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Effect of Organic Fertilizer on CO_2, CH_4 and N_2O Emissions in a Paddy Field

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Abstract

A study on the effect of organic fertilizer (cow manure) on carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions in a paddy field was conducted. Suphanburi 1 rice varieties were planted in a double-crop organic rice field at Pathum Thani Rice Research Center, Pathum Thani Province, Thailand. The study was categorized into 4 sets of experiments as follows: 1) control, without added fertilizer, 2) addition of organic fertilizer (cow manure) at 3.13 $t \cdot ha^{-1}$, 3) addition of organic fertilizer at 9.38 $t \cdot ha^{-1}$ and 4) addition of organic fertilizer at 12.50 $t \cdot ha^{-1}$. The study showed that the set with the addition of organic fertilizer at 12.50 $t \cdot ha^{-1}$ had the highest emissions rate of methane at an average rate of 4.94 $mg \cdot m^{-2}$ d. Lower methane emissions were found in the sets with added organic fertilizer at 9.38 $t \cdot ha^{-1}$ and in the control set without added fertilizer and the set with added organic fertilizer at 3.13 $t \cdot ha^{-1}$, with an average emission rate of 3.08, 1.77 and 1.49 $mg \cdot m^{-2} \cdot d$, respectively. The differences in the methane emissions of all of the sets are statistically significant, ($P<0.05$). Compared to the other sets, the carbon dioxide emissions were highest in the set with added organic fertilizer at 9.38 $t \cdot ha^{-1}$, at an average rate of 380.55 $mg \cdot m^{-2} \cdot d$. The rates were lower in the set with added organic fertilizer at 3.13 $t \cdot ha^{-1}$, the control set without added fertilizer, and the set with the addition of organic fertilizer at 12.50 $t \cdot ha^{-1}$, with emission rates of 325.24, 253.92 and 198.16 $mg \cdot m^{-2}$ d, respectively. However, these results had no significant difference. Meanwhile, the nitrous oxide emissions during the growing season of the rice were the highest in the set with the addition of organic fertilizer at 9.38 $t \cdot ha^{-1}$, which had an average rate of 1.41 $mg \cdot m^{-2} \cdot d$. The rate was lower in the control set without added fertilizer, the set with added organic fertilizer at 3.13 $t \cdot ha^{-1}$, and the set with added organic fertilizer at 12.50 $t \cdot ha^{-1}$ with average emissions rates of 1.10, 1.40 and 0.60 $mg \cdot m^{-2} \cdot d$, respectively.

Keywords: organic fertilizer, paddy field, methane, nitrous oxide, carbon dioxide

1. Introduction

Global climate change is caused by the proliferation of greenhouse gases in the atmosphere. The greenhouse gases produced in nature include steam, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). In addition, greenhouse gases are also produced by human activities, which contribute to the increase of greenhouse gas emissions concentrations in the atmosphere. Paddy field farming is an essential source of greenhouse gas emissions because rice fields are flooded for farming, where the anaerobic condition favors the activities of methanogens in presence of organic matter. These methanogens grow well in anaerobic conditions (Dubey, 2005). Thus, this was believed to contribute substantially to the increase in the methane content of the atmosphere (Banik et al., 1995). The emission of carbon dioxide into the atmosphere can be derived from several processes, for instance, fuel combustion and deforestation. On the contrary, during the process of tree growth, trees can absorb carbon dioxide and transform it to biomass. This process is called "carbon sequestration" and is regarded as the most proficient process to reduce the amount of carbon dioxide (Jitpitak, 1999). Moreover, the use of fertilizers in paddy fields is another essential cause of greenhouse gas emissions. Agriculture is the main source of most nitrous oxide emissions (Yang et al., 2009). Similarly, according to Gogoi and Baruah's report (2012), the emission of nitrous oxide from agricultural activities increased 17% worldwide between 1990 and 2005 is expected that emissions could increase to 35-60% by 2030 due to activities involving nitrogen fertilizers and stable manure. Nitrous oxide is produced by microorganisms living in soil through the processes of nitrification and denitrification (Davidson & Schimel, 1995). Therefore, rice farming is a crucial problem that may have an effect on the world's quantity of greenhouse gas emissions. While rice consumption and competition in the market are continually increasing, there is much research studying how to reduce greenhouse gas emissions from rice farming using several means, including a study on the effect of fertilizers on greenhouse gas emissions in paddy fields. The purpose of this study is to determine a method for farmers to use fertilizer properly. For instance, a study on the effect of organic fertilizers on methane emission in off-season rice farming reported that the application of 6.25 $t{\cdot}ha^{-1}$ of manure on rice paddies resulted in lower greenhouse gas emissions than the use of chemical fertilizers (Sampanpanish, 2011). Thus, the objective of this study is to determine the effect of organic fertilizer or cow manure on the emission of greenhouse gases at different rates of fertilizer application; this was inform the optimum rate of fertilizer use in paddy field to reduce the emissions of carbon dioxide, methane, and nitrous oxide, which are the most common greenhouse gases in the world.

