Nitrous oxide emissions from nitrogen-enriched cattle manure compost pellets applied to Andosols

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Abstract
High levels of nitrous oxide (N_2O) are emitted when manure compost pellets are applied to soil. In order to find ways to decrease this emission, we studied the N_2O emissions for nitrogen-enriched manure compost pellets; preliminary incubation tests showed that these pellets produced lower N_2O emissions than the commonly used manure compost pellets. In the field experiments, 4 types of manure—nitrogen-enriched manure compost pellets (N + MCP), manure compost pellets (MCP), nitrogen-enriched manure compost (N + MC, non-pelletized), and manure composts (MC, non-pelletized)—were applied to a forage corn field in autumn 2008 and summer 2009, and the N_2O emissions during each treatment were measured. The total N_2O emission rates (kg N/ha) in the 2 cultivation periods were 2.519 (MCP treatment), 0.755 (N + MCP treatment), 0.441 (MC treatment), 0.287 (N + MC treatment), and 0.150 (control treatment). The emission rate during the N + MCP treatment was slightly higher than that during the non-pelletized manure treatment (MC and N + MC treatment) but significantly lower than that during the MCP treatment. These results indicate that the use of nitrogen-enriched manure compost pellets resulted in a decrease in the N_2O emissions from manure compost pellets applied to the soil.

Key Words
Mitigation of GHG emissions, organic material, agriculture.

Introduction
Manure compost pellets have gained attention for their excellent handling properties in agricultural practices and their contribution to the improvement in the balance of manure distribution in agricultural areas. However, it was reported that compared to the ordinary manure compost (non-pelletized) or chemical fertilizers, the application of manure compost pellets leads to most of the nitrous oxide (N_2O) emissions (Inoue and Shibukawa 2008; Hayakawa *et al*. 2009; Yamane and Yamada 2009). Nitrous oxide (N_2O) is one of the most important greenhouse gases and relates to the depletion of stratospheric ozone. To increase the use of manure compost pellets, it is important to develop techniques for decreasing N_2O emissions from the pellets. We have conducted incubation experiments based on the reduction of N_2O emission; the results showed that the N_2O emissions from nitrogen-enriched manure compost pellets mixed with soil were lower than those from ordinary manure compost pellets (data not shown). The nitrogen-enriched manure compost is a side product of the systems for deodorizing offensive odors from animal wastes and is created as a result of aeration and absorption of the odor by well-matured manure composts; its nitrogen content is higher than that of ordinary manure composts because the odor contains a high amount of ammonia. Our objective is to verify the N_2O-decreasing effect of nitrogen-enriched manure compost pellets in fields.

Methods
Study site and experimental design
The experiments were conducted in a field located in the National Agricultural Research Center for Kyushu Okinawa Region (KONARC, 32°52’ N, 130°44’ E) during 2 cultivation periods (autumn 2008 and summer 2009). Forage corn (*Zea mays* L.) was grown in this field. The soil in the field belonged to Andosols. In the field experiment, a total of 5 treatments, comprising 4 types of manure-application treatments and a control treatment, were performed. The treatments were as follows (1) nitrogen-enriched manure compost pellet treatment (N + MCP), (2) manure compost pellet treatment (MCP), (3) nitrogen-enriched manure compost treatment (N + MC, non-pelletized), (4) manure compost treatment (MC, non-pelletized), and (5) control treatment (no nitrogen). The physical and chemical properties of the manures and the application rates of the manure and nitrogen in each treatment are shown in Table 1. The application rates of the manures were adjusted to the carbon rate when the MC was applied at the rate of 10 Mg DM/ha. The inorganic nitrogen applied during each treatment was 246.8 kg N/ha; this was the value in the N + MCP treatment. If the inorganic nitrogen was insufficient in the other treatments, it was complemented with chemical fertilizer

(urea). Manure compost pellets (N + MCP and MCP) in a columnar shape (5 mm, diameter; 8 mm, length) were prepared using a disc pelletizer. Each treatment was carried out in 2 plots (18 m^2 each) and plots were arranged randomly.

