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Effects of soil amendment from herbal and eucalyptus industrial waste on methane emission and rice yield

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ABSTRACT

The use of chemical fertilizer in rice fields contributes to increased global warming via enhanced emission of methane (CH_4) into the atmosphere. Therefore, composting has been proposed to reduce methane emissions in the agricultural field. This study aimed to determine the CH_4 emission and rice yield affected by compost from three different types of compost: herbal compost, eucalyptus compost, and manure compost. This randomized block design study was conducted from November 2019 to May 2020. There were 8 fertilizer treatments applied to the rice fields, namely: herbal compost 10 t.ha^{-1}. (O1), eucalyptus compost 10 t.ha^{-1} (O2), manure compost 10 t.ha^{-1} (O3), no compost no chemical fertilizer (as a control) (O4), herbal compost 5 t.ha^{-1} + chemical fertilizer/CF (C1), eucalyptus compost 5 t.ha^{-1} + CF (C2), manure compost 5 t.ha^{-1} + CF (C3), and only chemical fertilizer (C4), then all treatments replicated three times. For the chemical fertilizer (CF) the dose is 166 kg.ha^{-1} Urea + 166 kg.ha^{-1} ZA + 330 kg.ha^{-1} TSP. The result indicated that the compost manure 10 t.ha^{-1} (O3) and the combination compost manure 5 t.ha^{-1} + CF (C3) produced the highest rice yields (6.89 - 6.94 t.ha^{-1}) but impacted the highest methane emissions (505.3 – 544.6 Kg CH_4.ha^{-1}.season^{-1}). The important finding showed that among all the treatments, a combination of compost eucalyptus 5 t.ha^{-1} + CF (C2) and compost eucalyptus 10 t.ha^{-1} (O2) mitigated methane emission to the lowest level (296.6 - 305.2 Kg.CH_4.ha^{-1}.season^{-1}) and gave high rice yields (6.77 - 6.78 t.ha^{-1}) that were not significantly different from those of compost manure (O3 and C3). In addition, the combination of compost herbal 5 t ha^{-1} and chemical fertilizer (C1) affected the lower methane emissions than manure compost and gave a high level of grain yield that was not significantly different from those of manure compost (O3 and C3) and eucalyptus compost (O2 and C2).

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1. INTRODUCTION

Climate change is a worldwide phenomenon caused by human activities, including the use of fossil fuels, natural processes, biomass burning, and agricultural practices. Increased anthropogenic methane emissions partly contribute to climate change. Rice agriculture is the primary source of anthropogenic methane emissions, accounting for approximately 7 to 17% of global methane emissions (25 to 100 terragrams [Tg] of CH_4 gas per year) (Conrad, 2009; Liu & Whitman, 2008). Rice has become an important crop worldwide, and several approaches to increasing rice production have been employed, such as the development of high-yielding varieties, a system of rice intensification, and the use of mineral fertilization (Haque et al., 2019; Mboyerwa et al., 2022; Sopha et al., 2022). Increased production leads to higher application of nitrogen fertilizers to rice fields, resulting in greater methane emissions (Wang et al., 2017). Excessive application of inorganic fertilizer in rice fields can cause environmental consequences, such as contributing to the increase of global warming by emitting CH_4 gas into the atmosphere (Trinh et al., 2017).

Methane gas emissions are one of the contributors to greenhouse gases leading to global warming and climate change. Methane gas emission production from rice fields occurs in subtropical to tropical regions. Southeast Asia, a rice-producing country, provides around 10,000 kg of methane gas per km^2. Increasing rice production resulted in increasing methane emissions (Epule et al., 2011). As a result, initiatives to limit methane emissions from paddy fields are required in order to promote sustainable agriculture and safeguard the earth's ozone layer. Composting has emerged as a feasible method of reducing pollution from agricultural and industrial waste. Composting has also been proposed as a strategy to reduce CH_4 emissions (Ayalon et al., 2001), decreasing CH_4 emissions by 35% from the rice fields (Jeong et al., 2018). In addition, compost increases soil organic matter content, which has been recognized as a crucial element in determining soil fertility and productivity (Sarwar et al., 2007). The positive effects of compost application have proven benefits such as nutrient supply and carbon sequestration (Martínez-Blanco et al., 2013). Razavipour et al. (2018) and Hossen et al. (2015) confirmed that the application of compost resulted in a higher tiller number, spike number, spike weight, and grain yield of rice plants. However, the application of compost derived from herbal medicine and eucalyptus distillation industry wastes as biofertilizer is still in its early stages, notably in rice production. Furthermore, only a few research have employed these composts to enhance plant yield by augmenting nutrient uptake in horticulture (Zhang et al., 2023).

Compost created from herbal and eucalyptus distillation waste is thought to include a variety of compounds that reduce CH_4 emissions by inhibiting the growth of methanogenic archaea. In organic farming systems, herbal or eucalyptus waste can be selected as a fertilizer. Herbal medicine industry waste is valuable because it contains tannin and polyphenolic compounds that can impede nitrification (Schirmer et al., 2014). In addition to retaining Nitrogen in the form of NH_4^+, nitrification inhibitors are anticipated to reduce N_2O and CH_4 emissions from rice fields (Kartikawati & Nursyamsi, 2013). Sallam et al. (2010) demonstrated a significant reduction in cumulative CH_4 gas production of approximately 51% with eucalyptus waste. Eucalyptus waste contains compounds that hinder archaea methanogen growth, including antioxidants and antiprotozoal, antifungal, and anti-hyaluronidase activities (Pujiarti et al., 2011).

No research was found to date on the influence of compost made from herbal waste and eucalyptus distillation in rice fields on CH_4 emissions and rice yields. Therefore, this study aimed to determine the effect of compost from the herbal and eucalyptus distillation industries on CH_4 emissions and rice yields for soil amendment in rice fields. We postulated that using eucalyptus and herbal compost for soil amendment can reduce CH_4 emissions while maintaining rice yield.

2. MATERIALS AND METHODS

The series of research steps started from the composting process, initial analysis of soil characteristic before planting, rice planting and measurement of rice growth and yield, sampling and analysis of methane gas emission and data analysis.

2.1. Composting

Composting was carried out at a compost house from March to August 2018 for 120 days. The two materials composts were the herbal medicine industrial waste and the eucalyptus oil distillation industrial waste. The herbal medicine industrial waste and eucalyptus oil distillation industrial waste were cut 0.5–3 cm long, and each compost pile was stacked with a size of 120 × 180 × 80 cm, with as much as 300 kg on the floor of the compost house. The compost materials were mixed with 100 mL of bioactivator (consisted of cow rumen, sugarcane molasses, pineapple, banana stalks, rice washing waste, and herbal rhizome). Turning over and adding water to the compost heap is performed every 2 weeks to maintain air circulation and humidity of approximately 70%. Composting ends after 120 days. Manure was obtained by composting cow dung with an aerobic method using 100 mL of bioactivator, and cow dung composting took 1 month. The manure compost was prepared by farmers using fried cow dung with bioactivator. The application of compost was 5 t.ha^{-1}, where the chemical fertilizers (CF) (166 kg.ha^{-1} of Urea, 166 kg.ha^{-1} of ZA, and TSP 330 kg.ha^{-1}). The characteristics of herbal waste compost, eucalyptus oil waste compost, and manure are shown in Table 3.

2.2. Initial Analysis of Soil Characteristic Before Planting

Before planting, the soil samples of Andisol rice field were taken from Ngadiluwih, Matesih, Karanganyar Regency, Central Java (7°38'6"S, 111°0'51"E) using purposive random sampling at a depth of 0–15 cm in the tilled layer and composited. The samples were then air-dried and sieved using a 2 mm diameter sieve for further analysis. Soil chemical analysis was conducted including total organic carbon using the Walkey and Black method, total-N using the Kjedahl method, available-P using the Bray 1 method, and available-K using the NH_4OAC.pH 7.0 solution (Sparks et al., 2020). Soil biological analysis was determined according to Bläsing and Amelung (2018), where the PD of bacteria and fungi was identified using the spread plate method. Soil moisture content was measured using gravimetric method, while soil pH and potential redox was measured using an ORP meter (*Extech* type *SDL 100*).

