of different combinations of cattle dung compost and mineral fertilizers, together with an unfertilized control (T0). Each experimental unit (plot) measured 2 m × 3 m × 0.5 m (width × length × depth), corresponding to a surface area of 6 m^2. The plots were separated by 1-m-wide alleys, while adjacent blocks were separated by a distance of 2 m. Rice seedlings were transplanted at a spacing of 20 cm × 20 cm between and within rows.

Preparation and characterization of composted cattle dung

Cattle dung was composted for six months in a pit measuring 90 cm in depth. The compost pile was regularly moistened and turned every two weeks to ensure uniform decomposition of the organic material. During the first six weeks, the internal temperature of the compost pile ranged from 55 to 65 °C, indicating an active thermophilic phase, before gradually declining to approximately 24 °C at the end of the composting process, indicating compost maturity. Before field application, the mature compost was cleared of coarse impurities. The main physical and chemical characteristics of the composted cattle dung are presented in Table 2.

Fertilization treatments

The fertilization treatments evaluated in this study included a reference mineral fertilization, an organic fertilization based on composted cattle dung, and different organo-mineral fertilization combinations. A total of twelve treatments were assessed, including an unfertilized control (T0). The fertilization treatments are described in Table 3. Composted cattle dung was incorporated into the soil during land preparation. The NPK fertilizer was applied as a basal application before sowing at a rate of 180 g $plot^{-1}$, corresponding to 300 kg ha^{-1} for the reference treatment (T1). Urea was applied at a rate of 90 g $plot^{-1}$ (150 kg ha^{-1}) in two equal split applications of 45 g $plot^{-1}$ each: the first at transplanting and the second between 30 and 40 days after transplanting (DAT). For treatments receiving the reduced urea rate (50 kg ha^{-1}), the fertilizer was also applied in two equal split applications following the same schedule.

Greenhouse gas measurement setup

Gas sampling was carried out using cylindrical static chambers with a diameter of 30 cm and a height of 150 cm, corresponding to an internal volume of approximately 0.106 m^3 (106 L) and a ground surface area of 0.0707 m^2. The chambers were fitted with airtight lids equipped with a valve connected to a portable S316 multi-gas detector (Henan Zhongan Electronic Detection Technology Co., Ltd.). The chamber bases were inserted 5-10 cm into the soil at least 24 h before the first gas measurement. Four rice plants were enclosed within each chamber installed in the experimental plots. Greenhouse gas measurements were conducted from 3 days after transplanting (DAT) until 2 weeks after harvest during both cropping seasons. The sampling frequency varied according to the crop growth stage. During the vegetative stage, gas concentrations were measured every 3 days until the flowering stage. From the onset of flowering, measurements were performed twice weekly to minimize disturbances associated with crop management operations. From physiological maturity until 1 month after harvest, gas concentrations were again measured at 3-day intervals.

Estimation of greenhouse gas emissions

The portable S316 multi-gas detector was used to directly measure methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) concentrations inside the static chambers. Gas concentrations were expressed in parts per million (ppm). The measured concentrations were subsequently converted into surface-based emissions (g m^{-2}) using the ideal gas law, taking into account the chamber volume, atmospheric pressure, air temperature, the molar mass of each gas, and the chamber surface area (Hutchinson and Livingston, 1993).

Grain yield and calculation of fertilizer and greenhouse gas emission reductions

Grain yield was determined by relating the total grain weight harvested to the cultivated area and was expressed in tons per hectare (t ha^{-1}). The percentage reduction in mineral fertilizer inputs was calculated using the fertilizer rates applied in the reference treatment (T1), consisting of 300 kg ha^{-1} of NPK and 150 kg ha^{-1} of urea, which represented 100% of the mineral fertilizer input. The percentage reduction was calculated as follows:

$$\text{Fertilizer reduction (\%)} = \frac{F_{T1} - F_i}{F_{T1}} \times 100 \quad (1)$$

where $F_{T1}$is the amount of fertilizer applied in the reference treatment (T1), and F_i is the amount of fertilizer applied in the treatment under consideration.

