

## Evaluation N<sub>2</sub>O Emissions from Intensive Manure Managements in a Dairy Area

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### Abstract

To investigate N<sub>2</sub>O emissions from intensive manure managements, eight farmer's fields covering paddy rice and uplands cropping systems in a livestock watershed of central Japan has been selected. The manure was popular applied with PIAF (Ploughing Immediately after Fertilization), FKSSL (Fertilizer Keeping on the Surface Soil for a Longer Time) and only applied in winter fallow season for paddy rice under the application rate of 200-800 kg N ha<sup>-1</sup>yr<sup>-1</sup>. Field gas samples were conducted by static chamber method. The result showed that N<sub>2</sub>O flux varied from 0 to 1607 μg N m<sup>-2</sup>h<sup>-1</sup> in upland crop systems and from 0 to 924 μg N m<sup>-2</sup>h<sup>-1</sup> in paddy fields. And the annual emission ranged from 1.91-9.26 kg N ha<sup>-1</sup>yr<sup>-1</sup> accounting for 0.48 ± 0.41% of input N in uplands and 1.28-1.91 kg N ha<sup>-1</sup>yr<sup>-1</sup> accounting for 0.43 ± 0.27% of input N in paddy rice, respectively. In rice/fallow system, more N<sub>2</sub>O emitted and the emission factor was 0.59 ± 0.07% due to the manure applied in fallow winter season. The N<sub>2</sub>O emission from FKSSL was 0.85 ± 0.79% of input N, and 3.4 times higher than PIAF. Slurry application contributed N<sub>2</sub>O emission 0.71 ± 0.37% of input N with 2 times higher than that of dry compost manure plots.

**Keywords:** Uplands; Paddy rice; Slurry; Compost; Manure managements

### Introduction

Livestock manure management accounts for 10% of greenhouse gas emissions from agriculture worldwide [1]. The nitrous oxide (N<sub>2</sub>O) emissions contributed about 30% of the anthropogenic global warming in whole livestock farming system [2]. Manure applied to soil is a significant N<sub>2</sub>O emission sources [3-5]. Hayakawa reported that the poultry manure stimulated over 2-7 times of N<sub>2</sub>O emission than that of chemical fertilizer [6]. Hirata also found that much higher N<sub>2</sub>O emission from manure plots than chemical fertilizer plots [7]. To feed more people in future, however, the manure N would reach to about 140 Tg. yr<sup>-1</sup> in 2050 which equivalent to 1.5-fold that of 2000 [8]. The increasing manure production will promote to elevate N<sub>2</sub>O emission from the livestock system [3,5]. More researches regarding manure managements are needed to mitigate N<sub>2</sub>O fluxes from livestock sector.

To mitigation N<sub>2</sub>O emission from manure management, most of studies focus the researches on manure storages. For example, Sommer reported that shortening the in-house manure storage time could reduce GHG emission up to 40% and a combination of slurry separation and incineration could reduce 82% of GHG emissions [9]. Owen and Silver found the larger N<sub>2</sub>O emission from anaerobic lagoons (0.9 ± 0.5 kg N<sub>2</sub>O hd<sup>-1</sup>yr<sup>-1</sup>) and barns (10 ± 6 kg N<sub>2</sub>O hd<sup>-1</sup>yr<sup>-1</sup>) than corrals, solid manure piles, slurry tanks, compost areas and concrete pens [1]. Considering the area, manure applied to fields would significant increase the area than the manure stored. Regarding the manure managements in crop fields, a few studies has been conducted to mitigate N<sub>2</sub>O emission. Herrero summarized the N<sub>2</sub>O emission could be significant reduced if manures are applied to match plant N demand at times and avoid heavy rains [2]. Ball reported the uses of nitrification inhibitors could significant reduce N<sub>2</sub>O emission during manure application [10]. However, farmers are generally applied manure with ploughing immediately after fertilization (PIAF) in summer season and fertilizer keeping on the surface soil for a longer time (FKSSL) in winter season, especial for the livestock farmers in Japan. The N<sub>2</sub>O emissions from those farmers manure fields managements are unclear.

Manure applied to different crop systems could produce different N<sub>2</sub>O emissions. The paddy fields with flooded is generally different from uplands [11]. Many studies reported that N<sub>2</sub>O emission from paddy fields was negligible [12,13]. For paddy fields N<sub>2</sub>O measurements, most studies has conducted in rice growing season, rice/other crop rotation or rice/fallow where the fertilizer has been only applied in rice growing season. But in Japan, rice/fallow is one the main crop system. To keep high rice quality, many farmers only apply manure in fallow season and nearly no fertilizer used in rice season. However, the N<sub>2</sub>O emission in this crop system has received little attention.