Field measurements

N_2O flux was measured by the closed-chamber method (Ralston 1986) using an acrylic chamber (20 cm × 30 cm × 30 cm). Three chambers were prepared for each treatment (1 chamber in 1 plot and 2 chambers in the other plot). In each chamber, 500 mL of the air was sampled with a pump at 0 min, 15 min, and 30 min after the chamber was set. The N_2O concentration of the sampled gas was determined using a gas chromatograph (GC-2014, SHIMADZU Co. Ltd., Kyoto, Japan) equipped with an electron capture detector. N_2O gas flux was calculated from the difference in the N_2O concentration at different sampling times. Manure was applied on September 3, 2008 (for autumn 2008) and April 16, 2009 (for summer 2009). The N_2O fluxes were measured from August 31 to November 22 in 2008 (for autumn 2008) and from April 12 to August 20 in 2009 (for summer 2009). The gas was sampled 4–7 times/week, immediately after manure application; once a week, 7–30 days after application; and 2–3 times a month, from 30 days after the application to the end of the experiment. The N_2O emission rates were calculated using the linear trapezoidal method. Soil moisture was represented by the water-filled pore space (WFPS). WFPS was calculated with the following formula: WFPF (%) = [(gravimetric water content × soil bulk density)/total soil porosity], where soil porosity = [1 - (soil bulk density/particle density)]. Temperatures in the soil (at a depth of 5 cm) and chamber were recorded by a thermo-recorder (ONDOTORI; T&D Co. Ltd., Nagano, Japan) with 2 channels. Climatic data were collected from the Kikuchi automated weather station (32°56.8' N, 130°46.9' E; autumn 2008) and an observatory in KONARC (summer 2009).

Table 1. Physical and chemical properties of the manures used in the field experiments and the application rates of the manures and nitrogen in each treatment. Abbreviations: N + MCP, nitrogen-enriched manure compost pellet; MCP, manure compost pellet; N + MC, nitrogen-enriched manure compost; MC, manure compost. The values in parentheses in the inorganic nitrogen values column indicate the amount of inorganic nitrogen added as a chemical fertilizer (urea).

Treatments	Manure compost moisture (kg/kg)	Components in manure compost (g/kg DM)			Manure rates applied (Mg DM/ha)	Nitrogen rates (kg N/ha)	
		T-C	T-N	Inorganic N		T-N	Inorganic N
N + MCP	0.12	324.9	36.5	21.7	11.37	415.1	246.8 (-)
MCP	0.11	352.9	20.4	1.1	10.47	448.9	246.8 (235.3)
N + MC	0.18	361.0	38.7	20.6	10.24	432.1	246.8 (35.9)
MC	0.15	369.5	20.2	1.1	10.00	437.8	246.8 (235.8)

Results

N_2O flux and emission rate in autumn 2008

In autumn 2008, the mean air temperature was 19.0°C, and the total rainfall was 408.5 mm at the time of measurement. The N_2O flux in autumn 2008 is shown in Fig.1A. N_2O emissions in all the treatments except the control treatment peaked at 1–3 days after the application. The peak N_2O emission in the MCP treatment (2460.2 μg N_2O-N/m^2/hr) was notably (48–94 times) higher than that in the other treatments (26.1–51.3 μg N_2O-N/m^2/hr). The peak N_2O emission decreased 13–31 days after the application. Following this, lower levels of N_2O emissions (< 10 μg N_2O-N/m^2/hr) were observed in all the treatments. In autumn 2008 (Table 2), the emission rates for the MCP treatment were the highest (1.658 kg N/ha), followed by those for the N + MCP treatment (0.157 kg N/ha), MC treatment (0.130 kg N/ha), N + MC treatment (0.096 kg N/ha), and control treatment (0.056 kg N/ha). The N_2O emission rate for the MCP treatment was significantly higher ($p < 0.05$; Tukey test) than those in the other treatments. The percentages of N_2O-N to total-N applied [(N_2O emission rate in the treatment - N_2O emission in the control treatment)/(total nitrogen rate applied in the treatment) × 100] were 0.357% for the MCP treatment, 0.024% for the N + MCP treatment, 0.017% for the MC treatment, and 0.009% for the N + MC treatment.