Subsequently, the percentage reduction in greenhouse gas (CH_4, CO_2, and N_2O) emissions was calculated using the treatment that recorded the highest emissions during the cropping season as the reference (T1: exclusive mineral fertilization), which was assigned a value of 100% (Linquist et al., 2012). The percentage reduction in greenhouse gas emissions was calculated using the following equation:

$$\text{Emission reduction (\%)} = \frac{E_{T1} - E_i}{E_{T1}} \times 100 \quad (2)$$

where $E_{T1}$is the greenhouse gas emission measured in the reference treatment (T1), and E_i is the greenhouse gas emission measured in the treatment under consideration.

Statistical analysis

Statistical analyses were performed using the Positron integrated development environment with R software version 4.5.2 (R Foundation for Statistical Computing, Vienna, Austria). A one-way analysis of variance (ANOVA) was conducted to evaluate the effects of the fertilization treatments on the percentage reductions in CH_4, CO_2, and N_2O emissions, as well as on rice grain yield. When treatment effects were significant, means were separated using the Newman-Keuls multiple comparisontest at the 5% significance level**.** Pearson's correlation analysis was then performed to examine the relationships between greenhouse gas emission reductions and rice grain yield. Finally, principal component analysis (PCA)was conducted to describe the relationships among fertilization treatments, the percentage reductions in CH_4, CO_2, and N_2O emissions, and rice grain yield.

RESULTS

Effect of reduced mineral fertilizer inputs on rice grain yield

Table 4 presents the cattle dung application rates, the percentages of NPK and urea input reductions, and the corresponding rice grain yields under the different fertilization treatments. Analysis of variance revealed a significant effect of fertilization treatment on rice grain yield ($p < 0.001$. The highest grain yield (9.60 t ha^{-1}) was obtained with treatment T3 (30 t ha^{-1} cattle dung compost, 100% reduction in NPK, and 67% reduction in urea). Treatments T10 (7.90 t ha^{-1}), T7 (7.80 t ha^{-1}), T5 (7.50 t ha^{-1}), T11 (7.30 t ha^{-1}), and T9 (7.20 t ha^{-1}) also produced high grain yields, although these were significantly lower than that of T3. In contrast, treatments T4 (6.50 t ha^{-1}), T1 (6.00 t ha^{-1}), and T6 (5.70 t ha^{-1}) recorded intermediate grain yields, whereas T2 (4.50 t ha^{-1}), T8 (4.00 t ha^{-1}), and the unfertilized control T0 (3.19 t ha^{-1}) produced the lowest grain yields.

Effect of fertilization treatments on greenhouse gas emissions

Methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) emissions under the different fertilization treatments are presented in Table 5. Fertilization treatments significantly affected the emissions of all three greenhouse gases ($p < 0.001$). Regardless of the gas considered, the exclusive mineral fertilization treatment (T1) produced the highest emissions, reaching 3.47 g m^{-2} forCH_4, 7.30 g m^{-2} for CO_2, and 0.11 g m^{-2} for N_2O. In contrast, the unfertilized control (T0) recorded the lowest emissions, with 0.47 g m^{-2} of CH_4, 1.18 g m^{-2} of CO_2, and no detectable N_2O emissions. Organic and organo-mineral fertilization treatments generally reduced the emissions of all three greenhouse gases compared with the mineral fertilization treatment. Methane emissions ranged from 1.49 to 2.80 g m^{-2}, with the highest values recorded for T9 and T10, whereas T7 and T8 exhibited the lowest CH_4 emissions. Carbon dioxide emissions under the organic and organo-mineral treatments ranged from 2.20 to 3.16 g m^{-2}, with the highest values observed for T9, T3, and T10. For N_2O, T9 and T10 produced the highest emissions (0.06 g m^{-2}) after the reference mineral treatment (T1), whereas T2, T3, T7, and T8 recorded the lowest emissions (0.02-0.03 g m^{-2}). Treatments T4, T5, T6, and T11 exhibited intermediate N_2O emissions, averaging approximately 0.04 g m^{-2}.

