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Beneficial effect of compost utilization on reducing greenhouse gas emissions in a rice cultivation system through the overall management chain

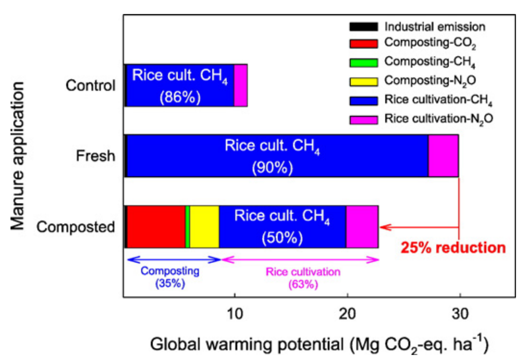
Seung Tak Jeong [a], Gil Won Kim [a], Hyun Young Hwang [a], Pil Joo Kim [a,b,*], Sang Yoon Kim [c,*]

[a] Division of Applied Life Science (BK 21 + Program), Gyeongsang National University, Jinju 52828, Republic of Korea
[b] Institute of Agriculture and Life Sciences, Gyeongsang National University, Jinju 52828, Republic of Korea
[c] National Academy of Agricultural Science, Rural Development Administration, Wanju 55365, Republic of Korea

HIGHLIGHT

- Manure composting and its land application reduced net GWP by 25%.
- Impact of greenhouse gas emission from composting process was negligible.
- Compost application suppressed CH_4 flux by 58% during rice cultivation.

GRAPHICAL ABSTRACT



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ABSTRACT

Livestock manure application can stimulate greenhouse gas (GHG) emissions, especially methane (CH_4) in rice paddy. The stabilized organic matter (OM) is recommended to suppress CH_4 emission without counting the additional GHG emission during the composting process. To evaluate the effect of compost utilization on the net global warming potential (GWP) of a rice cropping system, the fluxes of GHGs from composting to land application were calculated by a life cycle assessment (LCA) method. The model framework was composed of GHG fluxes from industrial activities and biogenic GHG fluxes from the composting and rice cultivation processes. Fresh manure emitted 30 Mg CO_2-eq. ha^{-1}, 90% and 10% of which were contributed by CH_4 and nitrous oxide (N_2O) fluxes, respectively, during rice cultivation. Compost utilization decreased net GWP by 25% over that of the fresh manure during the whole process. The composting process increased the GWP of the industrial processes by 35%, but the 60% reduction in CH_4 emissions from the rice paddy mainly influenced the reduction of GWP during the overall process. Therefore, compost application could be a good management strategy to reduce GHG emissions from rice paddy systems.

1. Introduction

Rice (*Oryza sativa L.*) paddies are considered one of the major methane (CH_4) sources. Methane has 28 times higher global warming potential (GWP) than that of carbon dioxide (CO_2) over a 100-year time

* Corresponding authors at: Division of Applied Life Science (BK 21+ Program), Gyeongsang National University, Jinju 660-701, Republic of Korea.
E-mail addresses: pjkim@gnu.ac.kr (P.J. Kim), s.y.kim@korea.kr (S.Y. Kim).

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horizon (Pachauri et al. 2014). Agriculture sector contributes approximately half (50.6%) of the anthropogenic CH_4 emissions at the global level (Karakurt et al. 2012) out of which rice paddy fields contribute about 20% (Ke et al. 2014). To satisfy the demand of an increasing population, rice production should be doubled by the year 2020, which could increase CH_4 emissions by up to 50% over the present CH_4 emissions from arable lands (Bouwman 1991).

Organic amendments such as livestock manures and crop residues have been applied worldwide to improve soil fertility and thus increase crop productivity. However, this process can increase CH_4 emissions under flooded paddy soil conditions (Ma et al. 2010; Kim et al. 2012; Kim et al. 2014a & b; Hwang et al. 2017). The release of labile organic carbon (OC) compounds from decaying soil organic matter (SOM) may be an important factor for determining methanogen activity and CH_4 production rates (Lu et al. 2000; Kim et al. 2012). Therefore, the application of comparatively stabilized organic substrates such as compost and biochar may be better options to mitigate CH_4 emissions during rice cultivation (Zhang et al. 2010). In our previous studies (Kim et al. 2014a; Pramanik and Kim 2014), the application of composted manure decreased CH_4 emissions by approximate 20–50% during rice cultivation compared to the fresh manure treatment. The application of composted rice straw was also less effective at increasing CH_4 emissions than fresh rice straw during rice cultivation (Yagi and Minami 1990; Corton et al. 2000).

However, since higher amounts of GHGs such as CO_2, CH_4 and nitrous oxide (N_2O) could be emitted during the composting process (Fukumoto et al. 2003; Szanto et al. 2007; Ahn et al. 2011; Zhong et al. 2013), the effect of compost selection on suppressing GHG emissions during rice cultivation is still under debate. To evaluate properly the effect of compost utilization on suppressing GHG emissions from a rice paddy soil system, the overall influence of composted OM application on the total GWP and GHG intensity should be evaluated by including the GHG emissions that occur during the composting process. Therefore, we assessed the effect of compost utilization (from livestock manure composting to land application) on reducing GHG emissions from a rice paddy system using a life cycle assessment (LCA).