The objectives of this study were (i) to investigate the effects of manure application methods with PIAF and FKSSL on N<sub>2</sub>O fluxes, and (ii) to estimate N<sub>2</sub>O emission from rice/fallow system where the fertilizer only applied in winter season.

### Materials and Methods

#### Study site and field management

This study was conducted from May 2009 to April 2010 at upstream of Naka River watershed in Japan. In this region, major crop systems are one season cultivation of rice (R), maize (M), a rotation of grass and maize (G/M). Dairy cow manure is the main fertilizer source, which was up to 700 kg N ha<sup>-1</sup>yr<sup>-1</sup> [14]. Five sampling sites were chosen according to different land uses (uplands and paddy rice), soil textures (loam, silt loam, sandy loam and loam sand) and location (G/M1 and R1 37.02N, 139.98E; G/M2 37.00N, 140.00E; G/M3 36.96N, 139.91E;

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G/M4 and R4 36.94N, 140.00E; M5 and R5 36.83N, 140.00E). In total there are 8 fields and the soils are Andosol. In each farmer field, the areas are bigger than 100 m<sup>2</sup> and each field has been evenly divided into three plots to get three replications. Three samples were taken at each plot randomly.

In G/M system, Italian ryegrass (*Lolium multiflorum* L.) was planted in October and harvested in May, immediately followed by the planting of maize, which was harvested in September. For R system, the field was flooded from May to late August and the rice seedlings were transplanted in May and harvested in October. For M5 and R5, the fields are maize/barley rotation and forage rice/barley rotation, the maize sowed in the end of June, forage rice transplanted in the mid of May and barley sowed in the beginning of November. Except one season rice (R1, R4) and barley are human food crops, other crops are fodder crops.

Dairy cow manure was the main fertilizer, which ranged in 400-800 kg N ha<sup>-1</sup>yr<sup>-1</sup> for uplands and 150-480 kg N ha<sup>-1</sup>yr<sup>-1</sup> for paddy rice fields. The chemical fertilizer only applied in R1 and G/M2 and R5 before summer crop planting with 50, 100, 20 kg N ha<sup>-1</sup>yr<sup>-1</sup>, respectively. The manure application was conducted twice for uplands before seeding in both summer and winter seasons. In summer season, the ploughing was immediately followed with fertilization. But, the manure was generally kept long time on surface soil in winter crop season, and the ploughing did over 10 days later. For rice/fallow, the manure was applied once in the winter fallow season and kept it on the surface soil long time. In forage paddy rice/barley system, once manure applied before winter crop seeding and another time applied slurry in the beginning of August rice pre-heading stage. According the fertilization and ploughing management methods, here we defined that the method of ploughing immediately after fertilization as PIAF and the fertilizer keeping on the surface soil for a longer time as FKSSL. PIAF included the all summer fertilization events and the winter of fields G/M2, M5, R5. Others were FKSSL which involved the winter fertilization of G/M1, G/M3, G/M4, R1, R4. The information about soil and management could be found in Deng [15]. Due to there is no control(no fertilizer) treatment, the literature review has been done to survey N<sub>2</sub>O emission on Andosol from no fertilizer plots across Japan.

### Sampling and measurements

Nitrous oxide (N<sub>2</sub>O) and carbon dioxides (CO<sub>2</sub>) fluxes from field were measured by a closed chamber method. The chamber was inserted and stabilized into the soil at the depth of 5 cm, the first gas sample was taken at an open condition. The second and third gas samples were collected at 6 and 20 minutes after closing the chamber. Nitrous oxide concentrations of the first and third gas samples, and CO<sub>2</sub> concentrations of the first and second sample were measured. Nitrous oxide and CO<sub>2</sub> fluxes in field were calculated according to the changes in the gas concentration in the chambers with time using a line regression, and expressed as arithmetic means (n=3). The sampling was carried out under intensive monitoring and intermitted monitoring. For intensive monitoring, N<sub>2</sub>O flux and CO<sub>2</sub> were measured every 2 days in the periods just after manure application. It will be stop until the flux was near zero (about 2 weeks). For intermitted monitoring, gas measurements were conducted bimonthly. The concentration of N<sub>2</sub>O was measured using a gas chromatograph equipped with an electron capture detector (GC-2014, Porapak Q column, Shimadzu). That of CO<sub>2</sub> was measured by a thermal conductivity detector gas chromatograph (GC6A, Shimadzu).