2. Materials and Methods

2.1 Paddy Field Plot Preparation

The preparation of the paddy field included 4 of 20 x 20 meter organic paddy fields provided by the Pathum Thani Rice Research Center. The test field preparation was performed by pulling out rice stubble and plowing the test fields to 30 cm deep at the maximum. No fresh or dried straw was added to the test fields. All of the test fields were prepared in this way. Bund walls were built to separate each test field and to prevent contamination or the overflow of water from other test fields. The off-season rice was grown by the transplant method.

2.2 Seeding Preparation

The preparation of the Suphanburi 1 rice varieties was conducted by selecting seeds of equal size and weight, with a seed germination rate higher than 80% and without contamination. The seeds were provided by the Rice Department of the Ministry of Agriculture and Cooperatives. The rice seeds were soaked in water for 12 hours and then covered with gunnysacks for 2 nights before they germinated. The germinated seeds were sown in smaller plots and were left in the fields for 28 days to obtain rice sprouts. The sprouts were then transplanted into the previously prepared 20 x 20 meter plots.

2.3 Fertilizer Preparation

The fertilizer used in this research was an organic fertilizer or cow manure obtained from the Pathumthani region. The fertilizer was sampled and analyzed to measure pH, moisture content, total nitrogen, the carbon/nitrogen ratio (C/N) and total organic carbon. The fertilizer used in this experiment contained 17.85% carbon and 1.5% nitrogen, and its C/N ratio was 12:1. The fertilizer application rates are shown in Table 1. The application of the fertilizer was conducted in 3 stages: the before-planting stage, the vegetative stage and the panicle-formation stage.

Table 1. Rate of added fertilizer in the paddy field

Plots	Note	Rate of added fertilizer
A plots	Control plots without added fertilizer	Without added fertilizer through the stage of rice growth
B plots	Plots with the addition of organic fertilizer (cow manure) 3.1 $t{\cdot}ha^{-1}$	1^{st} = 1.56 $t{\cdot}ha^{-1}$
		2^{nd} = 0.94 $t{\cdot}ha^{-1}$
		3^{rd} = 0.63 $t{\cdot}ha^{-1}$
C plots	Plots with the addition of organic fertilizer (cow manure) 9.4 $t{\cdot}ha^{-1}$	1^{st} = 4.69 $t{\cdot}ha^{-1}$
		2^{nd} = 2.81 $t{\cdot}ha^{-1}$
		3^{rd} = 1.88 $t{\cdot}ha^{-1}$
D plots	Plots with the addition of organic fertilizer (cow manure) 12.5 $t{\cdot}ha^{-1}$	1^{st} = 6.25 $t{\cdot}ha^{-1}$
		2^{nd} = 3.75 $t{\cdot}ha^{-1}$
		3^{rd} = 2.50 $t{\cdot}ha^{-1}$

2.4 Rice Planting and Maintenance

Sprouts were transplanted into flooded test fields. The flooding level had been controlled at a height of 5-10 cm, and this level was maintained until the rice produced grains. At this point, the fields were drained out and dried off to allow grains to be stronger and later harvested.

2.5 Sample Collection and Analysis

In this study, the sampling of soil, water and air were conducted in 5 stages: the before-planting stage, the initial stage (30 days post-transplantation), the vegetative stage, the panicle formation stage and the maturation stage.

