BAMBOO BIOCHAR APPLICATION MITIGATES CH_4 AND N_2O EMISSIONS FROM A RICE PADDY

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ABSTRACT

Biogas production from livestock production is very common in rural areas in the Mekong Delta. Biogas effluent is an excellent organic fertilizer for rice cultivation. Since the effluent contains labile organic carbon, the substrate for microbial CH_4 production, there is concern that the waterlogged soil will transmit more gases (CH_4) under reductive conditions. Therefore, in this study, the option of combining wastewater after biogas and bamboo biochar was proposed to reduce greenhouse gas in rice fields. A greenhouse potted experiment with six treatments was set up, with the soil supplemented with bamboo biochar ranging from 2 to 20 tons/ha and post-biogas wastewater used instead of chemical fertilizers. According to the study results, all treatments that include bamboo biochar had a reduction in CH_4 emissions of 20% to 46% compared to the control. Simultaneously, N_2O emissions were reduced by up to 44%. Finally, bamboo biochar reduced greenhouse gas emissions by 35.9 - 45.6% (in CO_2 equivalent).

ỨNG DỤNG THAN SINH HỌC TRE LÀM GIẢM PHÁT THẢI CH_4 VÀ N_2O TRÊN RUỘNG LÚA

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TỪ KHÓA

Than sinh học tre
Nước thải biogas
CH_4
N_2O
Ruộng lúa

TÓM TẮT

Sản xuất khí sinh học từ chất thải chăn nuôi rất phổ biến ở các vùng nông thôn Đồng bằng sông Cửu Long. Nước thải sau biogas còn được tận dụng như một nguồn phân bón hữu cơ cho cây lúa. Tuy nhiên, nước thải sau biogas có chứa hàm lượng cacbon hữu cơ không bền cao có tác dụng như chất nền giúp vi sinh vật sản xuất khí CH_4 nên đã dẫn đến lo ngại rằng dùng nước thải sau biogas bón cho lúa sẽ sinh ra nhiều khí CH_4. Vì vậy, nghiên cứu này kết hợp nước thải sau biogas và than sinh học tre nhằm làm giảm phát thải khí nhà kính trên ruộng lúa. Một thí nghiệm trong chậu đã được thiết lập trong điều kiện nhà lưới bao gồm sáu nghiệm thức, trong đó đất được bổ sung than sinh học tre từ 2 đến 20 tấn/ha và nước thải sau biogas được sử dụng thay cho phân bón hoá học. Theo kết quả nghiên cứu, tất cả các nghiệm thức được bổ sung than tre có lượng phát thải khí CH_4 giảm từ 20% đến 46% so với nghiệm thức đối chứng. Đồng thời, lượng khí thải N_2O cũng giảm tối đa đến 44%. Việc bổ sung than sinh học tre đã làm giảm 35,9-45,6% phát thải khí nhà kính (tính theo CO_2 tương đương).

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1. Introduction

It is possible to use nitrogen-rich livestock waste as crop fertilizer, which is a promising technology that solves the problems of eutrophication and water pollution while also helping to reduce the use of inorganic fertilizers [1]. In the Mekong Delta, a study was conducted to use waste water from biogas composting as organic fertilizer for rice (rice variety OM5451), and the results show that when the total nitrogen use rate in wastewater ranges between 90 and 210 kg/ha/rice crop, rice growth and yield are comparable to treatment with inorganic fertilizers [2]. However, the utilization of biogas wastewater as a source of organic nitrogen has the potential to increase greenhouse gas emissions [3]. Because the effluent contains labile organic carbon, the substrate for microbial CH_4 production, there is concern about increased methane (CH_4) emission from the flooded soil under reductive conditions. As a result, this research will continue to clarify the effects of biogas wastewater on greenhouse gas emissions and look for ways to reduce gas emissions by incorporating biochar increasing crop yields and lowering greenhouse gas emissions [4]. According to a review of the literature, biochar is an effective tool for lowering greenhouse gas emissions. As stated by Xiao et al. [5] adding 600^{o}C straw biochar to rice land under water-saving conditions reduced CH_4 emissions by 15.6-29.7%. Moreover, Xiao et al. [5] surveyed when adding biochar at the rate of 20 tons/ha, the emission reduction performance is equivalent to the rate of 40 tons/ha. However, several studies have shown that the use of biochar did not make a significant difference in CH_4 flux between soil treated with biochar at a rate of 24 tons/ha and subtropical acid forest soils. Additionally, the study of Qin et al. [6], showed that combining suitable fertilizers and biochar can cut N_2O emissions by 17-39%. Oo et al. [7] reported that when using bamboo biochar at rates of 0.5%, 1%, and 2% in potted experiments, they reduced the amount of N_2O gas released by 38%, 48%, and 61%, respectively. A similar study found that combining biochar with sludge at a biochar concentration of 3% reduced N_2O emissions by 47% [8]. Therefore, this study continued to investigate the impact of bamboo biochar on CH_4 and N_2O emissions in rice fields, as well as the use of biogas wastewater instead of chemical fertilizers.

