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Comparison of methane emission characteristics in air-dried and composted cattle manure amended paddy soil during rice cultivation

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ABSTRACT

Application of organic matter is essential for sustaining the health and productivity of a soil. However, organic amendments produce methane (CH_4) emissions from rice (*Oryza sativa* L.) paddy soils. In this experiment, we evaluated the relative effects of composted and air-dried forms of different manures on CH_4 emission from rice paddy soils. Air-dried and composted manures from both Korean cows and dairy cows were applied to evaluate their effects on CH_4 emissions in rice paddy soils. Application of organic amendments increased CH_4 emissions from soil during rice cultivation. Application of composted manures reduced CH_4 emission by up to 50% compared to air-dried manures. The chemical composition of applied cattle manures may also determine the level of CH_4 emissions from rice paddy soils. The amount of decomposable organic C, its distribution in lighter soil aggregates and the potential of these soil aggregates to generate labile C compounds in soil were possible influencing factors in the emission of CH_4 from organic amended rice paddy soils.

1. Introduction

Methane (CH_4) is considered to be the second most potent greenhouse gas in the atmosphere after carbon dioxide (CO_2) (IPCC, 2001). However, the global warming potential of CH_4, per molecule basis, is 25 times higher than that of CO_2 (IPCC, 2007). The current average atmospheric CH_4 concentration is 1.77 ppmV, which is double the pre-industrial value (Bodelier, 2011). Rice (*Oryza sativa* L.) fields have been identified as one of the most important sources of CH_4, contributing approximately 15–20% of global anthropogenic CH_4 emission to the atmosphere (Aulakh et al., 2001). Lampe (1995) indicated that world rice yield is expected to increase to 880 million tons by 2025 to meet the increasing food demand of the global population; therefore, maintenance of soil health in rice paddy fields is essential. Organic amendments have gained worldwide significance as a practical method to improve and/or sustain soil fertility; however, the process stimulates CH_4 emission from paddy fields (Ma et al., 2010) as decomposition of applied organic matter under the anaerobic conditions of flooded rice field facilitates CH_4 production in soil (Agnihotri et al., 1999). Methanogenic archaea, a phylogenetically diverse group of strictly anaerobic Euryarchaeota, have an energy metabolism restricted to the formation of CH_4 from simple carbon (C)-compounds, such as CO_2, acetate, and formate (Thauer, 1998; Ferry and Kastead, 2007). The release of soluble C compounds from decomposing organic substrates in soil may be an important factor in determining methanogen activity and CH_4 emission. Therefore, controlling anaerobic decomposition of organic substrates may mitigate CH_4 emission from organic amended rice paddy soils. Thus, application of comparatively stabilised organic substrates may be a better option to help mitigate CH_4 emission during rice cultivation. Compost is a nutrient-rich stabilised form of organic substrates produced by controlled microbial decomposition (mineralisation) (Hoitink and Kutar, 1986). Chen et al. (2011) showed that CH_4 emissions from irrigated paddy fields may be mitigated by application of aerobically composted livestock manures. Singh et al. (2012) observed that changes in the community structure of methanogenic archaea were attributed to reduced CH_4 emission from compost treated rice paddy soils. Pramanik and Kim (2014) also found that compost application recorded approximate 20% decrease in CH_4 emission during rice

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cultivation compared to fresh manure treatment. Recently, several field studies have been investigated to characterize CH_4 emission from rice paddy soils treated with composts or manures (Chen et al., 2011; Singh et al., 2012; Pramanik and Kim, 2014), but the relationship between organic C distribution in aggregates of organic amended soils and changes in CH_4 emissions in compost-treated soils have not previously been examined.

Cattle manure is the most readily available organic waste in several countries and is widely applied in agricultural fields. In 2007, 42 million tons of livestock manure were generated in Korea and a major portion of that manure was produced by cattle farms (Kim et al., 2011). This manure is generated from both Korean cows (used for meat production), as well as dairy cows (used for milk production). In addition to the use of this manure to reduce CH_4 emission in paddy fields, the process may also be useful as a means of recycling the manure. In this study, air-dried and composted manures (from both Korean cows and dairy cows) were applied to soil to evaluate the effects on CH_4 emission and grain yield during rice cultivation. The objectives of this experiment were to study changes in CH_4 emissions due to air-dried and composted cattle manure applications during rice cultivation and to evaluate the possible reason behind variations in CH_4 emission due to compost applications.