1) Soil sampling in the before-planting stage was conducted by sampling soil from 3 locations in each test field. Soil from all 3 locations was combined to obtain a composite sample. The composite sample was divided into 2 portions. The first portion was dried out at room temperature, and then it was sent to a laboratory to analyze the following parameters: soil texture, moisture, pH, cation exchange capacity (CEC), electrical conductivity (EC), organic matter (OM), oxidation-reduction potential (ORP), nitrogen content, phosphorous content, and potassium content. The second portion was dried out at 105 °C for 24-48 hours and then ground and sieved using a 2 millimeter mesh size to analyze heavy metals, i.e., Cd, Cr, Cu, Pb, Mn, Ni, Zn, As, Se, and Hg. The pH was measured for the initial stage, the vegetative stage, the panicle formation stage and the maturation stage of the sample.

2) Water sampling in the before-planting stage was conducted by sampling water from the flooded fields into 1,000 ml bottles, which were analyzed in the laboratory. The following parameters were analyzed for water sampled in the before-planting stage: BOD, DO, pH, EC, and ORP. The temperature and pH of the samples from the initial stage, the vegetative stage, the panicle formation stage and the maturation stage were measured.

3) Air sampling was conducted by using chambers with a 0.6 x 0.6 x 0.8 m (0.29 m^3) covering on all 4 test fields. Three chambers were used and spread out in each test field, and the sampling was performed in all 5 stages. The covering time was from 8.00-11.00 in the morning. A personal pump air sample was used to suck the air in the chambers through a tube and into air bags. The temperature and pressure of the air both inside and outside of the chambers were measured. The air samples were analyzed to determine the quantities of carbon dioxide, methane, and nitrous oxide.

2.6 Air Analysis

The air samples were analyzed for carbon dioxide and methane using gas chromatography (GC), and nitrous oxide was analyzed using Fourier transform infrared spectroscopy (FTIR). The concentration of greenhouse gas emissions was analyzed for flux using the following equation (Singh et al., 1998).

$$[F]=\frac{BV_{STD}\times dC\times MW\times 1,000\times 60}{10^4\times 22,400\times A\times dt} \quad (1)$$

$$[BV_{STD}]=\frac{BV\times B.P.\times 273}{(273+T)\times 760} \quad (2)$$

where

F = Flux value for each gas ($mg/m^2/hr$)

BV = Volume inside the plastic box at a point located above the flooding level (cm^3)

B.P. = Ambient pressure at that time (mm Hg)

MW = Molecular weight for each gas

T = Temperature of the air in the box ($^{\circ}C$)

A = Cross Section of the box (m^2)

dC = Differential concentration of each gas at time zero and t (minute)

dt = Contact time (minute)

3. Statistical Analysis

The variation of carbon dioxide, methane and nitrous oxide emissions data from the experiment was analyzed using ANOVA, and the differences of the data were compared using Duncan's new multiple range test (DMRT). The statistical analysis was implemented using Statistical Package for the Social Sciences (SPSS).

4. Results and Discussion

4.1 Soil Chemical and Physical Properties

The soil texture was clay, and was composed of 1.1% sand, 36.6% silt and 62.3% clay. Methane production increased when soil density increased (Sass & Fisher, 2004). Moreover, it was found that the soil in all of the test fields consisted of 3.21% organic matter by weight, on average. Table 2 shows the properties of the soil from the test fields.

After analyzing soil properties in all stages of rice growth, it was found that soil pH fell in the range of 4.2-6.9 (shown in Table 3) and soil from the panicle formation stage showed the highest pH values. This high pH value might be from the final application of manure in the panicle formation stage, as the manure was strongly alkaline, with a pH value of 9.3. As a result, the test fields had higher pH values. The level of pH is essential to methane production in flooded rice fields, and the process is sensitive to changes in pH.

The electrical conductivity of the soil in the vegetative stage increased over that of soil in the initial stage, and the conductivity tended to decrease during panicle formation stage (Table 3). The electrical conductivity values of the soil during all stages of rice growth ranged from 228-502 µs/cm. The test fields that had manure applied during the before-planting stage through the panicle formation stage tended to be lower in oxidation-reduction potential (the concentration of electrons from oxidation and reduction processes) in the later stages, compared to the oxidation-reduction potential of the fields that had manure applied in the before-planting stage. This result may be due to a loss of oxygen due to the waterlogged condition of fields. After the fields had been flooded, the dissolved oxygen in the water was quickly consumed by facultative anaerobic organisms and true anaerobic organisms for electron reception (Wang et al., 1996). Meanwhile, the controlled test field with no fertilizer applied during the entire test period had an oxidation-reduction potential that tended to change slightly. This could result from the absence of manure, which directly corresponded to the rise of organic matter and aerobic microorganisms.