2. Method

2.1. Research instrument in the experiment

Bamboo biochar: The biochar sample used in this study was produced from bamboo (*Bambusa blumeana*) that was collected from Chau Thanh district, An Giang province. The bamboo trees were washed and chopped into pieces of 1 mm size and sawed to powder by electric mills. Next, the samples were air dried until constant weight. The dried biomass then was pyrolysed in a furnace (VFM165, Yamada Denki, Tokyo, Japan) at 700°C, with a fixed residence time of 2h. Table 1 lists the primary properties of biochar.

Table 1. *Bamboo biochar properties at 700 ^oC* [9]

Yield (%)	Fixed carbon content (wt.%$_{db}$)	CEC (cmolc/kg)	C/N	pH	EC (µS/cm)	BET	Moisture (wt.%)	Ash content (%)
28.4	55.1	14	136.4	9.3	323.3	357.5	5.5	<13

The biogas wastewater: This wastewater used in the experiment was collected from compost bags that contained an average of 7.5-9.5 kg of pig manure per day. The incubation bag is now operational and producing stable gas. As mixed samples, wastewater samples collected in the middle of the day (10-11 p.m.) after incubation bags were used. Prior to the experiment, a representative sample was taken to analyze physical and chemical parameters. The following parameters were found in wastewater after biogas bags: pH (7.31), EC (3.68 mS/cm), TN (477 mg/L), TP (126 mg/L), and total K (98 mg/L).

Soil: soil samples were collected on rice cultivation land for more than 10 years, at a depth of 20 cm, in Binh Minh district, Vinh Long province. The soil is classified as silty clay, consisting of 40.48% clay, 59.09% alluvium, and 0.43% sand. The main soil properties include: pH (1: 2.5 H_2O) 6.87, EC (1: 2: 5 H_2O) 217.5 S, organic matter (OC) content 2.99%, total N 0.335%, total P 0.091%, total K 1.33%, density 0.86 g/cm^3, density 1.56 g/cm^3, porosity 44.65%.

The rice used in the experiment was OM 5451, which was purchased from the Mekong Delta Rice Institute. This is a high-yielding rice variety with excellent resistance to brown planthopper and blast.

Plastic pots: The diameter and height of the plastic pots were 25 x 20 cm. The required land surface area for tree planting was 0.042 m^2.

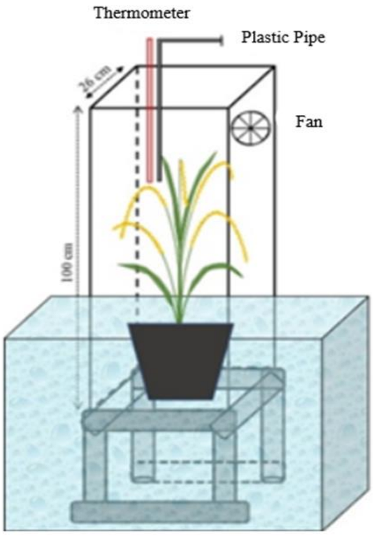

Figure 1. *The gas collection model on rice*

Chamber designed to collect samples of CH_4 and N_2O consists of two parts: (1) Chamber base: made of plastic pipe with a diameter of 21 cm and dimensions of 26 x 26 x 20 cm. (2) Air collection chamber: made of opaque white plastic, box-shaped, with dimensions of length x width x height of 26 x 26 x 100 cm, volume of 62.87 L. The air chamber is attached with a thermometer (range from 0–100^{o}C) to measure the temperature of the inside air of the chamber, a small fan for mixing the outside air connected to a 9V battery, a plastic air collector with a diameter of 4.8 mm and a length of 60 cm, the tube inside the barrel is 40 cm long and the outside is 20 cm long, connected to a 60 mL syringe (Figure 1). The syringe tip connects to a 3-way valve that is connected to a 2.5 m fine needle tip for gas sampling.

Table 2. *Layout experiment*

Symbol	Tre	Biochar weight (g/pot)	Total biogas volume (*) (mL/pot)
Tre 1	Control (tap water only)	_	_
Tre 2	Soil + bamboo biochar (2 tons/ha)	8.4	_
Tre 3	Soil+biogas (no biochar)	_	1320
Tre 4	Soil+biogas+bamboo biochar (2 tons/ha)	8.4	1320
Tre 5	Soil+biogas+bamboo biochar (10 tons/ha)	42	1320
Tre 6	Soil+biogas+bamboo biochar (20 tons/ha)	84	1320

The experiment was arranged in a completely randomized design with six treatments and four replications as shown in Table 2. Biogas wastewater with a high nitrogen concentration was used to replace chemical fertilizers. The water level in the pots was calculated based on the data of Minamikawa et al. [2] and maintained at 4 cm to ensure suitable conditions for rice growth. The amount of evaporated water was replenished daily with tap water (pH = 6.80 and EC = 42.5 µS/cm). Bamboo biochar was added to the soil at a rate of 2 to 20 tons per hectare.