2.3. Rice Planting and Measurement of Rice Growth and Yield

This randomized block design study was conducted for one growing season from Januari 2019 to Mei 2019. There are eight treatments employed, namely: herbal compost 10 t.ha^{-1}. (O1), eucalyptus compost 10 t.ha^{-1} (O2), manure compost 10 t.ha^{-1} (O3), no compost no chemical fertilizer (control) (O4), herbal compost 5 t.ha^{-1}+ chemical fertilizer (CF) (C1), eucalyptus compost 5 t.ha^{-1} + CF (C2), manure compost 5 t.ha^{-1} + CF (C3), and only chemical fertilizer (C4), with three replicates (Table 1). Chemical fertilizer (CF) dose is 166 kg.ha^{-1} Urea + 166 kg.ha^{-1} ZA + 330 kg.ha^{-1} TSP. A week before planting compost treatments were applied. Rice seedling with variety of Inpari 32 (age 20 days after sown) were planted with planting distance 20 x 20 cm. Two weeks after planting chemical fertilizer treatments were applied.

Table 1. Treatments applied in the experiment

Label	Treatments
O1	Herbal compost 10 t.ha^{-1}
O2	Eucalyptus compost 10 t.ha^{-1}
O3	Manure compost 10 t.ha^{-1}
O4	No Compost no chemical fertilizer
C1	Herbal compost 5 t.ha^{-1} + Chemical fertilizer (CF)
C2	Manure compost 5 t.ha^{-1} + Chemical fertilizer (CF)
C3	Herbal compost 5 t.ha^{-1} + Chemical fertilizer (CF)
C4	Chemical fertilizer§ (CF)

Note: § = 166 kg.ha^{-1} Urea + 166 kg.ha^{-1} ZA + 330 kg.ha^{-1} TSP

Table 2. Initial soil characteristics (Soil Type: Andisols)

Soil characteristics	
Eh (mV)	-116.20
pH	4.98
Total C organic (%)	6.75
Total N (%)	0.32
C/N	21.63
P available (ppm)	6.58
K available (ppm)	7.13
Total bacteria (x10^{10} CFU.g^{-1})	0.62
Total fungi (x10^{6} CFU.g^{-1})	0.05

Table 3. Characteristics of composts

Parameter	Herbal waste compost	Eucalyptus oil waste compost	Manure
Moisture content (%)	23.44	22.67	25.77
pH	7.40	7.67	7.88
TOC (%)	30.51	31.55	33.4
Total N (%)	1.77	1.88	1.93
C/N ratio	17.27	16.82	15.44
Total P (%)	1.96	1.95	2.02
Total K (%)	1.48	1.45	1.35
Phenol (%/bb)	8.43	15.34	2.1
Total bacteria (x10^{8} CFU/g)	6.54	9.60	4.02
Total fungi (x10^{4} CFU/g)	2.07	2.10	1.55

Table 4. ANOVA of treatments on each soil parameter (100 DAP)

Parameter	Sig.
CH_4	<0.01**
Eh	<0.01**
pH	<0.01**
C	<0.01**
N	<0.01**
C/N	<0.01**
P	<0.01**
K	<0.01**
PD Bacteria	<0.01**
PD Fungi	<0.01**
NO_3	<0.01**

Note: α 0.05, *ns*= not signifcant; *= significant; and **= highly significant; PD= Population Density

Rice were grown and harvested at 100 days after planting (DAP). During growing period the standing water was kept minimum at the level of 5 cm height.

Plant growth parameter consisted of plant height and the number of tiller that were observed on the same day of methane sampling, and plant fresh and dry weigh that were observed at harvest time. Parameter of plant yield was measured from the grain yield that obtained at harvest time. In addition, at the harvest time, soil samples were taken from the each treatment for the analysis of chemical characteristics (pH H_2O, NO_3, total C, total N, C/N ratio, Available P, Available K) and biological characteristics (population density of bacteria and fungi).

2.4. Sampling and Analysis of methane gas emission

A sampling of the CH_4 gas using the survey method was carried out four times for each location, during the vegetative phase of 15 days after planting (DAP), the active tillering phase of 35 DAP, the generative phase of 65 DAP, and the ripening phase of 100 DAP. Soil pH, redox potential, plant height and number of tillers were measured on the same day of gas sampling. In the sampling of CH_4 gas, a box chamber cap with a size of 50 × 50 × 100 cm was used, and the cover was made of polycarbonate material. Samples were collected around 6–9 a.m. The chamber was equipped with a thermometer and fan placed on the top of the chamber's lid. Briefly, before gas sampling, the lid was left open for 2–3 mins to stabilize the gas concentration inside the chamber. After that, the lid was closed, and the rubber cover at the gas sampling was opened for 2–3 minutes to stabilize the air. After another 2–3 minutes, the rubber cap was closed and the gas was collected in quadruplicate (5, 10, 15, and 20 mins). The gas sample was collected using a 20 mL BD syringe with a 23 G ¼ TW (0.6 mm × 32 mm) needle mounted in an upright position, injected into the septum rubber. The syringe was closed with the septum as soon as possible to avoid leakage and was transferred to a tighter vial. The vial was covered with aluminum foil and put in a box, immediately taken to the greenhouse gas laboratory for CH_4 gas analysis. The height of the water above the ground surface and changes in temperature inside the chamber were also recorded.

2.5. Data analysis

Statistical analysis for all data was conducted using univariate ANOVA analysis, followed by DMR test (DMRT). Statistical significance was set at $p < 0.05$. Multivariate analysis of stepwise regression and correlation and linear regression analyses were also conducted.

3. RESULTS

Table 4 shows treatments that resulted in significantly high methane emission and soil parameters, such as soil Eh, pH, total-C, total-N, available-P, available-K, and population density (PD) of bacteria and fungi. Table 5 describes the result of DMRT of treatments on each soil parameter at 100 DAP. The highest soil redox potential (Eh) was found in C2, and the lowest data was found in C4, which accounted for −56.70 ± 1.50 mV and −129.30 ± 5.10 mV, respectively. Potential redox was significantly higher in the treatments of eucalyptus

Table 5. Soil properties under variation treatments at 100 DAP with DMRT analysis

Treat.	Eh (mV)	pH	C (%)	N (%)	C/N	Av. P (ppm)	Av. K (ppm)	PD Bacteria (x 10^{10} CFU.g^{-1})	PD Fungi (x 10^{10} CFU g^{-1})	NO_3 (μg N/g)	Total CH_4 Emission (Kg.CH_4 ha^{-1}.season-^{1})
O1	-73.70 ± 1.50 e	6.22 ± 0.03 f	7.61 ± 0.07 e	0.57 ± 0.02 e	13.44 ± 0.59 ab	7.17 ± 0.02 e	16.77 ± 0.42 de	1.15 ± 0.03 e	1.60 ± 0.05 g	0.14 ± 0.02 b	332.97 ± 3.26 c
O2	-68.70 ± 3.10 e	6.08 ± 0.03 e	7.52 ± 0.03 e	0.65 ± 0.03 f	11.52 ± 0.57 ab	7.11 ± 0.03 e	17.18 ± 0.24 e	1.22 ± 0.03 f	1.73 ± 0.05 h	0.17 ± 0.02 b	305.27 ± 6.06 b
O3	-96.00 ± 3.00 c	6.31 ± 0.03 g	7.64 ± 0.12 e	0.71 ± 0.02 g	10.81 ± 0.30 a	7.28 ± 0.04 f	16.36 ± 0.40 d	1.12 ± 0.03 e	1.26 ± 0.08 f	0.15 ± 0.03 b	544.63 ± 5.58 g
O4	-129.30 ± 5.10 a	5.72 ± 0.06 d	7.22 ± 0.07 d	0.34 ± 0.04 b	21.67 ± 2.67 c	7.12 ± 0.04 e	10.27 ± 0.71 b	0.82 ± 0.05 b	0.57 ± 0.05 b	0.16 ± 0.03 b	437.97 ± 4.54 e
C1	-72.00 ± 3.00 e	5.06 ± 0.05 b	6.48 ± 0.04 bc	0.46 ± 0.01 c	14.10 ± 0.36 b	6.53 ± 0.08 c	16.73 ± 0.25 de	0.89 ± 0.04 cd	0.90 ± 0.02 d	0.09 ± 0.03 a	325.33 ± 3.83 bc
C2	-56.70 ± 1.50 f	5.03 ± 0.06 b	6.40 ± 0.06 b	0.49 ± 0.04 cd	13.03 ± 0.92 ab	6.44 ± 0.02 b	16.30 ± 0.27 d	0.93 ± 0.02 d	0.99 ± 0.02 e	0.16 ± 0.02 b	296.63 ± 4.89 a
C3	-83.30 ± 5.00 d	5.18 ± 0.04 c	6.56 ± 0.04 c	0.53 ± 0.02 de	12.46 ± 0.56 ab	6.62 ± 0.03 d	15.06 ± 0.29 c	0.85 ± 0.01 bc	0.81 ± 0.04 c	0.15 ± 0.02 b	505.33 ± 6.42 f
C4	-102.70 ± 5.50 b	4.53 ± 0.08 a	6.19 ± 0.08 a	0.28 ± 0.03 a	22.04 ± 2.73 c	6.19 ± 0.02 a	5.40 ± 0.14 a	0.28 ± 0.04 a	0.04 ± 0.03 a	0.17 ± 0.02 b	392.43 ± 5.84 d