N_2O flux and N_2O emission rate in summer 2009

In summer 2009, the mean air temperature was 22.4°C, and the total rainfall was 880.5 mm at the time of measurement. The N_2O flux in summer 2009 is shown in Fig.1B. Except for the control treatment, N_2O

emissions in all the treatments peaked 5–10 days after the application. Similar to autumn 2008, the peak N_2O emission was the highest for the MCP treatment (342.4 μg N_2O-N/m^2/hr) and was approximately 5–15 times higher than that for the other treatments (23.4–65.9 μg N_2O-N/m^2/hr). However, in summer 2009, the peak N_2O emission for the MCP treatment decreased to approximately one-seventh that of autumn 2008. Once N_2O emissions settled 14–30 days after the application in all the treatments, N_2O emissions ranged 5–45 μg N_2O-N/m^2/hr had been observed mainly in the treatments applied manure compost pellets (MCP and N + MCP treatment) from 37 days after the application to the end of the experiment. The N_2O emission rates in autumn 2009 (Table 2), were similar to those in autumn 2008; the emission rate in the MCP treatment was the highest (0.860 kg N/ha), followed by that in the N + MCP treatment (0.599 kg N/ha), MC treatment (0.311 kg N/ha), N + MC treatment (0.190 kg N/ha), and control treatment (0.093 kg N/ha). However, the difference between the N_2O emission rates during the MCP treatment and those during the other treatments was smaller in summer 2009 than in autumn 2008; in summer 2009, no significant difference was observed between the N_2O emission rates of the MCP and N + MCP treatments ($p = 0.05$; Tukey test). Percentages of N_2O-N for total-N applied were 0.171% in the MCP treatment, 0.122% in the N + MCP treatment, 0.050% in the MC treatment, and 0.022% in the N + MC treatment.