Regarding the N<sub>2</sub>O emission factors analysis, the N<sub>2</sub>O emission

from no fertilizer fields were collected from references review where N<sub>2</sub>O emission from no fertilizer Andosol with paddy rice fields and uplands in whole year measurements across Japan has been searched. The average value from the literature review has been used for calculated N<sub>2</sub>O emission factors, the equation as following:

$$\text{N}_2\text{O emission factors} = (\text{Cumulated N}_2\text{O from measured treatment} - \text{Average of no fertilizer value from literature review}) / \text{Fertilizer application rate} \times 100\%$$

In case for summer or winter emission factors, the no fertilizer value used the half of average N<sub>2</sub>O fluxes from literature review. For paddy rice no fertilizer value, there was little researches regarding Andosol N<sub>2</sub>O fluxes from paddy with whole year. Due to most of N<sub>2</sub>O from paddy rice system emitted from un-flooding period, the paddy soil in no fertilizer value used the half value from uplands literature review.

The soil moisture and temperature at 0-5 cm was measured, and air temperature was measured during the gas sampling near each chamber. Three 500g soil samples were collected nearby gas chambers from topsoil layer (0-10 cm) in each field for measure soil physical and chemical parameters. Soil nitrate (NO<sub>3</sub><sup>-</sup>) and ammonium (NH<sub>4</sub><sup>+</sup>) content were respectively measured by the dual wavelength spectrophotometric method and the indophenol blue method.

### Statistical analysis

Analysis of variance (ANOVA) was performed to test the difference among the fertilizer type, fertilizer applied methods and land uses. The relationship between N<sub>2</sub>O fluxes and soil chemical and physical properties were test by Pearson product moment correlation. Statistical analysis was conducted with SigmaStat 3.5 (Systat Software, Inc).