Note: n = 3; values in the same column followed by the same letter are not significantly different at p<0.01 according to Duncan's test. All data were reported as means ± standard deviation; O1 : herbal compost 10 t.ha^{-1}, O2 : eucalyptus compost 10 t.ha^{-1}, O3 : manure compost 10 t.ha^{-1}, O4 : no compost, C1 : herbal compost 5 t.ha^{-1}+ CF, C2 : eucalyptus compost 5 t.ha^{-1} + CF , C3 = manure compost 5 t.ha^{-1} + CF, C4 : CF

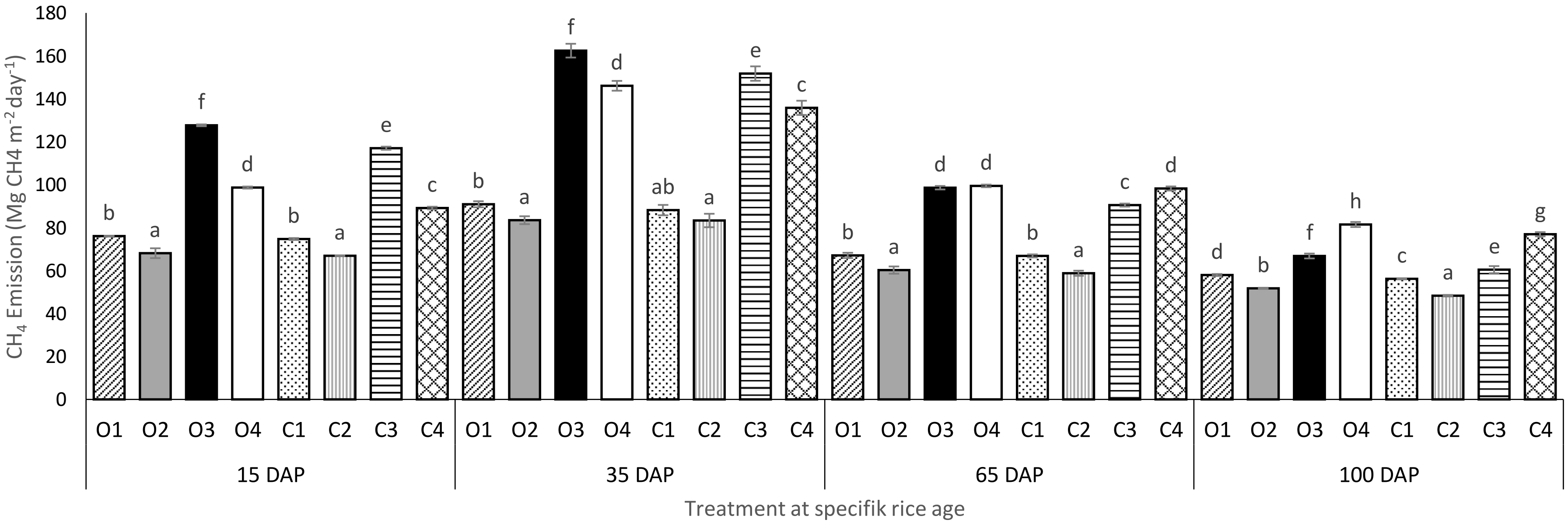


Figure 1. Methane emission of compost variation nested in farming system at 15, 35, 65 and 100 DAP

Notes: Same letter on the bar indicates not significant difference in the same rice age (DAP); O1 : herbal compost 10 t.ha^{-1} , O2 : eucalyptus compost 10 t.ha^{-1}, O3 : manure compost 10 t.ha^{-1}, O4 : no compost, C1 : herbal compost 5 t.ha^{-1} + CF, C2 : eucalyptus compost 5 t.ha^{-1} + CF , C3 = manure compost 5 t.ha^{-1} + CF, C4 : CF composts 5 $t.ha^{-1}$ + CF (C2) followed by eucalyptus compost 10 $t.ha^{-1}$ (O2) treatment. Whereas the lowest potential redox found in control (O4) followed by CF (C4) treatment. Soil pH under all treatments with compost 10 $t.ha^{-1}$ (O1, O2, and O3) were significantly increase the soil pH status than all treatment with chemical fertilizer (C1, C2 and C3). The results showed that the highest total-N was found in treatment with compost 10 $t.ha^{-1}$ (O3) of 0.71% followed by eucalyptus compost 10 $t.ha^{-1}$ (O2) of 0.65%, while, the lowest total-N found in treatment CF (C4) of 0.28%, followed by control (O4) of 0.34 %. Available-P in all compost treatment significantly different compared with all treatment with chemical fertilizers and the highest Av-P found in manure compost treatment (O3).

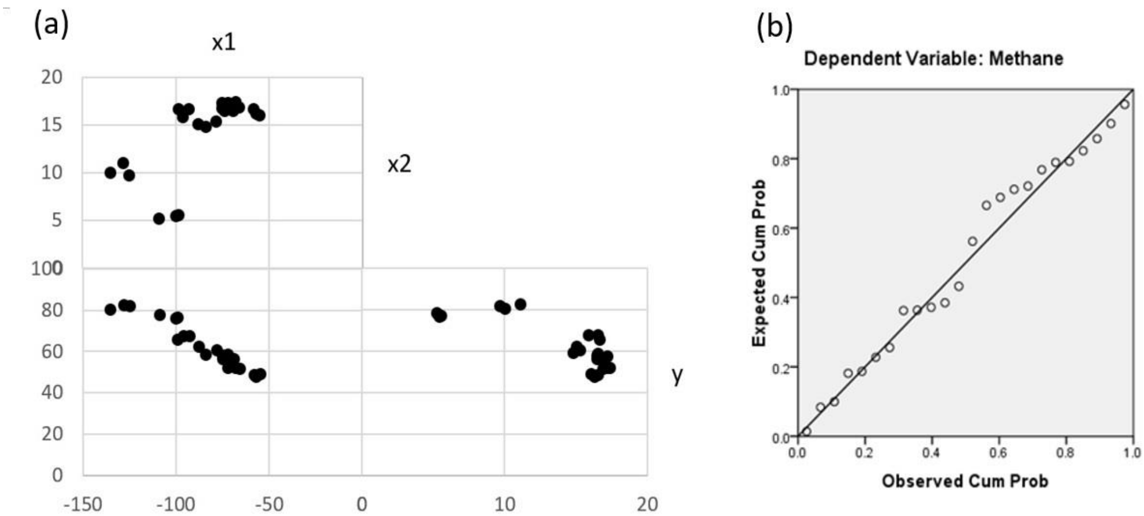
The low level of available K in C4 treatment after one growing season represented the initial concentration of available K for each farming system (Table 2). Moreover, all eucalyptus compost (O2 and C2) could increase available K, PD of bacteria, PD of fungi by 5%, 7%–9%, and 8%–22% than manure compost, respectively. In addition, C2 treatment resulted in the lowest soil nitrate (0.09 ± 0.03 μg N/g), and the other treatments were not statistically different. All treatment with compost 10 $t.ha^{-1}$ have a higher population density of bacteria compared with control and compost + CF treatment. The highest population density of bacteria found in eucalyptus compost 10 $t.ha^{-1}$ treatment (O2) ($1.22x10^{10}$ $CFU.g^{-1}$), followed by herbal compost (01) ($1.15x10^{10}$ $CFU.g^{-1}$), manure compost (O3) ($1.12x10^{10}$ $CFU.g^{-1}$) and the lowest found in chemical fertilizer/CF (C4) treatment ($0.28x10^{10}$ $CFU.g^{-1}$). The results of population density of fungi similar with bacteria, the highest population density found in O2 treatment ($1.73x10^{10}$ $CFU.g^{-1}$), followed by O1 ($1.60x10^{10}$ $CFU.g^{-1}$) and O3 ($1.26x10^{10}$ $CFU.g^{-1}$), with the lowest found in C4 treatment (0.04 $x10^{10}$ $CFU.g^{-1}$) (Table 5).