2.3. Measurement of CH_4 and N_2O fluxes

During the growing period, CH_4 and N_2O were measured using closed static chambers, as described in [10]. Each pot contained one of these chambers. Gas samples were collected from the chamber headspace with a 60 mL plastic syringe equipped with a 3-way stopcock at 0, 10, and 20 minutes after chamber deployment and stored in 20 mL pre-evacuated vacuum vials crimped with butyl rubber lids and aluminum crowns. Gas samples were collected once a week between the hours of 8:00 and 11:00 am. The collected gas samples were immediately transferred to butyl rubber septum-sealed bags and transported to the laboratory (Cuu Long Delta Rice Research Institute, Can Tho) for analysis of CH_4 and N_2O. The levels of CH_4 and N_2O were measured using a gas chromatography (SRI 8610C) equipped with a flame ionization detector (FID) and an electron capture detector (ECD).

The gas fluxes were calculated by the formula (1) [10]:

$$\mathrm{f} = \left(\frac{\Delta C}{\Delta t}\right) * \left(\frac{v}{A}\right) * \left(\frac{M}{V}\right) * \left(\frac{P}{P_0}\right) * \left(\frac{273}{T_{kelvin}}\right) \quad (1)$$

where F is the gas flux (mg CH_4/N_2O m^2/ h), ΔC the change in the concentration of gas of interest in the time interval Δt, v the chamber volume (L), A the soil surface area (m^2), M the molecular mass of the gas of interest, V the molecular volume occupied by 1 mol of the gas (L/ mol) at standard temperature and pressure, P the barometric pressure (mbar), P_0 the standard pressure (1013 mbar) and T the average temperature inside the chamber during the deployment time.

The cumulative CH_4 and N_2O emissions were calculated by the formula (2) [10]:

$$CH_4/N_2O = (n_2 - n_1) * \frac{(F_{n1} + F_{n2})}{2} + (n_3 - n_2) * \frac{(F_{n2} + F_{n3})}{2} + \cdots + (n_c - n_x) * \frac{(F_{nc} + F_{nx})}{2} \quad (2)$$

where n_1, n_2 and n_3 are the dates of the first, second and third sampling, n_x is the date of the last sampling and n_c is the date before the last sampling. Fn_1, Fn_2, Fn_3, and Fn_x are the fluxes of the gas of interest at the n_1, n_2, n_3, nx and tn sampling day.

The total amount of greenhouse gas emissions is calculated using the formula:

$$\text{GWP (kg } CO_{2eq}\text{ /ha)} = CH_4 \text{ emissions x 25} + N_2O \text{ emissions x 298} \quad (3)$$

3. Results and discussion

3.1. The influence of bamboo biochar on soil parameters

Effects of the evaluated bamboo biochar on several soil porosity are represented in Table 3.

Table 3. *Effect of bamboo biochar on pH, Eh, OM, and soil porosity*

Tre	pH	Eh (mV)	OM (%)	Porosity (%)
Tre 1	6.89 ± 0.02^c	-251.75 ± 25^a	3.35 ± 0.50^b	43.66 ± 0.04^d
Tre 2	7.06 ± 0.17^c	-248.50 ± 17^a	3.69 ± 0.00^{ab}	45.46 ± 0.20^c
Tre 3	7.10 ± 0.23^c	-386.00 ± 12^b	3.56 ± 0.05^{ab}	32.59 ± 0.01^f
Tre 4	7.37 ± 0.09^b	-296.00 ± 10^a	3.52 ± 0.05^{ab}	40.57 ± 0.09^e
Tre 5	7.52 ± 0.12^{ab}	-272.00 ± 38^a	3.79 ± 0.00^{ab}	47.11 ± 0.02^b
Tre 6	7.73 ± 0.07^a	-256.00 ± 20^a	3.86 ± 0.05^a	52.65 ± 0.07^a

In Table 3, the symbols a, b, and c in the same column indicate that there is a difference between Tres through Duncan's test at a 5%. Tre 1 = control; Tre 2 = biochar weight (2 tons/ha); Tre 3 = biogas irrigation without biochar; Tre 4 = biogas irrigation with biochar weight (2 tons/ha); Tre 5 = biogas irrigation with biochar weight (10 tons/ha); Tre 6 = biogas irrigation with biochar weight (20 tons/ha).