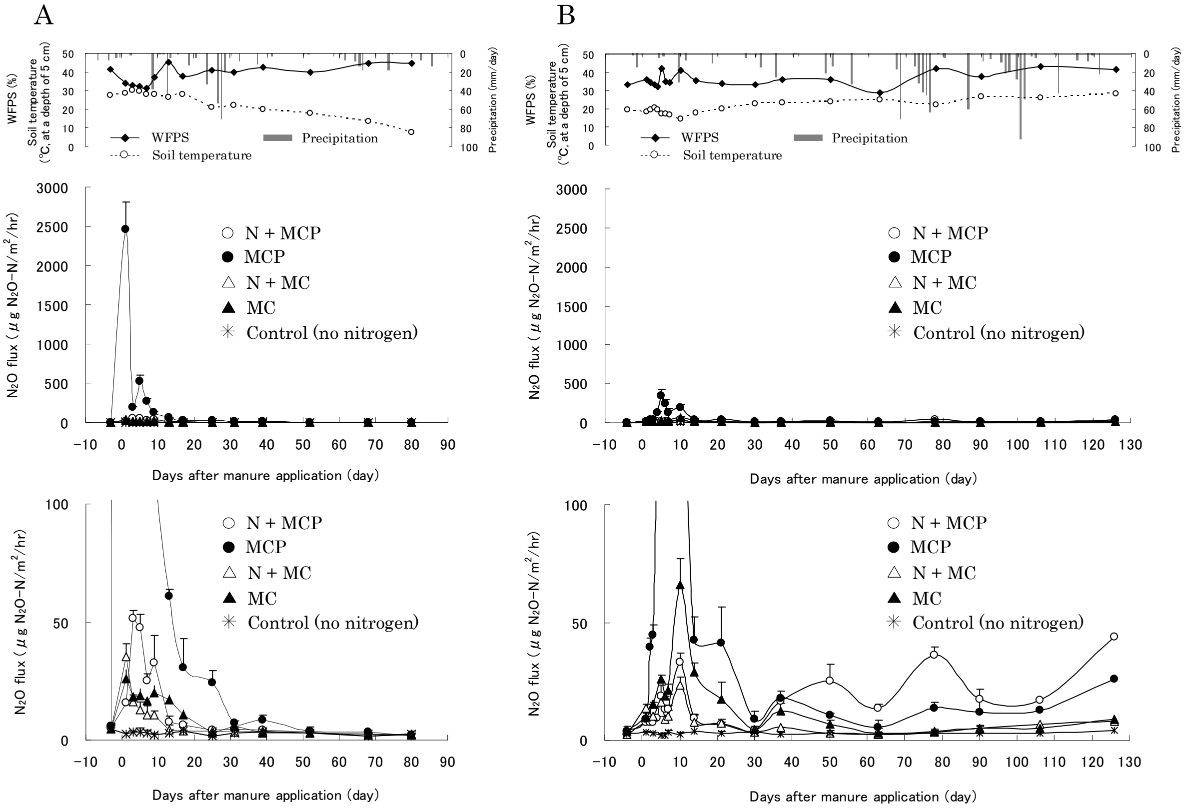

Figure 1. Nitrous oxide (N_2O) fluxes, soil temperature (at a depth of 5 cm), soil moisture (WFPS), and precipitation in the field experiments. The figures on the left (A) show the results for autumn 2008, and the figures on the right (B) show the results for summer 2009. Refer to Table 1 for the abbreviations used for the treatments. The lower 2 figures are enlarged versions of the upper ones. Manure was applied on September 3, 2008 (autumn 2008) and on April 16, 2009 (summer 2009).

Conclusion

The total N_2O emission rates in the 2 cultivation periods are shown in Table 2. The N_2O emission rate in the MCP treatment (2.519 kg N/ha) was the highest, followed by that in the N + MCP treatment (0.755 kg N/ha), MC treatment (0.441 kg N/ha), N + MC treatment (0.287 kg N/ha), and the control treatment (0.150 kg N/ha). While the emission rate in the N + MCP treatment was a little higher than that in the non-pelletized manure treatments (MC and N + MC treatment), it was significantly lower than that in the MCP treatment. These results suggest that the use of nitrogen-enriched manure compost pellets is an effective option for decreasing the level of N_2O emissions from manure compost pellets applied to the soil; it is important to elucidate the mechanism of decrease of N_2O emission with the use of these nitrogen-enriched pellets.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Table 2. N_2O emission rates and percentage of N_2O-N to total-N applied in the field experiments. Refer to Table 1 for the abbreviations used for the treatments. The different letters seen in the columns indicate a significant difference among N_2O emission rates ($p < 0.05$; Tukey test). Percentage of N_2O-N to total-N applied (%) = [(N_2O emission rate in the treatment - N_2O emission rate in the control treatment)/(total nitrogen rate applied in the treatment) × 100].

Treatments	Autumn 2008		Summer 2009		Total	
	N_2O emission rate (kg N/ha)	Percentage of N_2O-N to total-N applied (%)	N_2O emission rate (kg N/ha)	Percentage of N_2O-N to total-N applied (%)	N_2O emission rate (kg N/ha)	Percentage of N_2O-N to total-N applied (%)
N + MCP	0.157 b	0.024	0.599 a	0.122	0.755 b	0.073
MCP	1.658 a	0.357	0.860 a	0.171	2.519 a	0.264
N + MC	0.096 b	0.009	0.190 b	0.022	0.287 c	0.016
MC	0.130 b	0.017	0.311 b	0.050	0.441 bc	0.033
Control	0.056 b	-	0.093 b	-	0.150 c	-

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1 – 6 August 2010, Brisbane, Australia. Published on DVD.