Table 5 also shows that total CH_4 emissions combination eucalyptus compos 5 $t.ha^{-1}$ + CF (C2) were the lowest (296.63 kg $CH_4.ha^{-1}.season^{-1}$) compared to all the treatment, followed by eucalyptus compost (O2) (305.27 kg $CH_4.ha^{-1}.season^{-1}$). While, the highest CH_4 emissions found in treatment manure compost 10 $t.ha^{-1}$ (O3) (544.63 kg $CH_4.ha^{-1}.season^{-1}$), followed by manure compost 5 $t.ha^{-1}$ + CF (C3) (505.33 kg $CH_4.ha^{-1}.season^{-1}$). Other words, eucalyptus composts can decrease CH_4 emissions around 37% compared with the highest CH_4 emission obtained from the manure compost (O3) treatment, those results also shows that manure compost produced the highest CH_4 emission.

Figure 1 describes Methane emissions from variation treatments at 15, 35, 65, and 100 DAP. The trend showed that Methane emissions fluctuated during the rice growing season. After the vegetative stage (15 DAP), CH_4 emissions slightly increased during the active tillering stage (35 DAP). After reaching a peak, the emission gradually fell to a lower level at the milk cooking phase (100 DAP). In general, chemical fertilizer treatments resulted in lower CH_4 emissions compared to the organic amendment treatments during rice cultivation. The trend showed that manure compost 10 $t.ha^{-1}$ and control treatments (O4) produced higher methane emissions compared to herbal compost 10 $t.ha^{-1}$ (O1) and eucalyptus compost 10 $t.ha^{-1}$ (O2). In addition, during the vegetative stages (15 and 35 DAP), manure compost 10 $t.ha^{-1}$ recorded the highest Methane emission, while in the last two stages (65 and 100 DAP), C4 emitted more emissions compared to the others. This could be because the manure treatment had more tiller (Table 8), thus increasing CH_4 emission.

Figure 2 shows the stepwise regression analysis of CH_4 as the dependent variable and soil redox potential combined with available K as the determining factor, which influences CH_4 emission in all treatments. Both models were highly significant, with R^2 of 0.923 (model 1) and 0.966 (model 2). Model 2 was chosen due to the highest R^2 and resulted in the following equation:

$$CH_4 = 41.026 - 0.385\ Eh - 0.796\ K \quad [1]$$



$$y = 41.026 - 0.385\ x1 - 0.796\ x2$$
$$R^2 = 0.966$$

Figure 2. Matrix Plot (a) and Regression Plot of observed and expected methane emission (b) resulted from Stepwise Regression (y= methane emission; x1= potential redox (Eh); x2= soil potassium content (K))

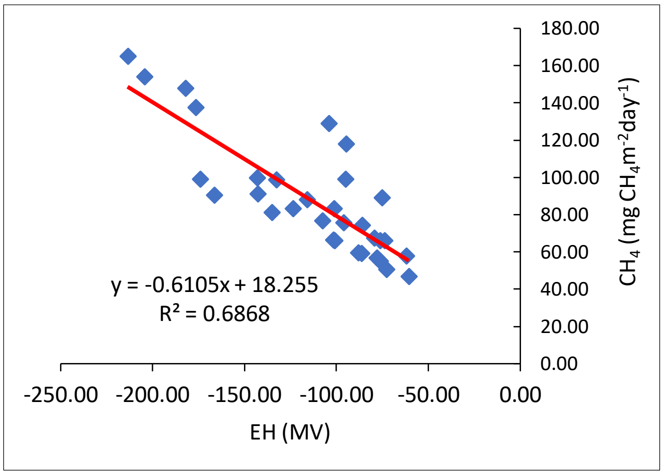


Figure 3. Relationship between soil redox potential and Methane emission

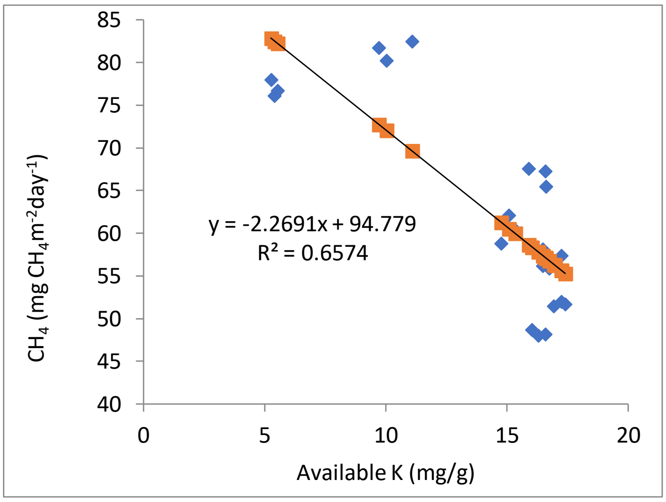


Figure 4. Relationship between soil available Potassium and Methane emission

According to Figures 3 and Figure 4, Methane emission had a linear relationship with soil redox potential and available K, with R^2 of 0.6868 and 0.6574, respectively. The increment of soil redox potential decreased CH_4 emission. In contrast, lower CH_4 emissions were influenced by the augmentation of available K in the soil. Figure 5 illustrates the linear regression of PD of fungi on CH_4 emission and available K in all treatments. The variation of available K in soil was due to soil amendments that could change the PD of fungi and ultimately influence Methane emission. Figure 4 shows that the increase of available K in the soil led to the incline of the PD of fungi in the soil. Furthermore, the increment in the PD of fungi could decline CH_4 emission from rice cultivation.

Table 6 indicates that CH_4 emission negatively correlated with soil N ($r = -0.579$, $p < 0.01$), PD bacteria ($r = -0.593$, $p < 0.01$), and PD fungi ($r = -0.668$, $p < 0.01$), and positively correlated with C/N ratio ($r = 0.774$, $p < 0.01$). The increase in Methane emission is highly influenced by the decrease in soil N, PD bacteria, and PD fungi and the incline of the C/N ratio. Negative correlations were found between soil redox potential with CH_4 emission ($r = -0.961$, $p < 0.01$) and the C/N ratio ($r = -0.678$, $p < 0.01$). Similar results were also found between available K with CH_4 emission ($r = -0.812$, $p < 0.01$) and C/N ratio ($r = -0.875$, $p < 0.01$). Moreover, soil N ($r = 0.466$, $p < 0.05$), PD bacteria ($r = 0.435$, $p < 0.05$), and PD fungi ($r = 0.558$, $p < 0.01$) were positively correlated with soil redox potential. In addition, positive correlations were also discovered between available K with soil N ($r = 0.809$, $p < 0.01$), P ($r = 0.447$, $p < 0.05$), PD bacteria ($r = 0.896$, $p < 0.01$), and PD fungi ($r = 0.857$, $p < 0.01$).

3.1. Rice yield

Table 7 indicates the ANOVA result for rice yield parameters in all treatments. All the treatments were highly significant for all agronomic parameters. Table 8 shows the DMRT result of rice growth parameters in all treatments. Generally, herbal compost 10 $t.ha^{-1}$ (O1), eucalyptus compost 10 $t.ha^{-1}$ (O2), herbal compost 5 $t.ha^{-1}$ + CF (C1) and eucalyptus compost 5 $t.ha^{-1}$ + CF (C2) treatment give the similar effect to plant height. Plant without compost (O4 and C4) growth shorter compared to plants with compost treatment. The tiller number, fresh weight, and dry weight of the rice in treatment O4 and C4 has lower results compared to those with compost treatment. The result also showed that the lowest rice yield found in the no compost treatment (O4 and C4), while, the highest rice yield found manure compost 5 $t.ha^{-1}$ + CF (C3) although it not significantly different with O2, O3 and C1.