The lowest pH was found in control (pH = 6.9), whereas the soil pH in the bamboo biochar treatment ranged from 7.1 to 7.7 (Table 3). The soil pH in the Tre supplemented with biochar at a rate of 20 tons/ha (Tre 6) was nearly 1 unit higher than in the control (Tre 1). This result showed that bamboo biochar had the effect of increasing soil pH. The addition of alkaline materials (700˚C bamboo biochar with pH = 9.3) and the use of biochar reduced the exchangeable aluminum content of the soil through Al^{3+} ion binding. This increased the abundance of exchangeable base cations in the soil, which ultimately leads to an increase in soil pH [11]. The findings of the current study were consistent with those of Rhoades et al [12]. Rhoades reported that using biochar at a rate of 20 tons/ha increased the pH of forest soils from 5.7 to 7.7.

The soil Eh value remained in the range (-386) - (-251) mV throughout the study (Table 3), indicating that this was a favorable condition for CH_4 emissions. In which the Eh value in the treatment of biogas application (Tre 3) was (-386) mV, lower than the Eh value in the Tre without biogas application (Tre 1), indicating that the application of biogas wastewater has reduced the Eh of the soil. This result was similar to Singla and Inubushi [3]. Furthermore, after adding biogas wastewater to treatment supplemented with bamboo biochar at rates ranging from 2 to 20 tons/ha, Eh increased from 1.2 to 1.4 times that of the biogas irrigation treatment (Tre 3). This demonstrated that the use of biochar increased Eh in the soil when compared to the soil without biochar. This suggests that biochar was a critical fundamental factor in controlling anaerobic CH_4 oxidation activity [13], [14].

The current study found that using biogas and biochar increased the organic matter content of the soil slightly (Table 3). The OM content of the biogas irrigation treatment (Tre 3) was 3.56% higher than the non-biogas treatment (Tre 1). Furthermore, after applying biogas to soil that had been mixed with a high rate of bamboo biochar (20 tons/ha), the organic matter content in the soil increased to 3.86%. This result demonstrated that high doses of biochar lead to an increase in the organic content of the soil. The findings are similar to those of Bruun [8], who found that adding 2–6 g of biochar per 200 g of soil increased organic matter content during a 55-day placement experiment. Similarly, Xiao et al. [5] found that adding biochar at rates of 20 tons/ha and 40 tons/ha increased organic matter content in soil by 2-3 times when compared to the control sample.

Table 3 shows that the biogas irrigation treatment (Tre 3) had the lowest soil porosity (39.95%), while the biogas and bamboo biochar Tres have soil porosities ranging from 43.96 to 52.65%. The findings show that bamboo biochar improves soil porosity and aeration. This was explained by the fact that adding biochar to the soil increases the abundance of macro- and micro-pores by 4 to 27% and 11 to 54%, respectively, and by the rearrangement of soil particles after biochar addition [13]. Similarly, Cayuela et al. [14], Xiao et al. [5], Dereje Dejene and Eyob Tilahun [15] concluded that biochar addition increased soil porosity and aeration.

3.2. Effect of bamboo biochar on CH_4 emissions in soil

Figure 2 showed that the CH_4 emission rates of the treatment ranged from 0.7 $mg/m^{-2}/h$ to 42 $mg/m^2/h$ and were classified into three major stages. In stage 1 (from day 3 to day 10), the rate of CH_4 emission was very low (0.7-2.9 $mg/m^2/h$) and there was no significant difference between Tres ($p > 0.05$). In stage 2 (from day 10 to day 31) the amount of CH_4 emitted was very high, peaking on day 31. The intensity of CH_4 emissions was highest in Tre 3 (the biogas-irrigated treatment without biochar) and lowest in Tre 6 (irrigated with biogas and 20 tons of bamboo biochar) ($p < 0.05$).

In stage 3 (from 31 to 38), the rate of CH_4 emissions tends to decrease. On day 38, Tre 3 had the highest average emissions (32.45 $mg/m^2/h$), while Tre 6 had only 6.05 $mg/m^2/h$ ($p<0.05$). In general, total CH_4 emissions decreased by 20%-46% in all Tres supplemented with biochar when compared to Tre 3. Among them, Tre 6 was the treatment supplemented with bamboo biochar with the highest rate (20 tons/ha) and the lowest total CH_4 emission of 10 $g/m^2/day$. However, total CH_4 emissions in Tre 4, Tre 5 (2–10 tons of bamboo biochar/ha) were not different (p>0.05). This demonstrates that the biochar mixing ratio affects the ability to reduce greenhouse gases. Bruun [8] also made similar observations.