2. Materials and methods

2.1. Life cycle assessment (LCA) of manure composting and land application

To compare the effect of compost application on reducing GHG emission, the compost treatment was selected as the main treatment. In addition, no-manure and fresh manure treatments were included for comparison. Fluxes of GHGs from manure management to land application were evaluated by the LCA method using the Gabi® education software (PE International, Stuttgart, Germany) and by direct measurement.

The model framework was composed of two sources of data related to GHG emissions (Fig. 1). The first one is GHG (CH_4, N_2O and fossil CO_2) fluxes from industrial activities, which included transportation, machinery operation, fertilizer production, and diesel supply processes. These GHG fluxes were based on European Emission Standards 3 and 4 (European Parliament Council 2000). The other source is biogenic GHG fluxes from manure composting (CH_4, CO_2 and N_2O) and rice cultivation (CH_4 and N_2O) processes, and these direct GHG emissions were determined by on-site observation.

2.2. Composting procedure

In this study, we selected a representative swine manure composting plant in *Jinju*, South Korea as a model from which to calculate the GHG emissions from a composting operation. The swine manure composting plant has an area of 5.96 ha and produces approximately 5.1 thousand tons of compost (45% moisture content) annually using an agitated bay composting system. The composting

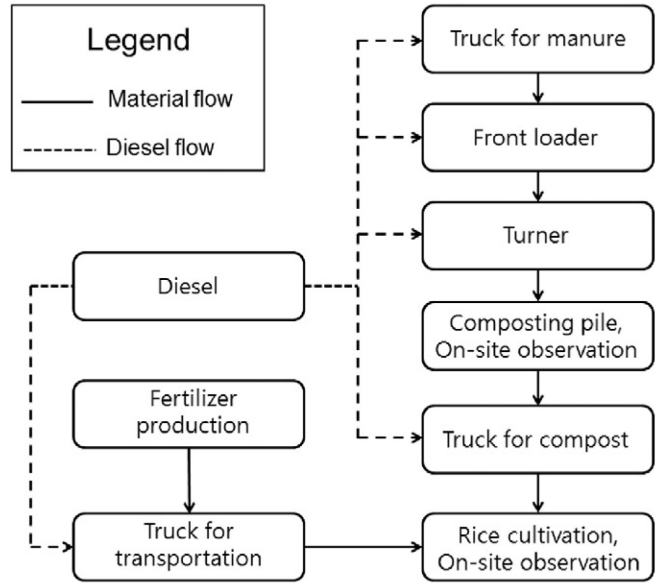

Fig. 1. Model framework of the system in composted manure treatment.

plant has two agitation lines, and each line is 80 m in length and 10 m in width. The agitated bay composting was subjected to a thermophilic stage for 3 weeks and a maturation stage for 4 weeks.

In this composting plant, swine manure was collected from the swine farm nearby. A dump truck (170 kw, 62 kgm), a front loader (349 kw, 1800 rpm) and a turner (50 kw) were used to transfer the manures, to build up compost piles, which are mixed with the fresh manure and the dried manure at a ratio of 8:5 (w w^{-1}), and to turn the piles once a day during the thermophilic stage. After the thermophilic stage, the mixtures were stacked in the open-backyard for post-maturity.

2.3. Manure composting

To evaluate the GHG fluxes from compost piles, the raw materials were collected from the same swine farm and transported for composting to the experimental station at *Gyeongsang* National University. In the selected farm, any bedding material was not used, and the solid and liquid phases of manure were separated by a solid-liquid separation system. The initial moisture content and C/N ratio of the collected solid manure were 77.6% (wt wt^{-1}) and 14.1, respectively (Table 1). The manure was dried for a day in a greenhouse and stabilized at an approximate 70% (wt wt^{-1}) moisture content.

The composting experiment was conducted using a conventional static composting chamber method for 45 days in a greenhouse. Six hundred and thirty-three kg of the air-dried manure was filled into a plastic box 1.2 m^3 in size (1.2 m × 1.0 m × 1.0 m), which was covered with expanded polystyrene (5 cm thick) to prevent heat loss. The active phase of composting was considered to be completed when the pile

Table 1
Chemical properties of fresh and composted swine manures used for composting and field test.

Parameters	Swine manure	
	Fresh	Composted
pH (1:5 with H_2O)	7.1 ± 0.0	7.2 ± 0.1
EC (dS m^{-1})	2.8 ± 0.1	8.0 ± 0.2
Total carbon (g C kg^{-1})	413 ± 7.6	355 ± 8.9
Total nitrogen (g N kg^{-1})	29 ± 0.2	114 ± 4.5
C/N ratio	14.1 ± 1.2	3.1 ± 0.7
Dissolved organic carbon (g C kg^{-1})	11.3 ± 0.4	8.2 ± 1.2
Dissolved organic nitrogen (g N kg^{-1})	3.1 ± 0.13	3.4 ± 0.15