Table 2. Physical and chemical properties of paddy field soil at before-planting stages

Stage of rice growth	Soil properties			
	pH	Electrical conductivity (µs/cm)	Oxidation-reduction potential (mV)	Cation exchange capacity (cmolckg-1)
Before planting	5.3	33.3	281.26	13.02

Table 3. Physical and chemical properties of paddy field soil at all stages of rice growth

Stage of rice growth / plots	Soil properties		
	pH	Electrical conductivity (µs/cm)	Oxidation-reduction potential (mV)
Initial stage			
A plots	4.7	332	241.5
B plots	5.2	256	234.0
C plots	5.2	283	259.8
D plots	5.0	267	310.7
Vegetative stage			
A plots	5.1	414	230.2
B plots	4.6	228	296.7
C plots	5.3	400	177.8
D plots	5.7	246	184.0
Panicle-formation stage			
A plots	5.1	263	278.2
B plots	5.3	338	290.1
C plots	6.9	243	170.9
D plots	6.4	249	109.3
Maturation stage			
A plots	4.2	385	368.5
B plots	6.0	289	106.3
C plots	5.2	400	210.6
D plots	4.8	502	240.6

Note:

A Plots = control plots without added fertilizer

B Plots = plots with the addition of organic fertilizer (cow manure) 3.13 $t{\cdot}ha^{-1}$

C Plots = plots with the addition of organic fertilizer (cow manure) 9.38 $t{\cdot}ha^{-1}$

D Plots = plots with the addition of organic fertilizer (cow manure) 12.50 $t{\cdot}ha^{-1}$

4.2 Water Chemical and Physical Properties

The analysis of water during the entire growing stages of rice showed that the pH ranged from 4.1-6.7 (Table 4). Moreover, during the preparation of test fields, the water in the fields was strongly acidic (pH 3.8). However, after the application of manure, the water pH was higher in all fields. This might be caused from the combination between the manure, which was strongly alkaline (pH 9.3) and water in the test fields.

Table 4 shows that pH is an essential factor that encourages the growth of methane-producing microorganisms. These microorganisms are sensitive to changes in pH. They grow well at pH levels from 6-8, with an optimum pH of 7 (Alexander, 1977; Nimrat, 2006). The electrical conductivity during all rice growing stages ranged from 524-3,101 µs/cm. The conductivity tended to be lower as rice growth progressed, which was demonstrated by the constant reduction of oxygen content. This result might be because the aerobic microorganisms used oxygen as electron receptors, causing a reduction in oxygen in the rice fields, which was demonstrated by lower electrical conductivity.

Table 4. Physical and chemical properties of water in paddy fields at all stages of rice growth

Stage of rice growth / plots	Water properties				
	pH	Electrical conductivity (µs/cm)	Oxidation-reduction potential (mV)	DO (mg/l)	BOD (mg/l)
Before planting	3.8	1,994	409.5	5.7	2.5
Initial stage					
A plots	4.1	2,670	284.5	7.7	1.5
B plots	4.2	3,101	340.9	9.2	10
C plots	6.1	2,510	229.5	9.2	3.7
D plots	6.2	1,920	266.7	10.7	3.5
Vegetative stage					
A plots	5.8	1,060	245.5	4.5	7.7
B plots	6.2	675	206.8	3.9	4.0
C plots	6.3	604	199.4	3.6	6.3
D plots	6.3	524	202.6	3.7	11
Panicle-formation stage					
A plots	5.1	1,585	283.5	2.8	5.1
B plots	5.6	740	280.1	3.4	3.9
C plots	5.9	823	284.5	3.1	2.8
D plots	5.9	847	281.8	1.9	4.0
Maturation stage					
A plots	5.7	910	235	2.7	3
B plots	6.3	650	212.2	1.8	2.7
C plots	6.3	567	211.6	3.1	2.5
D plots	6.7	572	213.4	2.6	3.5

Note:

A Plots = control plots without added fertilizer

B Plots = plots with the addition of organic fertilizer (cow manure) 3.13 $t{\cdot}ha^{-1}$

C Plots = plots with the addition of organic fertilizer (cow manure) 9.38 $t{\cdot}ha^{-1}$