Figure 2 showed that adding bamboo biochar at a rate of 20 tons per hectare had the greatest effect on lowering CH_4 emissions by 47.1%. A similar trend was found by Jeffery et al. [16], who presented that biochar addition to wetlands or acidic soils has the potential to significantly reduce CH_4 emissions. Additionally, Sudibandriyo and Oratmangun [17] used bamboo biochar to adsorb CH_4 emissions, but the efficiency was only 21.5%. Moreover, Xiao [5] discovered that straw biochar significantly reduced CH_4 emissions by 29.7% and 15.6%, respectively, at supplement levels of 20 tons/ha and 40 tons/ha. The results of this study, after comparing with some previous studies, found that bamboo biochar has the ability to reduce CH_4 emissions very well. This difference could be attributed to the influence of the biochar's burning temperature, the amount of biochar added, and the type of soil used.

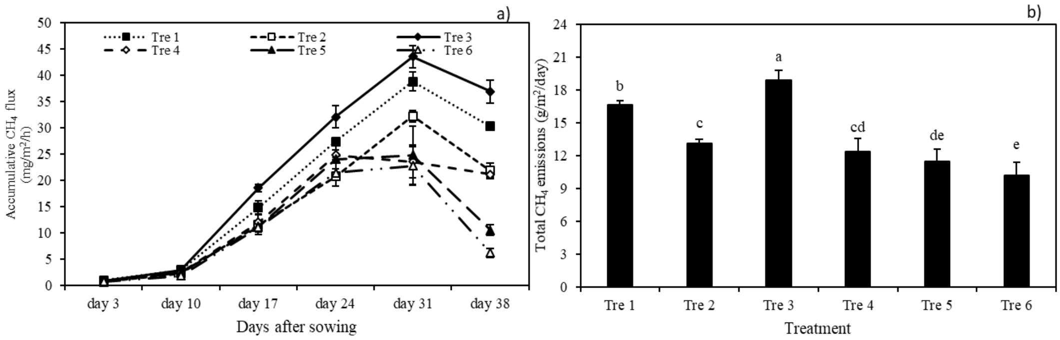

Figure 2. *Emission intensity (a) and total CH_4 emissions (b) on continuously flooded rice*

Note: The symbols a, b, and c in the columns indicate that there is a difference between Tres through Duncan's test at a 5%. Tre 1 = control; Tre 2 = biochar weight (2 tons/ha); Tre 3 = biogas irrigation without biochar; Tre 4 = biogas irrigation with biochar weight (2 tons/ha); Tre 5 = biogas irrigation with biochar weight (10 tons/ha); Tre 6 = biogas irrigation with biochar weight (20 tons/ha).

It is clear that the addition of bamboo biochar reduced total CH_4 emissions by changing soil properties such as pH, Eh, and OC (Table 3). The soil pH in the Tres supplemented with biochar at rates of 2 tons/ha, 10 tons/ha, and 20 tons/ha was significantly higher than in the control Tre (Tre 1, Tre 3). Because increasing soil pH can suppress methanogenic activity and lead to a reduction in CH_4 emissions, it has a large influence on methane-producing microbial activity [18]. According to Wang [19] methane formation is affected by both high and low pH. Most methane-producing microorganisms thrive in pH ranges of 6.9–7.1 [20]. Moreover, table 3 showed that the pH in the biochar-supplemented Tres exceeded the optimal activity threshold of methane-producing microorganisms, resulting in a decrease in CH_4 production.

Furthermore, Eh is a significant factor influencing CH_4 emissions as well as soil aeration. Table 3 showed the change in soil Eh after adding biochar to Tre 4, Tre 5, and Tre 6. After adding biochar he oxygen content increased, resulting in an increase in soil Eh and favorable conditions for heterotrophic organisms in the soil to work, as well as lower CH_4 emissions. This result was consistent with previous research by Cayuela, Oda, and Nguyen, Wang [21]–[23], who also found that CH_4 oxidation was significantly correlated with soil Eh. Supplementing with bamboo biochar yielded 2–20 tons/ha and significantly reduced CH_4 emissions in the current study.

The OC content is another factor that influences CH_4 emissions [21]. The current study found that adding biochar to the soil increased the OC content (Table 3). Although organic matter is the source of CH_4, methanogenic bacteria find it difficult to utilize the stable carbon source in biochar. This result is consistent with the findings of Liu et al. [24] and Xiao et al. [5]. The negative correlation between CH_4 and OC emissions suggests that biochar addition increases reoxidation capacity in the biosphere, which may inhibit CH_4 production [6]. The study's findings, however, contradict the findings of Wang et al, who reported that adding 300°C biochar to soil increased total CH_4 emissions and contributed to the enhancement of soil OC content, indicating that there is still debate about biochar's ability to reduce CH_4 emissions. The difference in CH_4 emission Tre efficiency can be attributed to the type of raw material used to create biochar as well as the pyrolysis temperature of biochar, because biochar fired at high temperatures has a higher fixed carbon content.