Effect of fertilization treatments on greenhouse gas emission reductions

The percentage reductions in CH_4, CO_2, and N_2Oemissions relative to the reference treatment (T1) are presented in Table 6. Fertilization treatments significantly affected the reductions in emissions of all three greenhouse gases ($p < 0.001$). The unfertilized control (T0) achieved the greatest emission reductions, reaching 91.00%, 86.33%, and 99.73% for CO_2, CH_4, and N_2O, respectively. Among the fertilized treatments, T7 and T8 exhibited the largest reductions in CH_4 emissions (56.57-68.24%), whereas T2, T3, T7, and T8 showed the greatest reductions in N_2O emissions (66.45-83.58%). In contrast, T9 and T10 exhibited the lowest reduction percentages for all three greenhouse gases, reflecting relatively higher greenhouse gas emissions than those recorded under the other organic and organo-mineral fertilization treatments.

Relationships among fertilization treatments, greenhouse gas emission reductions, and rice grain yield

Pearson correlation analysis

The Pearson correlation matrix is presented in Figure 1. Strong positive correlations were observed among the percentage reductions in CH_4, CO_2, and N_2O emissions, all of which were highly significant ($p < 0.001$). The reduction in CH_4 emissions was strongly correlated with the reductions in CO_2 ($r = 0.96$) and N_2O ($r = 0.91$) emissions. Likewise, a strong positive correlation was observed between the reductions in CO_2 and N_2O emissions ($r = 0.92$). In contrast, rice grain yield was negatively correlated with the reductions in CH_4 ($r = -0.49$), CO_2 ($r = -0.36$), and N_2O ($r = -0.35$) emissions. However, these correlations were not statistically significant ($p > 0.05$).

Principal component analysis (PCA)

The first two dimensions explained 96.85% of the total variance, with 77.21% explained by Dim1 and 19.65% by Dim2 (Figure 2). The vectors representing the percentage reductions in CH_4, CO_2, and N_2O emissions were oriented in a similar direction, whereas the vector corresponding to rice grain yield showed a different orientation. The fertilization treatments were distributed differently across the PCA biplot. Treatment T3 (30 t ha^{-1} cattle dung compost + 50 kg ha^{-1} urea) was projected in the upper part of the biplot, close to the grain yield vector. Treatments T5, T7, and T9 occupied intermediate positions on the PCA biplot. The unfertilized control (T0), together with T2 (30 t ha^{-1} cattle dung compost) and T8 (15 t ha^{-1} cattle dung compost + 175 kg ha^{-1} NPK), was projected on the positive side of Dim1, whereas T1 (300 kg ha$^{-1)}$) NPK + 150 kg ha^{-1} urea) was located on the negative side of this dimension. Treatments T4, T6, T10, and T11 remained clustered near the origin of the PCA biplot.

DISCUSSION

The present study achieved a maximum grain yield of 9.60 t ha^{-1}. This value was higher than those reported for several improved rice varieties cultivated in Côte d'Ivoire, including GT11 (5.03 t ha^{-1}), WITA9 (6.56 t ha^{-1}), and the hybrid variety AR043H (8.15 t ha^{-1}) reported by Kouadio et al. (2024). This yield was obtained with treatment T3, which combined 30 t ha^{-1} of cattle dung compost, complete elimination of NPK fertilizer, and a 67% reduction in urea application. These findings suggest that substantial reductions in mineral fertilizer inputs do not necessarily result in lower crop productivity when compensated by adequate organic matter inputs. The higher grain yield obtained with T3 may be attributed to the gradual release of nutrients from cattle dung compost, which ensures a more sustained nitrogen supply throughout the cropping cycle. This nutrient-release pattern promotes crop growth and improves nutrient use efficiency (Leogrande et al., 2024). In addition, organic matter improves the physical, chemical, and biological properties of the soil, thereby creating favorable conditions for rice growth (Liu et al., 2021). The relatively high grain yields obtained with treatments T5, T7, T9, T10, and T11 further confirmed that several organo-mineral fertilization combinations can sustain satisfactory rice production. In contrast, the low yields recorded under the unfertilized control (T0) and treatments T2 and T8 indicated that organic inputs alone do not always meet the nutritional requirements of a highly demanding crop such as rice.