D Plots = plots with the addition of organic fertilizer (cow manure) 12.50 $t{\cdot}ha^{-1}$

4.3 Quantity of Greenhouse Gas Emissions

1) Carbon Dioxide Emissions

The analysis of carbon dioxide emission from paddy fields in all 4 test sets (Figure 1) shows that the controlled field with no fertilizer applied during the entire period of the experiment emitted the highest amount of carbon dioxide at 301.42 mg·m^{-2}·d, and the emission rates declined to 298.27, 286.48, and 281.23 mg·m^{-2}·d in fields applied manure at 9.38, 12.50 and 3.13 t·ha^{-1}, respectively. However, these emission rates show no significant differences. Furthermore, the controlled field emitted the highest amount of carbon dioxide compared to that of all other fields with applied fertilizer. The application of organic substances or manure at high rates in the fields caused the deposition of soil and organic substances. The organic substances reacted with soil particles to form complex compounds that were hardly decomposed into carbon dioxide (Suwannarit, 2008). Thus, the test fields with fertilizer applied in all test sets tended to emit less carbon dioxide than the fields without fertilizer applied. When comparing these results with the result of Sampanpanish (2011) in which Suphanburi 1 rice varieties were grown and 6.25 t·ha^{-1} manure was applied, Sampanpanish found carbon dioxide emissions of 377.35 mg·m^{-2}·d, which was higher than the carbon dioxide emissions in fields with 3.13, 9.38 and 12.50 t·ha^{-1} of fertilizer applied in this study, as well as higher than the emissions in fields with no fertilizer applied. The reason for this could be that this study was conducted after a flood in the region, which caused depositions of dead plants and organic substances carried by the flood. The depositions reduced air circulation in the fields and resulted in lower carbon dioxide emissions than those in Sampanpanish's study.

Figure 2 provides the carbon dioxide emissions data in all growth stages and shows that the maturation stage had the highest rate of carbon dioxide emissions at 504.86 mg·m^{-2}·d on average. The differences between this emissions rate and the emissions rates of all other stages were statistically significant ($P<0.05$). These differences could result from higher oxygen content due to the draining of the water in the fields, leading to greater production of carbon dioxide. The second highest rate of carbon dioxide emissions occurred in the panicle formation stage at a rate of 339.21 mg·m^{-2}·d. During that stage, the rice consumed high energy to grow and produce its product. Light synthesis occurred at a higher rate than it did during the initial stage and the vegetative stage, when carbon dioxide was emitted merely at 206.32 and 117.02 mg·m^{-2}·d, respectively. These differences were statistically significant ($P<0.05$).

2) Methane Emissions

According to the amount of methane emissions, throughout the entire rice growth stages (Figure 3), the test field with a 12.50 t·ha^{-1} application of manure emitted the highest rate of methane emission, 4.93 mg·m^{-2}·d on average. This rate was higher than that of fields with 9.38 and 3.13 t·ha^{-1} of manure and that of the controlled field, which had rates of 3.08, 1.49, and 1.77 mg·m^{-2}·d, respectively. The differences were statistically significant ($P<0.05$). The methane emitted was produced by bacteria that decomposed organic matter in soil without air (Dubey, 2005).

Figure 4 shows that the methane emissions rates at each stage of rice growth are significantly different ($P<0.05$). The field applying 12.50 t·ha^{-1} of manure in the vegetative stage emitted the highest amount of methane; the amount declined in the control field, in the field with 9.38 t·ha^{-1} of manure, and in the field with 3.13 t·ha^{-1} of manure, in which the emission rates were 7.31, 6.90, 5.41 and 1.81 mg·m^{-2}·d, respectively. Figure 4 provides the average methane emissions through all of the rice growing stages and also shows that the use of manure in rice farming is an essential factor that encourages the process of methane production in paddy fields. The highest application rate of manure, 12.50 t·ha^{-1}, resulted in the highest rate of methane emissions because the production of methane in paddy fields is caused by the organic substance decomposition by microorganisms in an aerobic environment that transforms carbon into methane. As a result, the application of manure or any other organic substance into soil will raise the amount of carbon and the amount of microorganisms in soil. Once there were more organic substances, the microorganisms needed more oxygen to decompose the organic substances; therefore, the soil lost oxygen. This aerobic condition encouraged microorganisms to produce more methane through methanogenesis. Conversely, in the field with the least manure, 3.13 t·ha^{-1}, the methane emissions were lowest.