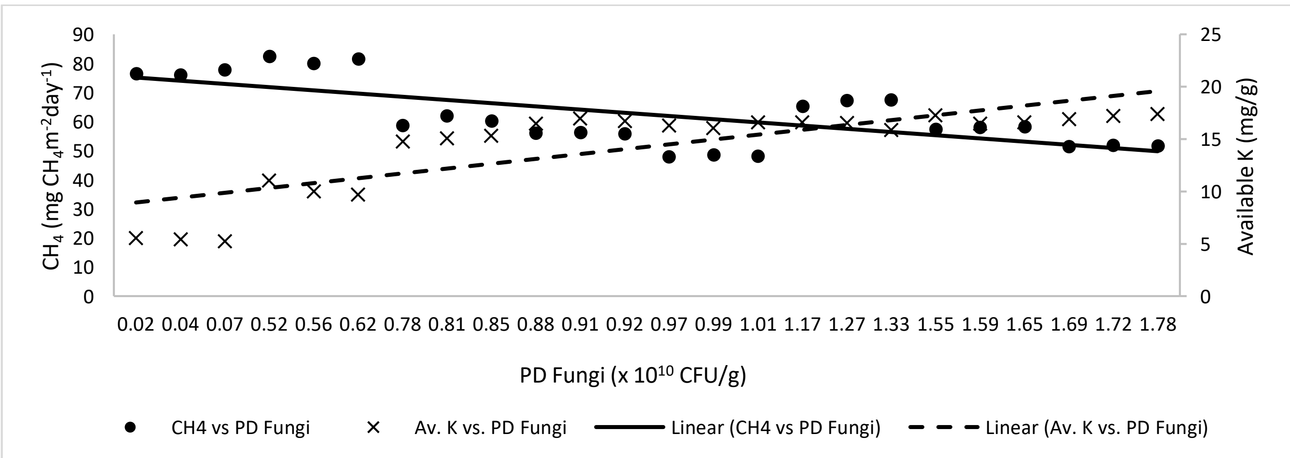


Figure 5. Linear regression of PD fungi on CH_4 emission and Available K

Table 6. Correlation of parameters

Parameters	CH_4	pH	C	N	C/N Ratio	P	PD Bacteria	PD Fungi	NO_3
CH_4		-0.105^{ns}	-0.010^{ns}	-0.579^{**}	0.774^{**}	0.044^{ns}	-0.593^{**}	-0.668^{**}	0.200^{ns}
Eh	-0.961^{**}	-0.034^{ns}	-0.111^{ns}	0.466^{*}	-0.678^{**}	-0.199^{ns}	0.435^{*}	0.558^{**}	-0.250^{ns}
Av. K	-0.812^{**}	0.547^{**}	0.433^{*}	0.809^{**}	-0.875^{**}	0.447^{*}	0.896^{**}	0.857^{**}	-0.269^{ns}

Note: **, * and ns denote that the correlation is significant at $p < 0.01$, $p < 0.05$ and not significant, respectively.

Table 7. ANOVA of rice yield parameters

Parameter	Sig
Plant height	<0.01**
Tiller number	<0.01**
Fresh weight	<0.01**
Dry weight	<0.01**
Dry grain	<0.01**

Note*:* **= highly significant at α=0.05

Table 9 shows the correlation between CH_4 and available K with rice growth parameters. CH_4 emission negatively correlated with plant height ($r = -0.891$, $p < 0.01$), tiller number ($r = -0.763$, $p < 0.01$), fresh weight ($r = -0.710$, $p < 0.01$), dry weight ($r = -0.718$, $p < 0.01$), and dry grain ($r = -0.776$, $p < 0.01$). Moreover, positive correlations were found between available K and plant height ($r = 0.934$, $p < 0.01$), tiller number ($r = 0.853$, $p < 0.01$), fresh weight ($r = 0.929$, $p < 0.01$), dry weight ($r = 0.944$, $p < 0.01$), and dry grain ($r = 0.956$, $p < 0.01$).

Figure 6 shows the linear regression of rice fresh weight on available K and CH_4 emission of compost variation nested in both farming systems. The variation of available K in soil affected plant growth indicators, and the fresh weight increased with the increment of available K in soil. Furthermore, the enhancement of CH_4 emission was also influenced by the decline of fresh weight.

4. DISCUSSION

Variations of the compost had diverse impacts on Methane emission and soil properties during the rice growing season. Total CH_4 emissions were lower under eucalyptus and herbal composts than the control (no compost no chemical fertilizer) and manure (Table 5). A former study reported that inorganic fertilizer combined with different sources of the organic amendment could influence soil fertility and CH_4 emissions (Haque et al., 2021). The distinctive chemical fertilizer application also significantly influenced soil chemical properties and CH_4 flux in rice fields (Table 5). In this study, the absence of chemical fertilizer recorded a better result in soil properties even in the control treatment (Table 5). This corroborates a previous study using rice bran for the organic rice system, which increased the N and P contents compared to the control treatment (Nira & Miura, 2019). However, amending soil with organic composts alone (O1, O2, O3, and O4) showed higher CH_4 emissions than incorporating it with chemical fertilizer (C1, C2, C3, and C4) (Figure 1). That is because organic matter sources become one of main factors for activating methanogens activity in anerobic condition, as explained by Minamikawa et al. (2015), supported with data in Table 2. Additionally, increased growth of rice during the vegetative stage promotes methane flux because up to 90% of methane emission released to the atmosphere via the aerenchyma system (Kim et al., 2018).

The incorporation of compost into the soil provided a stabilized form of organic matter that enhances the physical properties of the soil (Kranz et al., 2020) and promotes biological activities and nutrient content (Kelbesa, 2021). This study revealed that eucalyptus compost could double the available K compared to the initial soil before treatment (Table 5). Soumare et al. (2023) explained that the increased K solubilization in an acidic environment led to the protonation and acidification processes that released K ions into the soil. This was based on the acid pH of the soil sample used in this study (4.98) (Table 2). The characteristic of eucalyptus compost in this study showed that the PD of fungi and bacteria (2.10×10^4 CFU/g and 9.60×10^8 CFU/g, respectively) were higher than other composts ($1.6–2 \times 10^4$ CFU/g and $4–6.5 \times 10^8$ CFU/g, respectively) (Table 3). Other studies reported that compost addition could increase the number of organic substrates beneficial for microbial growth (Farrell et al., 2009) and the mechanism of K solubilization in the soil is influenced by microbial diversity and activity (Lopes et al., 2019).

Table 8. Plant parameters of rice under various treatments

Treat.	Plant height (cm)	Tiller number	Fresh weight (g)	Dry weight (g)	Grain yield (t ha^{-1})
O1	97.57 ± 1.23 c	17 ± 0.58 b	99.17 ± 0.17 c	54.07 ± 0.06 d	6.46 ± 0.06 c
O2	97.17 ± 0.76 bc	17 ± 1.00 b	101.34 ± 0.34 d	55.12 ± 0.12 e	6.77 ± 0.23 d
O3	95.57 ± 0.70 b	18 ± 1.15 bc	107.96 ± 2.21 e	58.48 ± 0.76 g	6.89 ± 0.08 d
O4	74.67 ± 0.68 a	13 ± 1.00 a	83.87 ± 0.42 b	44.26 ± 0.15 b	5.78 ± 0.06 b
C1	96.53 ± 1.17 bc	18 ± 0.58 bc	99.28 ± 0.87 c	52.90 ± 0.30 c	6.70 ± 0.11 d
C2	96.67 ± 0.68 bc	18 ± 0.58 bc	102.38 ± 0.97 d	54.17 ± 0.33 d	6.78 ± 0.23 d
C3	95.43 ± 0.61 b	19 ± 1.15 c	106.81 ± 0.83 e	55.94 ± 0.28 f	6.94 ± 0.02 d
C4	75.30 ± 1.31 a	12 ± 0.58 a	70.27 ± 0.23 a	37.84 ± 0.08 a	4.54 ± 0.03 a

Notes: Values in the same column followed by the same letter are not significantly different at p<0.01 according to Duncan's test. All data were reported as means ± standard deviation; O1 : herbal compost 10 t.ha^{-1}, O2 : eucalyptus compost 10 t.ha^{-1}, O3 : manure compost 10 t.ha^{-1}, O4 : no compost, C1 : herbal compost 5 t.ha^{-1}+ CF, C2 : eucalyptus compost 5 t.ha^{-1}+ CF , C3 = manure compost 5 t.ha^{-1}+ CF, C4 : CF

Table 9. Correlation of rice yield parameters

Parameters	Plant height	Tiller number	Fresh weight	Dry weight	Grain yield
CH_4	-0.891**	-0.763**	-0.710**	-0.718**	-0.776**
Av. K	0.934**	0.853**	0.929**	0.944**	0.956**