3.3. The role of bamboo biochar on N_2O emissions

Unlike CH_4, N_2O emitted a very low amount of 0.34-1.36 mg/m^2/h during the 38-day experiment. The experiment was set up in continuously flooded conditions, which caused this difference. The Eh value fluctuates continuously between (-386) and (-251.75) mV (Table 3), resulting in very little N_2O production (Figure 3). Because N_2O forms primarily in environments with an Eh of (+200)-(+400) mV, N_2O is completely reduced to N_2 when the Eh falls below +180 mV.

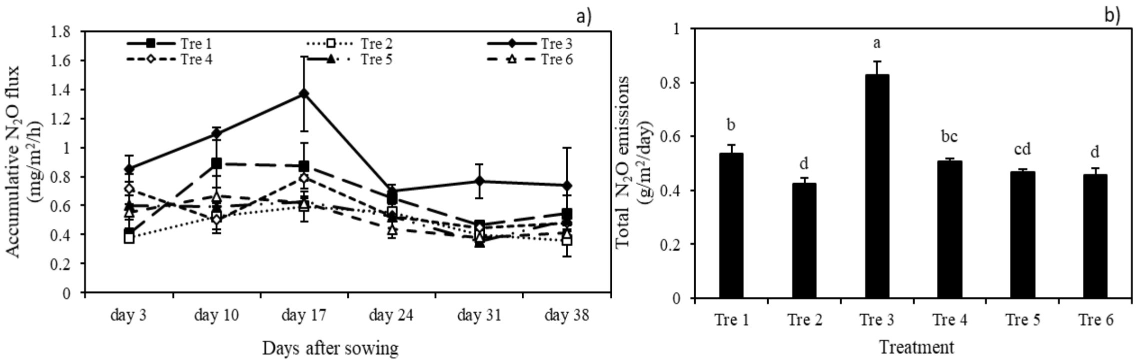

Figure 3. *Emission intensity (a) and total N_2O emissions (b) on continuously flooded rice*

The symbols a, b, and c in the column indicate that there is a difference between Tres through Duncan's test at a 5%. Tre 1 = control; Tre 2 = biochar weight (2 tons/ha); Tre 3 = biogas irrigation without biochar; Tre 4 = biogas irrigation with biochar weight (2 tons/ha); Tre 5 = biogas irrigation with biochar weight (10 tons/ha); Tre 6 = biogas irrigation with biochar weight (20 tons/ha).

In general, the rate of N_2O emission in the soil in Tres containing biochar was always low, ranging from 0.34 to 1 mg/m^2/h. In contrast, NT3 (biogas irrigation and non-biochar) had the highest amount of N_2O at 0.69-1.36 mg/m^2/h. This can be explained by the fact that bamboo biochar has a C/N ratio of 136.6, making biological N fixation easy, reducing the amount of N available in the soil, and thus lowering N_2O emissions from the production substrate [25]. At the same time, bamboo biochar also had a good ability to adsorb ammonium and nitrate from biogas wastewater, which has been demonstrated in previous studies by Pham et al [26], [27]. As a result, in the Tres supplemented with biochar, the majority of the ammonium and nitrate nitrogen was adsorbed by biochar, limiting the nitrification process and decreasing N_2O production.

According to Bruun et al. [8] using 1-2% biochar could significantly reduce N_2O emissions (27%). In comparison to the current experimental results, bamboo biochar at 2 tons/ha (equivalent to 0.13%) reduced total N_2O emissions by 38%. This could be due to the physicochemical properties of different types of biochar, which will have different effects on total N_2O emissions. It is also important to recognize the potential of bamboo biochar in the Tre of biochar N_2O emissions.

3.4. Total greenhouse gas emissions (converted to CO_2 equivalent)

After 38 days of the experiment, total greenhouse gas emissions (CH_4 and N_2O) were calculated and converted to equivalent total CO_2eq (Figure 4). The release of N_2O on rice soil was determined to be much lower than that of CH_4, so in this case, the increase of CH_4 gas emissions played a decisive role in the difference in total gas emissions equivalent to kgCO_2eq/ha between Tres. Total emissions in the biogas irrigation Tre, without biochar (718.85 ± 34.2 kgCO_2eq/ha), and in the Tres with the addition of biochar, ranged from 378.64 ± 16.1 to 440.77 ± 13.72 kgCO_2eq/ha. Thus, it can be seen that the addition of bamboo biochar has reduced greenhouse gas emissions by 35.9–45.6%. Therefore, bamboo biochar is a potential source of material for reducing greenhouse gas emissions in rice fields.