3) Nitrous oxide Emissions

Comparing all of the growth stages of rice, fields with 9.38 t·ha^{-1} manure applied had the highest emissions rate, 1.41 mg·m^{-2}·d of nitrous oxide (Figure 5). The emission rates were lower in fields with 0 (control set), 12.50 and 3.13 t·ha^{-1} of manure applied, with average rates throughout all growth stages of 1.09, 0.59, and 0.60 mg·m^{-2}·d, respectively. However, the differences between emissions rates were not statistically significant. Furthermore, Sampanpanish (2011), which used 6.25 t·ha^{-1} of manure, found that the average emissions rate of nitrous oxide was 1.21 mg·m^{-2}·d. Nitrous oxide is produced by a process called denitrification, which is the reduction reaction of nitrate to nitrous oxide gas or nitrogen gas by denitrifying bacteria (Takaya, 2002; Nimrat, 2006). The bacteria are facultative anaerobic bacteria that prefer to use nitrogen in nitrate form as electron receptors rather than oxygen (Paul & Clark, 1996) in waterlogged and aerobic environments. The application of organic fertilizers or manure onto paddy fields stimulated oxygen shortages, causing denitrification. However, the reason that the differences between manure application sets were not statistically significant might be because the nitrogen content in the manure was quite low compared to its carbon content. As a result, microorganisms had no nitrogen to use as a raw material in the denitrification process.

According to Figure 6, which illustrates the emissions of nitrous oxide in all growth stages of rice, rice during the initial stage emitted the highest amount of nitrous oxide, an average of 2.99 mg·m^{-2}·d. Rice during the maturation stage and the panicle formation stage emitted lower amounts of nitrous oxide, an average of 0.53 and 0.10 mg·m^{-2}·d, respectively. During the vegetative stage, rice emitted the lowest amount of nitrous oxide, 0.08 mg·m^{-2}·d. The differences between emissions rates were statistically significant (P<0.05). The differences could be explained by the diversion of water into the fields during the initial stage, which quickly caused an aerobic condition due to the reduction in oxygen, illustrated by the constant decline in oxidation-reduction potential (Tables 2-3) after creating a waterlogged condition in the fields. Additionally, a larger amount of manure was applied during the field preparation stage than during other stages. The organic matter from the manure caused facultative anaerobic bacteria to use nitrogen in nitrate form as electron receptors rather than the depleted oxygen. As a result, nitrous oxide was produced in large amounts.

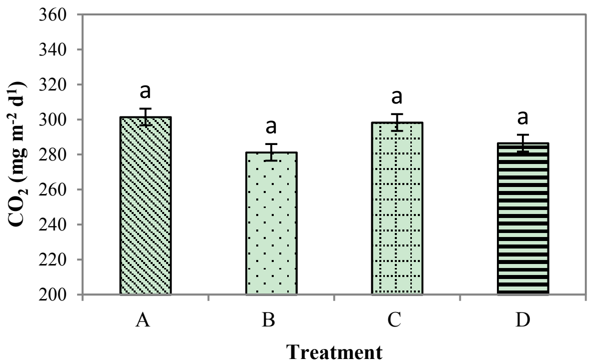

Figure 1. Carbon dioxide quantity in paddy fields each plot

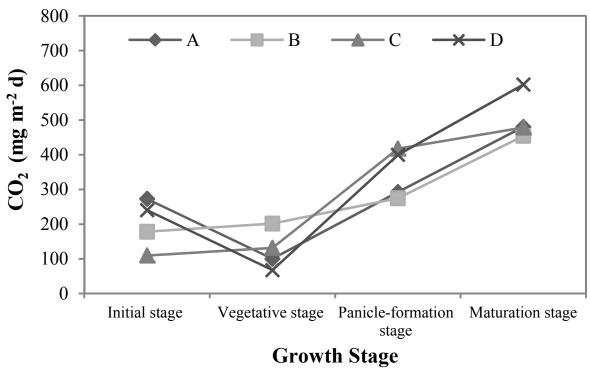

Figure 2. Carbon dioxide quantity in paddy fields at all plots throughout rice growth