Note: ** denotes that the correlation is significant at $p < 0.01$

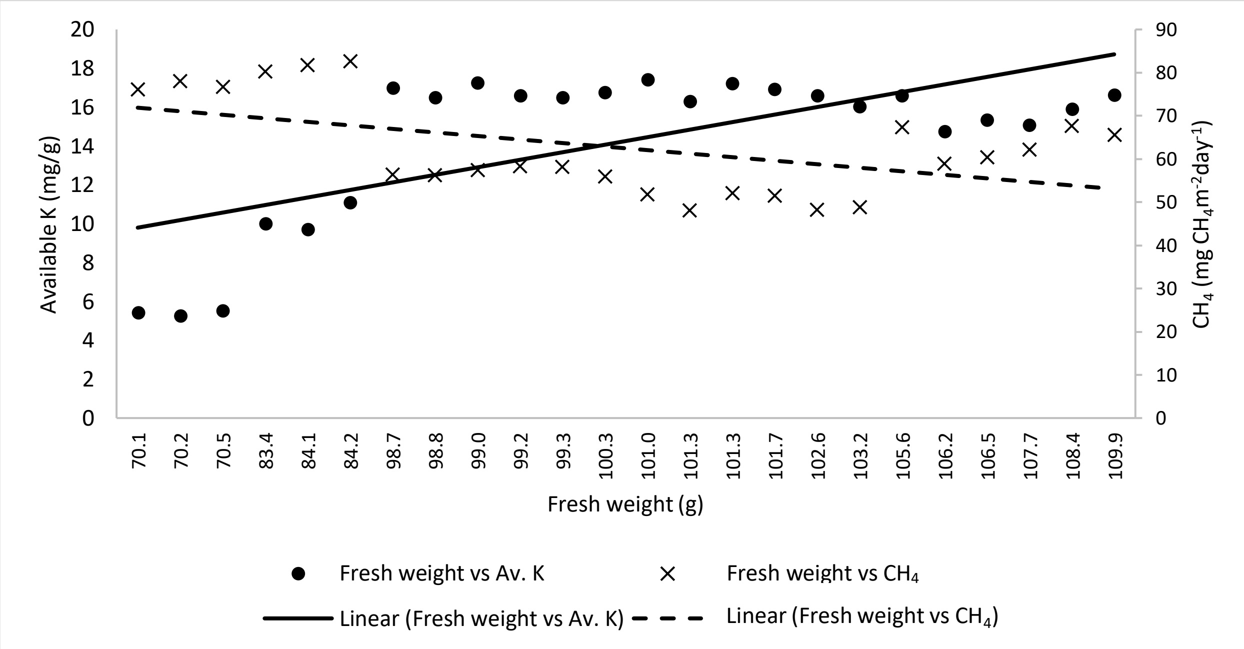


Figure 6. Linear regression of fresh weight on available K and CH_4 emission

Some studies also had found that during the thermophilic phase, composting can remove viruses and other microbiota that potentially harm plants (Cahyani & Kimura, 2009; Cahyani et al., 2009; Cahyani et al., 2002), so compost applied during rice cultivation expected to contain more beneficial microorganisms. In another study, the manure treatment produced the highest soil C, N, and P contents compared with other compost treatments using long term manure application (Ashraf et al., 2023). Despite the lower soil C, N, and P contents after eucalyptus and herbal compost application than manure, the levels were still categorized as high to very high based on the soil assessment of soil fertility criteria (Rachmadiyanto et al., 2020).

CH_4 flux in eucalyptus and herbal compost 10 $t.ha^{-1}$ treatments was significantly lower (Figure 1). Compost application helps minimize climate change through soil carbon sequestration, but it can also increase CH_4 emissions (Kim et al., 2022). Pujiarti et al. (2011) reported eucalyptus plants contain some chemical compounds, such as phenol and tannin, that inhibit some microbial growth in soil. This study discovered both herbal and eucalyptus comprising phenol (15% and 8%, respectively) higher than manure (2%). Furthermore, tannic compounds present in the eucalyptus compost 10 $t.ha^{-1}$ can reduce CH_4 emissions by reducing protozoa populations, which typically coexist with methanogens (Martin et al., 2010). The augmentation of PD bacteria in this study could be correlated to the increase in methanotrophs population because these bacteria dominate in optimum soil pH ranging from 5.5 to 6.5 (Zhao et al., 2015). Interestingly, the stepwise regression result demonstrated that available K and Eh became determinant factors in influencing the CH_4 flux that was emitted into the atmosphere (Table 6). This could be because available K is beneficial for plant growth and water uptake throughout the plant's development stage (Soumare et al., 2023). The increased plant growth might bring more oxygen to the rhizosphere, thus inhibiting methanogenic activity and improving methanotrophic activity (Dong et al., 2013). In addition, CH_4 emission had a linear regression with soil redox potential, with shrinking soil redox potential resulting in enhanced CH_4 emission. This agrees with a study conducted by Nungkat et al. (2015), in which CH_4 emission was found to be mainly influenced by oxygen availability in soil, and lower oxygen present in the soil promotes anaerobic fermentation.

The variation of treatments was highly significant in all rice yield indicators (Table 8). Amending soil with compost 10 $t.ha^{-1}$ increased grain yield. Rice yield in herbal compost 5 $t.ha^{-1}$ + CF and eucalyptus compost 5 $t.ha^{-1}$ + CF (C1 and C2) was not significantly different compared with the manure compost 5 $t.ha^{-1}$ (C3). Moreover, the grain yield in the eucalyptus compost 10 $t.ha^{-1}$ (O2) was not significantly different compared with manure compost 10 $t.ha^{-1}$ (O3), but slightly different with herbal compost 10 $t.ha^{-1}$ (O1). Overall, organic treatments resulted in a higher grain yield. Rice cultivation that uses organic farming system (not combination with CF) effectively increases farmers' income by augmenting the rice yield (Martiningsih et al., 2018). In particular, rice yield increased 16% in compost 10 $t.ha^{-1}$ and 34% in combination compost 5 $t.ha^{-1}$ and CF when manure and composts were applied. This validates a former study that used compost as soil amendment that created favorable soil condition in rice cultivation (Abdul Halim et al., 2018). Incorporating compost in the soil can enhance N uptake, resulting in better rice plant growth (Yang et al., 2016), leading to a higher decomposition process (Onwosi et al., 2017) and ultimately accelerating nutrient. The trend showed that manure treatment produced a higher yield at both vegetative and generative stages (Table 9). This could be because the C/N ratio of manure was released for plant growth (Yang et al., 2021).

Interestingly, available K positively correlated with all agronomic parameters, while a negative correlation was found between CH_4 emission and agronomic parameters in both organic and conventional farming systems (Table 9). Even though nitrogen becomes a critical soil nutrient for rice growth, the level of potassium in soil has a favorable link with ammonium concentration in a short period (IPI, 2022). Furthermore, (Carmeis Filho et al., 2017) explained that the increment of potassium concentration in rice cultivation increases root diameter and dry matter. The negative correlation between CH_4 emission and plant growth indicators might be because the density of rice plants stimulates more oxygen into the rhizosphere, thus enhancing CH_4 oxidation (Setyanto et al., 2004).

This study recommends the implementation of eucalyptus compost than manure compost because rice yield was statistically as high as that of the manure compost but resulting in a lower CH_4 emission. The application of chemical fertilizer was also not advised because the yield was similar and spending more cost for chemical fertilizer is unreasonable. As an alternative, herbal compost should be chosen over manure compost when available because it is low in CH_4 emission but has a slightly lower yield. Eucalyptus and herbal compost amendments support the sustainable agriculture by suppressing CH_4 emissions from rice field.

5. CONCLUSION

This study used different types of compost (herbal, eucalyptus, and manure compost) and its combination with chemical fertilizer (166 kg.ha^{-1} Urea + 166 kg.ha^{-1} ZA + 330 kg.ha^{-1} TSP) to decide the best soil amendment option for lowering methane emissions with a great yield on rice cultivation. The results showed that treatment with eucalyptus composts (eucalyptus compost 10 t.ha^{-1} (O2) and eucalyptus compost 5 t.ha^{-1} + chemical fertilizer (C2)) is best at reducing methane emissions from the rice field. While for rice yield, treatment with manure composts (manure compost 10 t.ha^{-1} O3 and manure compost 5 t.ha^{-1} + chemical fertilizer (C3)) resulted in the highest but not significantly different results with eucalyptus compost 10 t.ha^{-1} (O2), herbal compost 10 t.ha^{-1} + chemical fertilizer (C1) and eucalyptus compost 5 t.ha^{-1}+ chemical fertilizer (C2). Based on the results of this study, it can be concluded that the best amendment for the rice field is using eucalyptus compost as fertilizer, either on its own or combined with chemical fertilizer, because the results are not significantly different between O2 and C2 in terms of methane emission reduction and rice yield. Nevertheless, future studies are needed to develop the utilization of eucalyptus waste, herbal waste, and others with double functions as nutrient resources and to mitigate methane emissions.