Fertilization treatments also significantly affected CH_4, CO_2, and N_2O emissions. These findings are consistent with those reported by Slameto et al. (2024), who showed that combining organic and mineral fertilizers simultaneously improves rice yield while reducing CH_4 and N_2O emissions. The exclusive mineral fertilization treatment (T1) produced the highest emissions, indicating that intensive nitrogen fertilizer application stimulates the nitrification and denitrification processes responsible for N_2O production (Wang et al., 2024) and promotes CH_4 and CO_2 emissions (Chataut et al., 2023; Chen et al., 2021). Conversely, treatments incorporating cattle dung compost reduced the emissions of all three greenhouse gases compared with exclusive mineral fertilization. The lower emissions observed under the organic and organo-mineral treatments may be explained by several complementary mechanisms. Compost application improves soil structure and porosity, enhances biological activity, and increases plant nitrogen use efficiency, thereby reducing the amount of mineral nitrogen available to N_2O producing microorganisms (Charles et al., 2017). Furthermore, the relatively high C/N ratio (15.07) promotes temporary nitrogen immobilization, thereby limiting gaseous nitrogen losses (Liang et al., 2024). Similar findings were reported by Furukawa et al. (2021) and Park et al. (2024), who demonstrated that partially replacing mineral fertilizers with organic amendments significantly reduced N_2O emissions in rice paddies.

The analysis of greenhouse gas emission reductions confirmed the trends observed for absolute emissions. Although the unfertilized control (T0) achieved the greatest emission reductions, it also produced the lowest grain yield, highlighting that the absence of fertilization cannot ensure satisfactory crop production. Conversely, treatments T7 and T8 combined substantial reductions in greenhouse gas emissions, particularly for CH_4, whereas T2, T3, T7, and T8 achieved the greatest reductions in N_2O emissions. The relatively low emission reduction percentages observed for T9 and T10 may indicate that maintaining relatively high mineral fertilizer inputs limits the environmental benefits associated with organic amendments.

The multivariate analyses provided an overall view of the relationships among the variables investigated. The strong positive correlations observed among the reductions in CH_4, CO_2, and N_2O emissions indicate that management practices promoting the reduction of one greenhouse gas also tend to reduce the others, as previously reported by Chen et al. (2021) and Liang et al. (2024). In contrast, the negative correlations between grain yield and greenhouse gas emission reductions remained non-significant, suggesting that reducing greenhouse gas emissions does not necessarily compromise crop productivity. The PCA results further supported these findings. The close proximity of the vectors representing the reductions in CH_4, CO_2, and N_2O emissions confirmed their strong association, whereas the different orientation of the grain yield vector reflected a distinct response pattern. The distribution of treatments on the PCA biplot also highlighted their respective performance profiles. Treatment T3 was associated with the highest grain yield, whereas the unfertilized control (T0) together with T2 and T8 was more closely associated with greater greenhouse gas emission reductions. Treatments T5, T7, and T9 occupied intermediate positions, illustrating a compromise between agronomic performance and environmental performance.

Overall, these findings demonstrate that the partial substitution of mineral fertilizers with cattle dung compost represents a promising strategy for improving the sustainability of irrigated rice production systems. Treatment T3 emerged as the best compromise between productivity and reduced mineral fertilizer inputs by achieving the highest grain yield while maintaining substantially lower greenhouse gas emissions than the exclusive mineral fertilization treatment. These findings are consistent with those reported by Iboko et al. (2023), who showed that integrating organic amendments into fertilization strategies limits greenhouse gas emissions while maintaining high crop productivity.

CONCLUSION

Les résultats de cette étude montrent que l'intégration de compost de bouse de bovin à une réduction des apports en engrais minéraux permet de maintenir une production élevée de riz tout en limitant les émissions de gaz à effet de serre. Parmi les stratégies de fertilisation évaluées, l'application de 30 t ha^{-1} de compost de fumier bovin, associée à une suppression totale du NPK et à une réduction de 67 % de l'urée (T3), a permis d'obtenir le rendement en grains le plus élevé tout en réduisant sensiblement les émissions de CH_4, de CO_2 et de N_2O par rapport à la fertilisation exclusivement minérale. Les analyses de corrélation et l'analyse en composantes principales ont également montré que la fertilisation organo-minérale constitue un bon compromis entre performance agronomique et performance environnementale. Ces résultats suggèrent que la substitution partielle des engrais minéraux par du compost de fumier bovin représente une stratégie prometteuse pour améliorer la durabilité des systèmes de production du riz tout en contribuant à l'atténuation du changement climatique. Des études complémentaires menées dans différents contextes agroécologiques et sur plusieurs campagnes culturales permettront de confirmer la durabilité de cette stratégie de fertilisation.