## Results

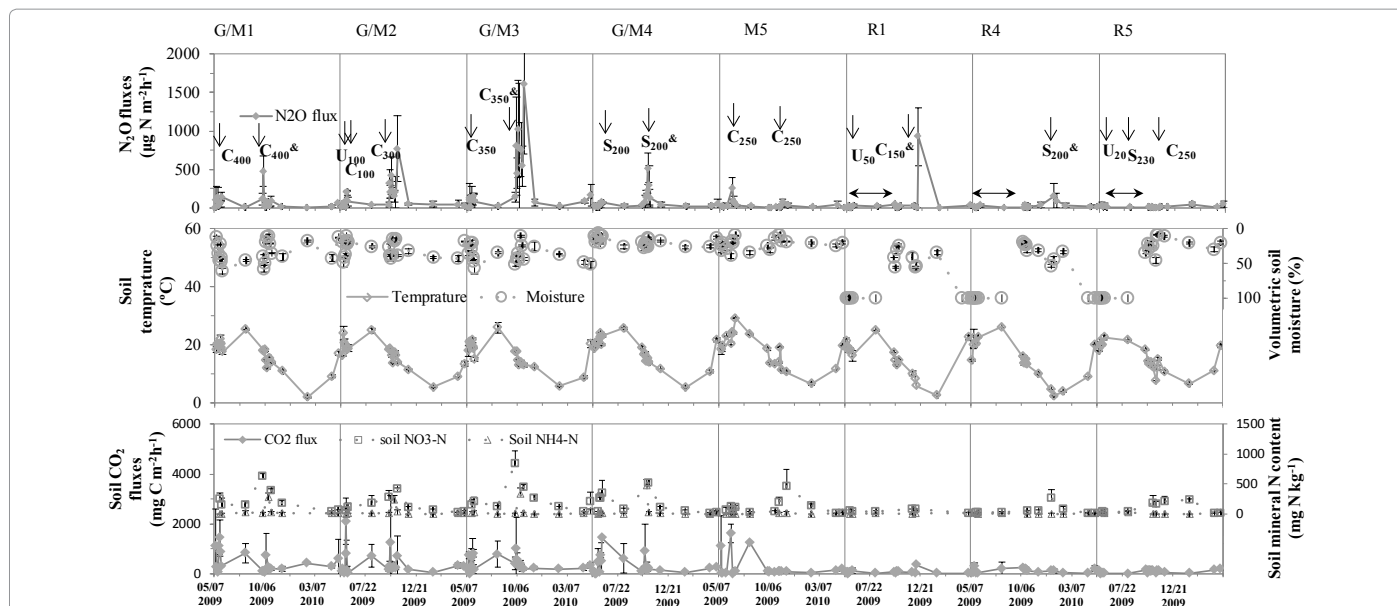
### N<sub>2</sub>O emissions

The daily N<sub>2</sub>O fluxes showed large spatial and temporal variability, which ranged from 0 to 1607 μg N m<sup>-2</sup>h<sup>-1</sup> in upland crop systems and from 0 to 924 μg N m<sup>-2</sup>h<sup>-1</sup> in paddy fields (Figure 1 and Table 1). The highest peak was found in field G/M3 28 day after winter fertilization. Field M5 showed very low N<sub>2</sub>O flux which varied 2.17-251 μg N m<sup>-2</sup>h<sup>-1</sup>. Fertilization events significantly stimulated N<sub>2</sub>O emission and the high flux can maintain 2-4 weeks after manure application. In other period, the N<sub>2</sub>O fluxes were mostly lower than 50 μg N m<sup>-2</sup>h<sup>-1</sup>. The peaks in winter fertilization season showed much higher than that of summer season except fields M5 and R5.

Comparing uplands, paddy rice showed much lower N<sub>2</sub>O emission. In case of paddy rice, the daily N<sub>2</sub>O emission in summer flooding season was negligible, which was less than 50 μg N m<sup>-2</sup>h<sup>-1</sup>. During un-flooding period, the N<sub>2</sub>O fluxes trended to increase after winter fertilization. The highest flux of 924 μg N m<sup>-2</sup>h<sup>-1</sup> was found in field R1 several days after manure application. And then field R4 also showed the peak of 146 μg N m<sup>-2</sup>h<sup>-1</sup> after winter slurry manure was applied. However, no any significant peaks was found in forage rice/barley field R5 with the N<sub>2</sub>O flux less than 50 μg N m<sup>-2</sup>h<sup>-1</sup>.

Consider different manure managements, the N<sub>2</sub>O emission from FKSSL have much higher fluxes. The peaks ranged from 146 μg N m<sup>-2</sup>h<sup>-1</sup> to 1607μg N m<sup>-2</sup>h<sup>-1</sup>, and most of the peaks higher than 500μg N m<sup>-2</sup>h<sup>-1</sup>. In case of PIAF, the highest amount peak found in G/M2 winter season with 769μg N m<sup>-2</sup>h<sup>-1</sup>, other peaks lower than 250μg N m<sup>-2</sup>h<sup>-1</sup>.

Over all, the calculated annual N<sub>2</sub>O emission changed from 1.91 to



**Figure 1:** The patterns of daily N<sub>2</sub>O fluxes, soil temperature (0-10 cm), soil moisture (0-10 cm), soil CO<sub>2</sub> fluxes and the concentrations of soil NH<sub>4</sub><sup>+</sup>-N and NO<sub>3</sub><sup>-</sup>-N (0-10 cm), over all fields. (Error bars indicated the standard error of average values. Fields G/M1, G/M2, G/M3, G/M4 suggested grass and maize rotation. Field M5 was maize and barley rotation. Fields R1 and R4 were one season rice. R5 was forage rice and barley rotation. Vertical arrows indicate the timing of fertilization and horizontal double arrows in Rice fields suggested the flooding periods. C, U and S indicated the fertilizer with air dry compost, urea and slurry, respectively. The numbers with the fertilizer type represented the fertilizer amount. And & denoted the fertilization with FKSSL, otherwise was PIAF).