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Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

References

Abdul Halim, N. S. a., Abdullah, R., Karsani, S. A., Osman, N., Panhwar, Q. A., & Ishak, C. F. (2018). Influence of Soil Amendments on the Growth and Yield of Rice in Acidic Soil. *Agronomy*, *8*(9), 165. https://doi.org/10.3390/agronomy8090165

Ashraf, M. N., Hu, C., Xu, X., Aziz, T., Wu, L., Waqas, M. A., Farooq, M., Hu, X., Zhang, W., & Xu, M. (2023). Long-term manure application increased soil organic carbon and nitrogen mineralization through accumulation of unprotected and physically protected carbon fractions. *Pedosphere*, *33*(2), 343-354. https://doi.org/10.1016/j.pedsph.2022.06.047

Ayalon, O., Avnimelech, Y., & Shechter, M. (2001). Solid Waste Treatment as a High-Priority and Low- Cost Alternative for Greenhouse Gas Mitigation. *Environmental Management*, *27*(5), 697-704. https://doi.org/10.1007/s002670010180

Bläsing, M., & Amelung, W. (2018). Plastics in soil: Analytical methods and possible sources. *Science of The Total Environment*, *612*, 422-435. https://doi.org/10.1016/j.scitotenv.2017.08.086

Cahyani, V. R., & Kimura, M. (2009). Succession and phylogenetic composition of microbial communities responsible for the composting process of rice straw. In J. C. Pereira & J. L. Bolin (Eds.), *Composting: Processing, Material and Approaches*. Nova Science Publishers, Inc.

Cahyani, V. R., Murase, J., Asakawa, S., & Kimura, M. (2009). Change in T4-type bacteriophage communities during the composting process of rice straw: Estimation from the major capsid gene (g23) sequences. *Soil Science & Plant Nutrition*, *55*(4), 468-477. https://doi.org/https://doi.org/10.1111/j.1747-0765.2009.00391.x

Cahyani, V. R., Watanabe, A., Matsuya, K., Asakawa, S., & Kimura, M. (2002). Succession of microbiota estimated by phospholipid fatty acid analysis and changes in organic constituents during the composting process of rice straw. *Soil Science and Plant Nutrition*, *48*(5), 735-743. https://doi.org/10.1080/00380768.2002.10409264

Carmeis Filho, A. C. D. A., Crusciol, C. A. C., Nascente, A. S., Mauad, M., & Garcia, R. A. (2017). Influência de níveis de potássio no crescimento radicular e na absorção de nutrientes em cultivares de arroz de terras altas. *Revista Caatinga*, *30*. https://doi.org/10.1590/1983-21252017V30N104RC

Conrad, R. (2009). The global methane cycle: recent advances in understanding the microbial processes involved. *Environmental Microbiology Reports*, *1*(5), 285-292. https://doi.org/https://doi.org/10.1111/j.1758-2229.2009.00038.x

Dong, D., Yang, M., Wang, C., Wang, H., Li, Y., Luo, J., & Wu, W. (2013). Responses of methane emissions and rice yield to applications of biochar and straw in a paddy field. *Journal of Soils and Sediments*, *13*(8), 1450-1460. https://doi.org/10.1007/s11368-013-0732-0

Epule, E. T., Peng, C., & Mafany, N. M. (2011). Methane emissions from paddy rice fields: strategies towards achieving a win-win sustainability scenario between rice production and methane emission reduction. *Journal of Sustainable Development*, *4*(6), 188. https://doi.org/10.5539/jsd.v4n6p188

Farrell, M., Griffith, G. W., Hobbs, P. J., Perkins, W. T., & Jones, D. L. (2009). Microbial diversity and activity are increased by compost amendment of metal-contaminated soil. *FEMS Microbiology Ecology*, *71*(1), 94-105. https://doi.org/10.1111/j.1574-6941.2009.00793.x

Haque, M. M., Biswas, J. C., Islam, M. R., Islam, A., & Kabir, M. S. (2019). Effect of long-term chemical and organic fertilization on rice productivity, nutrient use-efficiency, and balance under a rice-fallow-rice system. *Journal of Plant Nutrition*, *42*(20), 2901-2914. https://doi.org/10.1080/01904167.2019.1659338

Haque, M. M., Datta, J., Ahmed, T., Ehsanullah, M., Karim, M. N., Akter, M. S., Iqbal, M. A., Baazeem, A., Hadifa, A., Ahmed, S., & EL Sabagh, A. (2021). Organic Amendments Boost Soil Fertility and Rice Productivity and Reduce Methane Emissions from Paddy Fields under Sub-Tropical Conditions. *Sustainability*, *13*(6), 3103. https://doi.org/10.3390/su13063103

Hossen, M. S., Islam, M. N., Alamand, M. R., & Baten, M. A. (2015). Effects of Different Rates of Compost Application on Methane Emission and Crop Yield in Aman Rice [Compost, methane, rice, gas chromatography, FID]. *2015*, *2*(3), 7. http://www.journals.wsrpublishing.com/index.php/tjanrs/article/view/324

IPI. (2022). *The Effects of Nitrogen Form on Interactions with Potassium. E-ifc No.29 – Research findings.* International Potash Institute Retrieved December 10, 2022 from https://www.ipipotash.org/publications/eifc-214

Jeong, S. T., Kim, G. W., Hwang, H. Y., Kim, P. J., & Kim, S. Y. (2018). Beneficial effect of compost utilization on reducing greenhouse gas emissions in a rice cultivation system through the overall management chain. *Science of The Total Environment*, *613-614*, 115-122. https://doi.org/10.1016/j.scitotenv.2017.09.001

Kartikawati, R., & Nursyamsi, D. (2013). Pengaruh Pengairan, Pemupukan, Dan Penghambat Nitrifikasi Terhadap Emisi Gas Rumah Kaca Di Lahan Sawah Tanah Mineral [emisi gas rumah kaca, lahan sawah, pengairan, pemupukan, tanah mineral]. *2013*, *7*(2), 15. https://doi.org/10.20886/jklh.2013.7.2.93-107

Kelbesa, W. A. (2021). Effect of compost in improving soil properties and its consequent effect on crop production–A review. *Journal of Natural Sciences Research*, *12*(10), 15-25. https://doi.org/10.7176/JNSR/12-10-02

Kim, C., Walitang, D. I., Roy Choudhury, A., Lee, Y., Lee, S., Chun, H., Heo, T.-Y., Park, K., & Sa, T. (2022). Changes in Soil Chemical Properties Due to Long-Term Compost Fertilization Regulate Methane Turnover Related Gene Abundances in Rice Paddy. *Applied Sciences*, *12*(5), 2652. https://doi.org/10.3390/app12052652

Kim, W.-J., Bui, L. T., Chun, J.-B., McClung, A. M., & Barnaby, J. Y. (2018). Correlation between methane (CH4) emissions and root aerenchyma of rice varieties. *Plant breeding and biotechnology*, *6*(4), 381-390. https://doi.org/10.9787/PBB.2018.6.4.381

Kranz, C. N., McLaughlin, R. A., Johnson, A., Miller, G., & Heitman, J. L. (2020). The effects of compost incorporation on soil physical properties in urban soils – A concise review. *Journal of Environmental Management*, *261*, 110209. https://doi.org/10.1016/j.jenvman.2020.110209

Liu, Y., & Whitman, W. B. (2008). Metabolic, Phylogenetic, and Ecological Diversity of the Methanogenic Archaea. *Annals of the New York Academy of Sciences*, *1125*(1), 171-189. https://doi.org/https://doi.org/10.1196/annals.1419.019

Lopes, E. A. P., Silva, A. D. A. d., Mergulhão, A. C. d. E. S., Silva, E. V. N. d., Santiago, A. D., & Figueiredo, M. d. V. B. (2019). Co-Inoculation of growth promoting bacteria and glomus clarum in micropropagated cassava plants. *Revista Caatinga*, *32*. https://doi.org/10.1590/1983-21252019v32n116rc