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DECLARATION OF INTEREST STATEMENT

The authors report there are no competing interests to declare.

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TABLES

Table 1. Initial chemical properties of the experimental soil

Parameter	Value
Total carbon (%)	1.69
Total nitrogen (%)	0.14
C/N ratio	12.1
Available N (mg ha^{-1})	10
Total P (mg ha^{-1})	126
Available P (mg ha^{-1})	24
Exchangeable K (mg ha^{-1})	58.52
Exchangeable Na (mg ha^{-1})	123.20
Exchangeable Ca (mg ha^{-1})	350.56
Exchangeable Mg (mg ha^{-1})	42.32
Total Fe (mg ha^{-1})	6717
Cation exchange capacity (cmolc kg^{-1})	1.903
Soil pH (H_2O)	5.7

Table 2. chemical and Physical characteristics of the cattle dung compost

Mineral element	Value
Total carbon (%)	20.5
Total nitrogen (%)	1.36
C/N ratio	15.07
Nitrate (mg ha^{-1})	15
Nitrite (mg ha^{-1})	0.27
Ammonium (mg ha^{-1})	5.41
Phosphate (mg ha^{-1})	65.0
Potassium (mg ha^{-1})	1667.59
Sulfate (mg ha^{-1})	180.26
Calcium (mg ha^{-1})	29.32
Magnesium (mg ha^{-1})	12.14
Sodium (mg ha^{-1})	129.1
Iron (mg ha^{-1})	3.52
Copper (mg ha^{-1})	0.08
Manganese (mg ha^{-1})	0.08
pH	7.8

Table 3. Application rates of cattle dung compost, NPK fertilizer, and urea across the different treatments

Treatment	Cattle dung compost ($t\ ha^{-1}$)	NPK fertilizer ($kg\ ha^{-1}$)	Urea ($kg\ ha^{-1}$)
T0	0	0	0
T1	0	300	150
T2	30	0	0
T3	30	0	50
T4	30	175	0
T5	20	0	50
T6	20	175	0
T7	15	0	50
T8	15	175	0
T9	30	175	50
T10	20	175	50
T11	15	175	50

Table 4. Effects of cattle dung compost application and mineral fertilizer reduction on rice grain yield

Treatment	Cattle dung compost ($t\ ha^{-1}$)	NPK reduction (%)	Urea reduction (%)	Grain yield ($t\ ha^{-1}$)
T0	0	100	100	3.19±0.01^{h}
T1	0	0	0	6±1.41^{e}
T2	30	100	100	4.5±0.47^{f}
T3	30	100	67	9.6±2.19^{a}
T4	30	42	67	6.5±1.64^{d}
T5	20	100	67	7.5±1.41^{bc}
T6	20	42	100	5.7±0.61^{d}
T7	15	100	67	7.8±1.63^{b}
T8	15	42	100	4±0.35^{g}
T9	30	42	67	7.2±1.43^{c}
T10	20	42	67	7.9±1.70^{b}
T11	15	42	67	7.3±1.51^{c}
P-value				< 0.001

Values are means ± standard deviation. Within the same column, means followed by the same letter are not significantly different according to the Newman-Keuls test at the 5% significance level. T0: unfertilized control; T1: mineral fertilization; T2-T11: organic and integrated organic-mineral fertilization treatments.

Table 5. Mean greenhouse gas emissions under the different fertilization treatments