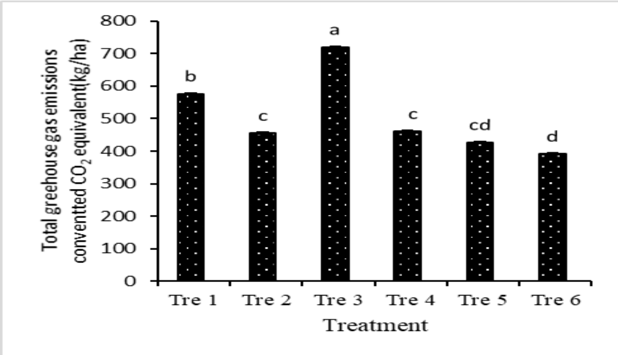

Figure 4. *Total greenhouse gas emissions (CO_2eq)*

Note: The symbols a, b, and c in the columns indicate that there is a difference between Tres through Duncan's test at a 5%. Tre 1 = control; Tre 2 = biochar weight (2 tons/ha); Tre 3 = biogas irrigation without biochar; Tre 4 = biogas irrigation with biochar weight (2 tons/ha); Tre 5 = biogas irrigation with biochar weight (10 tons/ha); Tre 6 = biogas irrigation with biochar weight (20 tons/ha).

4. Conclusions and recommendations

4.1. Conclusions

When biogas wastewater was used as a nitrogen fertilizer on rice land, CH_4 and N_2O emissions increased compared to the control. Simultaneously, the addition of bamboo biochar reduced greenhouse gas emissions (in CO_2 equivalent) by 35.9-45.6%, corresponding to a biochar ratio of 2 tons/ha to 20 tons/ha. A thorough examination of CH_4 emissions and N_2O emissions revealed that the most effective combination in this study was the use of bamboo biochar at a rate of 10 tons/ha in conjunction with biogas wastewater. In conclusion, the use of bamboo biochar reduced CH_4 and N_2O emissions.

4.2. Recommendations

Long-term biochar in the soil may impair its ability to reduce N_2O and CH_4 emissions, so additional research should look into multiple consecutive rice crops to see if degradation occurs or not.

REFERENCES

[1] T. Fujiwara, “Concept of an innovative water management system with decentralized water reclamation and cascading material-cycle for agricultural areas,” *Water Sci. Technol.*, vol. 66, no. 6, pp. 1171–1177, 2012.

[2] K. Minamikawa, C. K. Huynh, H. Yasukazu, S. N. Tran, and H. C. Nguyen, “Variable-timing, fixed-rate application of cattle biogas effluent to rice using a leaf color chart: microcosm experiments in Vietnam Kazunori,” *Soil Sci. Plant Nutr.*, vol. 10, no. 1, pp. 2–10, 2019.

[3] A. Singla and K. Inubushi, “Effect of biochar on CH_4 and N_2O emission from soils vegetated with paddy,” *Paddy Water Environ.*, vol. 12, no. 1, pp. 239–243, 2014.