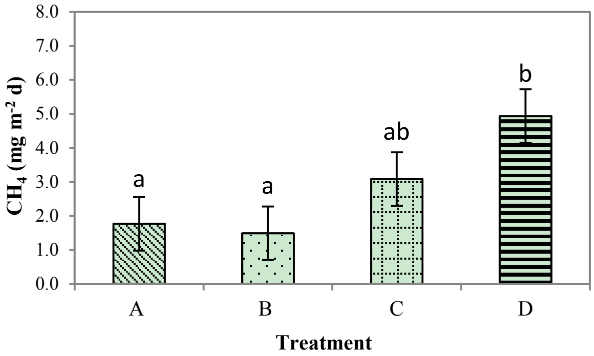

Figure 3. Methane quantity in paddy fields each plot

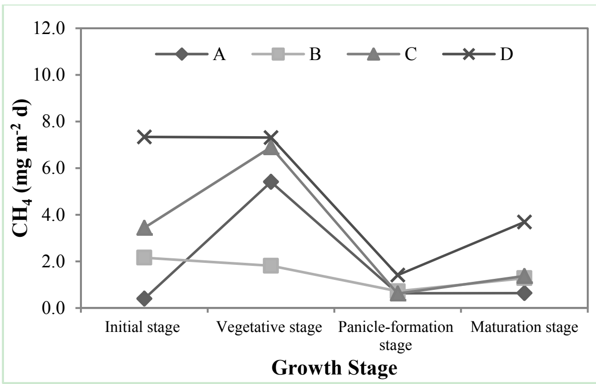

Figure 4. Methane quantity in paddy fields at all plots throughout rice growth

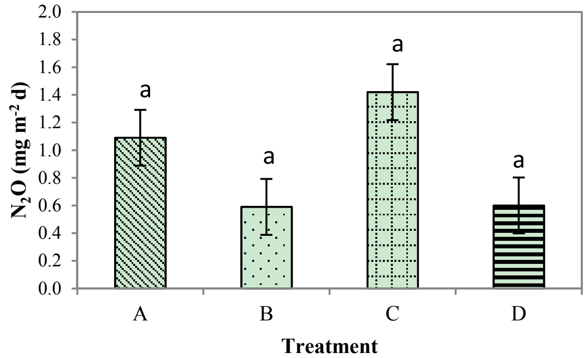

Figure 5. Nitrous oxide quantity in paddy fields each plot

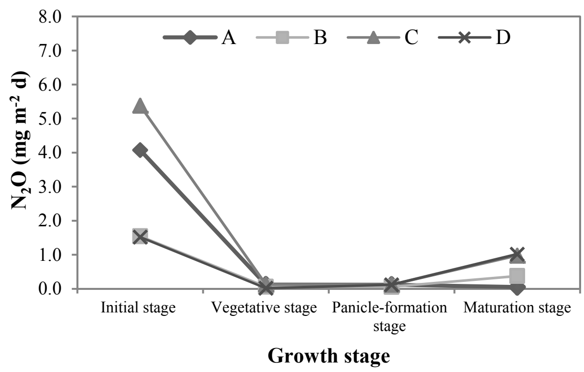

Figure 6. Nitrous oxide quantity in paddy fields at all plots throughout rice growth stages

Note:

A Plots = control plots without added fertilizer

B Plots = plots with the addition of organic fertilizer (cow manure) 3.13 t·ha^{-1}

C Plots = plots with the addition of organic fertilizer (cow manure) 9.38 t·ha^{-1}

D Plots = plots with the addition of organic fertilizer (cow manure) 12.50 t·ha^{-1}

5. Conclusions

The choice of manure application rates in paddy fields is not considered a negligible factor because overdoses of manure application can contribute to global warming. Methane was produced at the highest rate in the field with 12.50 t·ha^{-1} of manure applied. Meanwhile, the field with manure application at a rate of 9.38 t·ha^{-1} emitted carbon dioxide and nitrous oxide at high rates, which corresponds to the results from Sampanpanish's study (2011), which studied the effect of manure on the emission of greenhouse gases using 6.25 t·ha^{-1} of manure. Therefore, the optimum application rates of manure are between 3.13-6.25 t·ha^{-1} because those application rates have the least effect on quantities of greenhouse gas emissions. Although the application of fertilizer is inevitable, choosing organic fertilizers or manure over chemical fertilizers and applying them at optimum rates will help farmers alleviate the greenhouse gas emissions problem caused by fertilizer application in rice farming.

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