Treatment	CH_4 (g m^{-2})	CO_2(g m^{-2})	N_2O (g m^{-2})
T0	0.47±0.23^{k}	1.18±0.07^{h}	0.00±0.00^{g}
T1	3.47±1.22^{a}	7.30±0.13^{a}	0.11±0.04^{a}
T2	2.11±1.05^{h}	1.76±0.36^{g}	0.02±0.00^{f}
T3	2.56±1.26^{e}	3.07±0.050^{bc}	0.03±0.00^{e}
T4	2.38±1.17^{d}	3.02±0.053^{c}	0.04±0.00^{d}
T5	2.31±1.14^{f}	3.02±0.05^{c}	0.04±0.01^{d}
T6	1.99±1.46^{i}	2.56±0.26^{e}	0.04±0.00^{d}
T7	1.54±1.25^{j}	2.83±0.40^{d}	0.03±0.00^{e}
T8	1.49±1.22^{j}	2.20±0.08^{f}	0.03±0.00^{e}
T9	2.80±1.37^{b}	3.16±0.06^{b}	0.06±0.03^{b}
T10	2.66±1.31^{c}	3.06±0.05^{bc}	0.06±0.03^{b}
T11	2.22±1.10^{g}	2.95±0.07^{d}	0.04±0.02^{cd}
P-value	< 0.001	< 0.001	< 0.001

Values are means ± standard deviation. Within the same column, means followed by the same letter are not significantly different according to the Newman-Keuls test at the 5% significance level. CH_4: methane; CO_2: carbon dioxide; N_2O: nitrous oxide. T0: unfertilized control; T1: mineral fertilization; T2-T11: organic and integrated organic-mineral fertilization treatments.

Table 6. Percentage reduction in methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) emissions under the different fertilization treatments

Treament	CH_4 reduction (%)	CO_2 reduction (%)	N_2O reduction (%)
T0	86.33±0.01[a]	91±0.08[a]	99.73±0.01[a]
T1	00	00	00
T2	43.16±0.11[d]	51.5±0.35[c]	83.58±2.19[b]
T3	41.41±2.04[e]	49.74±0.77[d]	66.45±2.89[e]
T4	32.37±0.75[g]	47.59±0.22[e]	45.2±3.54[h]
T5	38.5±1.45[f]	43.6±0.75[f]	57.35±2.13[f]
T6	43.68±3.54[d]	41.42±0.28[g]	46.34±2.83[h]
T7	56.57±2.14[c]	69.5±0.41[b]	74.67±2.89[c]
T8	68.24±1.42[b]	70.79±0.37[b]	71.47±2.84[d]
T9	17.71±7.06[i]	26.69±0.15[h]	36.26±2.85[j]
T10	24.31±4.24[h]	43.48±0.33[f]	41.89±2.12[i]
T11	38.04±5.02[f]	52.61±0.53[c]	50.03±2.19[g]
P-value	< 0.001	< 0.001	< 0.001

Values are means ± standard deviation. Within the same column, means followed by the same letter are not significantly different according to the Newman-Keuls test at the 5% significance level. CH_4: methane; CO_2: carbon dioxide; N_2O: nitrous oxide. T0: unfertilized control; T1: mineral fertilization; T2-T11: organic and integrated organic-mineral fertilization treatments.