Martin, C., Morgavi, D. P., & Doreau, M. (2010). Methane mitigation in ruminants: from microbe to the farm scale. *Animal*, *4*(3), 351-365. https://doi.org/10.1017/S1751731109990620

Martínez-Blanco, J., Lazcano, C., Christensen, T. H., Muñoz, P., Rieradevall, J., Møller, J., Antón, A., & Boldrin, A. (2013). Compost benefits for agriculture evaluated by life cycle assessment. A review. *Agronomy for Sustainable Development*, *33*(4), 721-732. https://doi.org/10.1007/s13593-013-0148-7

Martiningsih, E., Sumantra, I. K., & Sujana, I. P. (2018). The Profile of Salak Gula Pasir's Farmer in Pajahan Village–Bali. *International Journal of Contemporary Research and Review*, *9*(8), 20254-20256. https://doi.org/10.15520/ijcrr/2018/9/08/583

Mboyerwa, P. A., Kibret, K., Mtakwa, P., & Aschalew, A. (2022). Lowering nitrogen rates under the system of rice intensification enhanced rice productivity and nitrogen use efficiency in irrigated lowland rice. *Heliyon*, *8*(3). https://doi.org/10.1016/j.heliyon.2022.e09140

Minamikawa, K., Tokida, T., Sudo, S., Padre, A., & Yagi, K. (2015). *Guidelines for measuring CH4 and N2O emissions from rice paddies by a manually operated closed chamber method*. National Institute for Agro-Environmental Sciences, Tsukuba, Japan. https://globalresearchalliance.org/wp-content/uploads/2018/02/Guidelines-for-Measuring-CH4-and-N2O-Emissions-from-Rice-Paddies-by-Manually-Operated-Closed-Chamber-Method-2015.pdf

Nira, R., & Miura, S. (2019). Rice yield and soil fertility of an organic paddy system with winter flooding. *Soil Science and Plant Nutrition*, *65*(4), 377-385. https://doi.org/10.1080/00380768.2019.1632675

Nungkat, P., Kusuma, Z., & Handayanto, E. (2015). Effects of organic matter application on methane emission from paddy fields adopting organic farming system. *2015*, *2*(2), 10. https://doi.org/10.15243/jdmlm.2014.022.303

Onwosi, C. O., Igbokwe, V. C., Odimba, J. N., Eke, I. E., Nwankwoala, M. O., Iroh, I. N., & Ezeogu, L. I. (2017). Composting technology in waste stabilization: On the methods, challenges and future prospects. *Journal of Environmental Management*, *190*, 140-157. https://doi.org/10.1016/j.jenvman.2016.12.051

Pujiarti, R., Ohtani, Y., & Ichiura, H. (2011). Physicochemical properties and chemical compositions of Melaleuca leucadendron leaf oils taken from the plantations in Java, Indonesia. *Journal of Wood Science*, *57*(5), 446-451. https://doi.org/10.1007/s10086-011-1183-0

Rachmadiyanto, A. N., Wanda, I. F., Rinandio, D. S., & Magandhi, M. (2020). Evaluasi kesuburan tanah pada berbagai tutupan lahan di Kebun Raya Bogor. *Buletin Kebun Raya*, *23*(2), 114–125-114–125. https://doi.org/10.14203/bkr.v23i2.263

Razavipour, T., Moghaddam, S. S., Doaei, S., Noorhosseini, S. A., & Damalas, C. A. (2018). Azolla (Azolla filiculoides) compost improves grain yield of rice (Oryza sativa L.) under different irrigation regimes. *Agricultural Water Management*, *209*, 1-10. https://doi.org/10.1016/j.agwat.2018.05.020

Sallam, S. M. A., Bueno, I. C. S., Nasser, M. E. A., & Abdalla, A. L. (2010). Effect of eucalyptus (Eucalyptus citriodora) fresh or residue leaves on methane emission in vitro. *Italian Journal of Animal Science*, *9*(3), e58. https://doi.org/10.4081/ijas.2010.e58

Sarwar, G., Hussain, N., Schmeisky, H., Muhammad, S., Ibrahim, M., & Safdar, E. (2007). Use of compost an environment friendly technology for enhancing rice-wheat production in Pakistan. *Pakistan Journal of Botany*, *39*(5), 1553-1558. https://www.researchgate.net/publication/271574351_USE_OF_COMPOST_AN_ENVIRONMENT_FRIENDLY_TECHNOLOGY_FOR_ENHANCING_RICE-WHEAT_PRODUCTION_IN_PAKISTAN

Schirmer, W. N., Jucá, J. F. T., Schuler, A. R. P., Holanda, S., & Jesus, L. L. (2014). Methane production in anaerobic digestion of organic waste from Recife (Brazil) landfill: evaluation in refuse of diferent ages. *Brazilian Journal of Chemical Engineering*, *31*.

Setyanto, P., Rosenani, A., Boer, R., Fauziah, C., & Khanif, M. (2004). The effect of rice cultivars on methane emission from irrigated rice field. *Indonesian Journal of Agricultural Science*, *5*(1), 20-31. https://repository.pertanian.go.id/server/api/core/bitstreams/459b62bf-b3cf-43bc-976a-392b9fe20deb/content

Sopha, G. A., Hermanto, C., Kerckhoffs, H., Heyes, J. A., & Hanly, J. (2022). Response of selected chemical properties of extremely acidic soils on the application of limes, rice husk biochar and zeolite. *Journal of Degraded & Mining Lands Management*, *10*(1). https://doi.org/10.15243/jdmlm.2022.101.4011

Soumare, A., Sarr, D., & DiÉDhiou, A. G. (2023). Potassium sources, microorganisms and plant nutrition: Challenges and future research directions. *Pedosphere*, *33*(1), 105-115. https://doi.org/10.1016/j.pedsph.2022.06.025

Sparks, D. L., Page, A. L., Helmke, P. A., & Loeppert, R. H. (Eds.). (2020). *Methods of Soil Analysis, Part 3: Chemical Methods* (Vol. 14). John Wiley & Sons.

Trinh, M. V., Tesfai, M., Borrell, A., Nagothu, U. S., Bui, T. P. L., Quynh, V. D., & Thanh, L. Q. (2017). Effect of organic, inorganic and slow-release urea fertilisers on CH4 and N2O emissions from rice paddy fields. *Paddy and Water Environment*, *15*(2), 317-330. https://doi.org/10.1007/s10333-016-0551-1

Wang, C., Lai, D. Y. F., Sardans, J., Wang, W., Zeng, C., & Peñuelas, J. (2017). Factors Related with CH4 and N2O Emissions from a Paddy Field: Clues for Management implications. *PLOS ONE*, *12*(1), e0169254. https://doi.org/10.1371/journal.pone.0169254

Yang, R., Dong, J., Li, C., Wang, L., Quan, Q., & Liu, J. (2021). The decomposition process and nutrient release of invasive plant litter regulated by nutrient enrichment and water level change. *PLOS ONE*, *16*(5), e0250880. https://doi.org/10.1371/journal.pone.0250880

Yang, Y.-L., Xu, J., Rao, Y.-C., Zeng, Y.-J., Liu, H.-J., Zheng, T.-T., Zhang, G.-H., Hu, J., Guo, L.-B., Qian, Q., Zeng, D.-L., & Shi, Q.-H. (2016). Cloning and functional analysis of pale-green leaf (PGL10) in rice (Oryza sativa L.). *Plant Growth Regulation*, *78*(1), 69-77. https://doi.org/10.1007/s10725-015-0075-5

Zhang, X., Khalid, M., Wang, R., Chi, Y., Zhang, D., Chu, S., Yang, X., & Zhou, P. (2023). Enhancing lettuce growth and rhizosphere microbial community with Bacillus safensis YM1 compost in soilless cultivation: An agricultural approach for kitchen waste utilization. *Scientia Horticulturae*, *321*, 112345. https://doi.org/10.1016/j.scienta.2023.112345

Zhao, T., Xing, Z., Zhang, L., Zhang, Y., & Gao, Y. (2015). Biodegradation of chlorinated hydrocarbons by facultative Methanotrophs [Review]. *Asian Journal of Chemistry*, *27*(1), 9-18. https://doi.org/10.14233/ajchem.2015.18022