2. Materials and methods

2.1. Experimental design and rice cultivation

Air-dried and composted cattle manure was applied in rice fields to study the manure's effects on CH_4 emission and rice productivity. The manure of both Korean cows and dairy cows were used in this study and chemical properties of those manures and their composts are presented in Table 1. The experiment was conducted at the Agronomy Field of Gyeongsang National University, Jinju City, South Korea for 2 years in 2011 and 2012. Soil in this experimental site belongs to the Pyeongtaeg series (fine-silty, mixed, nonacid, mesic Typic Endoaquept) (USDA, 2010). The organic C content of soil prior to manure application was 11.8 ± 1.5 m g g^{-1} and soil pH was 6.32 ± 0.43 (1:5 with H_2O). Five treatments (control, air-dried Korean, composted Korean, air-dried dairy and composted dairy cow manures) were arranged in the experimental plots (10 m × 10 m) following randomised block design with three replications. Hereafter, air-dried and composted cattle manures will be referred to as manure and compost, respectively; whereas Korean cow manure and dairy cow manure will be referred to as cattle manure and dairy manure, respectively. In all treatments (including control), chemical fertilisers (NPK treatment) were applied to avoid inaccurate measurements due to underdevelopment of rice plants and fertilisers. The plots were treated with urea (90 kg N ha^{-1}), superphosphate (45 kg P_2O_5 ha^{-1}) and potassium chloride (58 kg K_2O ha^{-1}) following the recommended doses for Korean paddy fields (RDA, 1999). Manures were applied at 2 Mg ha^{-1}, while compost was applied at 3 Mg ha^{-1} one week before rice transplanting to ensure the same amount of organic C in all treatment plots. The manures were incorporated mechanically into the surface soil (0–15 cm). Thirty days old rice (Dongjinbyeo cultivar, Japonica type) seedlings were transplanted in the flooded soil. Irrigation water was controlled at 5–7 cm depth during the cropping season and drained 3 weeks before rice harvesting. Rice plants (72 hills under 3.3 m^2) were harvested to determine grain yield in mid-October, and then the field was maintained under upland conditions, without irrigation in the following season. The experiment was conducted again in the following year to confirm the findings.

2.2. Methane gas sampling and analysis

A closed-chamber method (Ali et al., 2008, 2009; Kim et al., 2012) was used to estimate CH_4 flux from soil for the entire cultivation period. The acryl chambers having base-area 62 cm × 62 cm and height 112 cm were placed in each plot covering eight hills. Two holes at the bottom of the chamber-sides were installed to ensure the water level inside the chamber was equal to the water level of the whole plot. Gas samples were collected using

Table 1
Characteristics of cattle and dairy manures used.

Parameters	Manure				$HSD_{0.05}$[a]
	Cattle		Dairy		
	Air-dried	Composted	Air-dried	Composted	
Total contents (g kg^{-1})					
C	342	298	344	318	11
N	18.9	17.1	20.6	19.5	1.9
P_2O_5	15.7	18.9	14	15.5	0.6
K_2O	25.5	20.1	25	24.3	0.7
CaO	10.3	11.3	18.4	18.5	1.3
MgO	7.7	9.1	8.8	9.3	0.7
C/N ratio	18.1	17.4	16.8	16.4	ns[b]
Labile C (g kg^{-1})					
Cold water extractable	18.9 (5.5)[c]	11.0 (3.7)	16.9 (4.9)	11.5 (3.6)	2.1 (0.8)
Hot water extractable	38.6 (11.3)	27.0 (9.1)	35.2 (10.2)	23.7 (7.5)	4.4 (1.5)
Salt extractable	18.6 (5.4)	9.8 (3.3)	15.1 (4.4)	11.9 (3.8)	3.1 (1.0)
Total heavy metal contents (mg kg^{-1})					
Al	3382	6987	6290	7497	1104
Cu	118	119	130	129	4
Fe	1958	2487	2375	2598	ns
Mn	486	706	305	441	85
Ni	3.0	4.1	3.2	5.9	1.1
Zn	116	131	162	133	8

[a] *Note*: $HSD_{0.05}$ indicates honestly significantly different at 5% level.
[b] ns means not significant.
[c] The proportion of labile C in total soil organic C (in parenthesis).