FIGURES

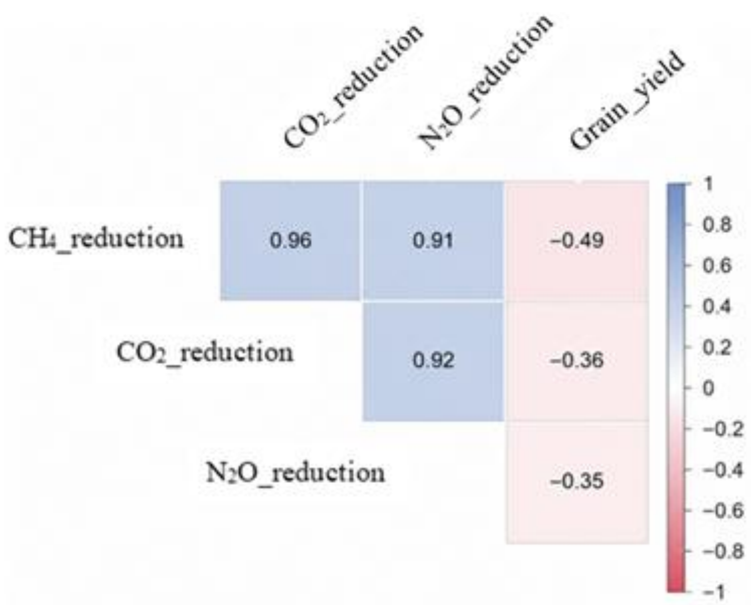
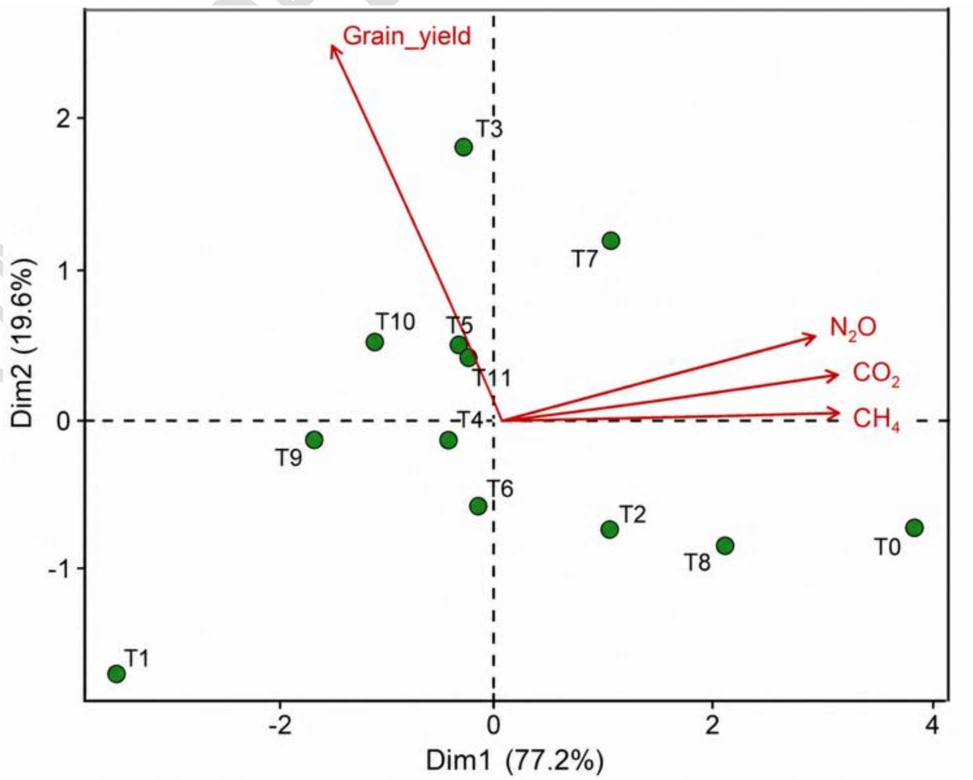


Figure 1. Pearson correlation matrix between greenhouse gas emission reductions (CH_4, CO_2 and N_2O) and rice grain yield.



Grain_yield
T3
T7
T10
T5
T11
N$_2$O
CO$_2$
CH$_4$
T4
T9
T6
T2
T8
T0
T1
Dim2 (19.6%)
Dim1 (77.2%)
2
1
0
-1
-2
0
2
4

Figure 2. Principal component analysis (PCA) biplot of reductions in greenhouse gas emissions, grain yield, and fertilizer treatments. CH_4, methane; CO_2, carbon dioxide; N_2O, nitrous oxide. T0 = control; T1 = 300 kg ha^{-1} NPK + 150 kg ha^{-1} urea; T2 = 30 t ha^{-1} cattle dung compost; T3 = 30 t ha^{-1} cattle dung compost + 50 kg ha^{-1} urea; T4 = 30 t ha^{-1} cattle dung compost + 175 kg ha^{-1} NPK; T5 = 20 t ha^{-1} cattle dung compost + 50 kg ha^{-1} urea; T6 = 20 t ha^{-1} cattle dung compost + 175 kg ha^{-1} NPK; T7 = 15 t ha^{-1} cattle dung compost + 50 kg ha^{-1} urea; T8 = 15 t ha^{-1} cattle dung compost + 175 kg ha^{-1} NPK; T9 = 30 t ha^{-1} cattle dung compost + 175 kg ha^{-1} NPK + 50 kg ha^{-1} urea; T10 = 20 t ha^{-1} cattle dung compost + 175 kg ha^{-1} NPK + 50 kg ha^{-1} urea; T11 = 15 t ha^{-1} cattle dung compost + 175 kg ha^{-1} NPK + 50 kg ha^{-1} urea.