[4] A. Zhang, G. Cheng, Q. Hussain, M. Zhang, H. Feng, M. Dyck, B. Sun, Y. Zhao, H. Chen, and X. Wang, "Contrasting effects of straw and straw–derived biochar application on net global warming potential in the Loess Plateau of China," *F. Crop. Res*., vol. 205, no. 2, pp. 45–54, 2017.
[5] Y. Xiao, S. Yang, J. Xu, J. Ding, X. Sun, and Z. Jiang, "Effect of biochar amendment on methane emissions from paddy field under water-saving irrigation*," Sustainability*, vol. 10, no. 5. pp. 3–13, 2018.
[6] X. Qin, Y. Li, H. Wang, C. Liu, J. Li, Y. Wan, Q. Gao, F. Fan, and Y. Liao, "Long-term effect of biochar application on yield-scaled greenhouse gas emissions in a rice paddy cropping system: A four-year case study in south China," *Sci. Total Environ.*, vol. 569–570, pp. 1390–1401, 2016.
[7] A. Z. Oo, S. Sudo, H. Akiyama, K. T. Win, A. Shibata, A. Yamamoto, T. Sano, and Y. Hirono, "Effect of dolomite and biochar addition on N_2O and CO_2 emissions from acidic tea field soil," *PLoS One*, vol. 13, no. 2, pp. 1–23, 2018.
[8] E. W. Bruun, D. Müller-Stöver, P. Ambus, and H. Hauggaard-Nielsen, "Application of biochar to soil and N2O emissions: Potential effects of blending fast-pyrolysis biochar with anaerobically digested slurry," *Eur. J. Soil Sci.*, vol. 62, no. 4, pp. 581–589, 2011.
[9] X. L. Nguyen, T. M. P. Do, H. C. Nguyen, R. Kose, T. Okayama, N. T. Pham, D. P. Nguyen, and T. Miyanishi, "Properties of Biochars Prepared from Local Biomass in the Mekong Delta, Vietnam," *Bioresources*, vol. 13, no. 4, pp. 7325–7344, 2018.
[10] T. Parkin, A. Mosier, J. Smith, R. Venterea, J. Johnson, D. Reicosky, G. Doyle, G. McCarty, and J. Baker, "Chamber-Based Trace Gas Flux Measurements," in *USDA-ARS GRACEnet Project Protocols*, 2003, pp. 1-28.
[11] Z. Dai, X. Zhang, C. Tang, N. Muhammad, J. W, P. Brookes, and J. Xu, "Potential role of biochars in decreasing soil acidification - A critical review," *Sci. Total Environ.*, vol. 581–582, pp. 601–611, 2017.
[12] P. Randolph, R. R. Bansode, O. A. Hassan, D. Rehrah, R. Ravella, M. R. Reddy, D. W. Watts, J. M. Novak, and M. Ahmedna, "Effect of biochars produced from solid organic municipal waste on soil quality parameters*," J. Environ. Manage.,* vol. 192, no. 1, pp. 271–280, 2017.
[13] Z. Wu, Q. Zhang, X. Zhang, P. Duan, X. Yan, and Z. Xiong, "Biochar-enriched soil mitigated N2O and NO emissions similarly as fresh biochar for wheat production," *Sci. Total Environ.*, vol. 701, 2020, Art. no. 134943.
[14] Q. Nan, L. Xin, Y. Qin, M. Waqas, and W. Wu, "Exploring long-term effects of biochar on mitigating methane emissions from paddy soil: a review," *Biochar,* vol. 3, no. 2, pp. 125–134, 2021.
[15] D. Dejene and E. Tilahun, "Role of biochar on soil fertility improvement and greenhouse gases sequestration," *Horticulture International Journal*, vol. 3, no. 6. pp. 291–298, 2019.
[16] S. Jeffery, F. G. A. Verheijen, C. Kammann, and D. Abalos, "Biochar effects on methane emissions from soils: A meta-analysis," *Soil Biol. Biochem.*, vol. 101, pp. 251–258, 2016.
[17] M. Sudibandriyo and M. Oratmangun, "Betung bamboo-based activated carbon bioadsorbent for the separation of hydrogen-methane gas mixture," *E3S Web Conf.*, vol. 67, pp. 1–6, 2018.
[18] S. Butnan, J. L. Deenik, B. Toomsan, M. J. Antal, and P. Vityakon, "Biochar Properties Influencing Greenhouse Gas Emissions in Tropical Soils Differing in Texture and Mineralogy," *J. Environ. Qual.*, vol. 45, no. 5, pp. 1509–1519, 2016.
[19] J. Wang, X. Pan, Y. Liu, X. Zhang, and Z. Xiong, "Effects of biochar amendment in two soils on greenhouse gas emissions and crop production," *Plant Soil*, vol. 360, no. 1–2, pp. 287–298, 2012.
[20] N. Wang, Y. F. L. Derrick, J. Sardans, W. Wang, C. Zeng, and J. Peñuelas, "Biochar decreases nitrogen oxide and enhances methane emissions via altering microbial community composition of anaerobic paddy soil," *Sci. Total Environ.*, vol. 581–582, pp. 689–696, 2017.
[21] J. Wang, W. Zhong, Y. Kang, H. Deng, and C. Han, "N_2O emission mitigation and microbial activity after Biochar and Cao application in a flooded nitrate-rich vegetable soil," *Acta Agric. Scand. Sect. B Soil Plant Sci.*, vol. 69, no. 3, pp. 257–267, 2019.
[22] M. L. Cayuela, L. van Zwieten, B. P. Singh, S. Jeffery, A. Roig, and M. A. Sánchez-Monedero, "Biochar's role in mitigating soil nitrous oxide emissions: A review and meta-analysis," *Agric. Ecosyst. Environ.*, vol. 191, pp. 5–16, 2014.
[23] M. Oda and H. C. Nguyen, "Methane emissions in triple rice cropping: Patterns and a method for reduction," *F1000Research*, vol. 8, no. 2, pp. 2–25, 2020.
[24] Y. Liu, M. Yang, Y. Wu, H. Wang, Y. Chen, and W. Wu, "Reducing CH4 and CO2 emissions from waterlogged paddy soil with biochar," *J. Soils Sediments*, vol. 11, no. 6, pp. 930–939, 2011.

[25] M. L. Cayuela, M. A. Sánchez-Monedero, A. Roig, K. Anley, A. Enders, and J. Lehmann, "Biochar and denitrification in soils: When, how much and why does biochar reduce N_2O emissions?," *Sci. Rep.,* vol. 3, no. Experiment 2, pp. 1–7, 2013.
[26] N. T. Pham, L. H. N. Tang, and H. C. Nguyen, "Research on ammonium adsorption capacity in biogas wastewater of bamboo biochar," *Journal of Natural Resources and Environment Science,* no. 37, pp.26-36, 2021.
[27] N. T. Pham, L. H. N. Tang, T. M. T. Dang, T. M. P. Do, X. L. Nguyen, and H. C. Nguyen, "Research on ammonium adsorption capacity in water environment of Melaleuca biochar," *Journal of Agriculture and Rural Development,* vol. 17, no. 01, pp.129-136, 2021.