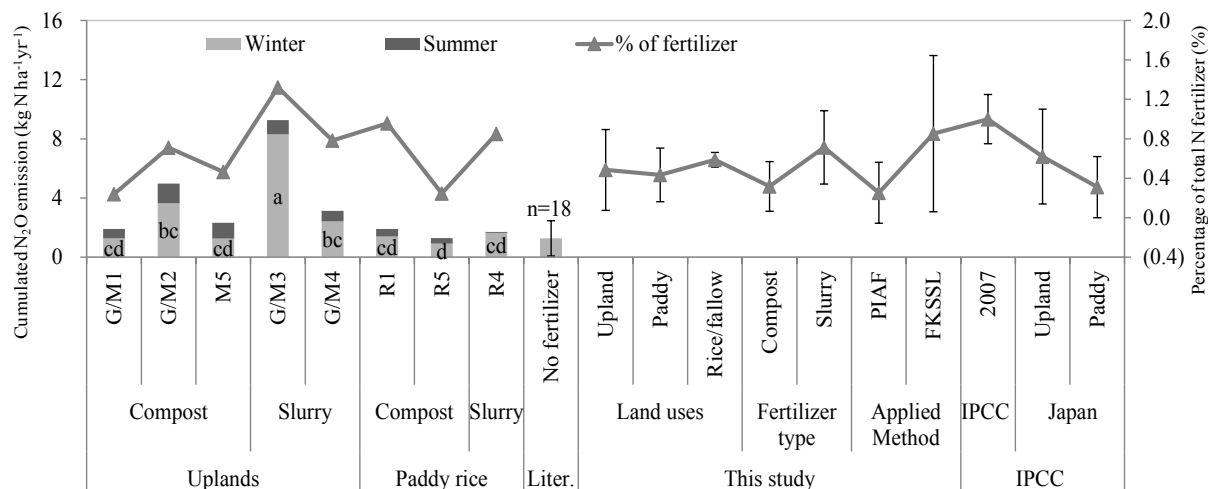
Upland	Summer Season (May-September)							Winter Season (October-April)							
	Fertilizer rate (kg N ha <sup>-1</sup> )	Soil moisture (%)	Soil temperature (°C)	NO <sub>3</sub> -N content (kg N kg <sup>-1</sup> )	NH <sub>4</sub> <sup>+</sup> -N content (kg N kg <sup>-1</sup> )	CO <sub>2</sub> flux (mg C m <sup>-2</sup> h <sup>-1</sup> )	N <sub>2</sub> O flux (µg N m <sup>-2</sup> h <sup>-1</sup> )	Fertilizer rate (kg N ha <sup>-1</sup> )	Soil moisture (%)	Soil temperature (°C)	NO <sub>3</sub> -N content (kg N kg <sup>-1</sup> )	NH <sub>4</sub> <sup>+</sup> -N content (kg N kg <sup>-1</sup> )	CO <sub>2</sub> flux (mg C m <sup>-2</sup> h <sup>-1</sup> )	N <sub>2</sub> O flux (µg N m <sup>-2</sup> h <sup>-1</sup> )	
G/M1	400 <sup>C</sup>	12.7-61.5	17.5-25.2	147.3-246.9	2.09-20.6	0-1435	0.90-141.8	400 <sup>C&amp;</sup>	10.7-57.8	1.82-18.1	42.3-638.2	4.20-282.0	72.4-737.2	0-474.4	
G/M2	100 <sup>U</sup> +300 <sup>C</sup>	10.7-48.4	18.2-24.9	55.7-175.9	1.95-5.7	19.4-2094	5.48-198.3	300 <sup>C</sup>	14.7-42.8	5.29-18.5	19.1-422.7	0.39-234.9	44.3-1232	24.3-769.1	
G/M3	350 <sup>S</sup>	20.1-57.3	15.0-25.8	127.9-215.6	1.64-20.7	1.05-811.9	0-145.1	350 <sup>S&amp;</sup>	10.7-51.6	5.70-20.2	34.4-849.6	0.71-340.2	176.8-991.2	21.5-1024	
G/M4	200 <sup>S</sup>	6.83-25.7	18.6-25.7	83.5-349.3	1.64-10.3	0-1431	4.86-67.8	200 <sup>S&amp;</sup>	13.0-28.1	5.17-21.6	15.5-519.3	0.76-482.0	54.7-904.9	19.1-510.3	
M5	250 <sup>C</sup>	9.56-38.9	18.2-25.7	31.1-120.9	0.27-5.44	3.66-1612	11.9-250.9	250 <sup>C</sup>	9.25-30.5	6.43-19.6	11.0-467.2	0.34-28.8	28.9-177.6	2.18-67.92	
Rice	Flooding period							Un-flooding period							
	R1	50 <sup>U</sup>	-	16.2-24.9	40.4-50.0	3.25-5.80	0-111.4	0-27.9	150 <sup>C&amp;</sup>	24.7-55.8	2.37-22.6	17.7-79.2	0.42-17.5	6.90-351.5	0-924.4
	R4	0	-	14.6-26.0	21.5-29.6	2.54-6.36	21.1-282.9	0-30.1	200 <sup>S&amp;</sup>	19.8-53.4	2.23-26.9	9.78-269.1	0.19-9.80	18.1-238.0	0-146.5
	R5	20 <sup>U</sup> +230 <sup>S</sup>	-	17.8-21.5	25.4-39.0	6.09-30.1	0-109.8	0-40.8	250 <sup>C</sup>	8.83-45.6	6.43-19.6	9.20-232.8	0.35-28.8	12.0-177.6	0.23-45.0

The letters of C, U and S indicate the fertilizer types with composted dry manure, urea and slurry respectively. & indicated the whole region which included the uplands and un-flooding values. The mark of \*denotes the fertilizer keeping on surface soil for a long time (FKSSL), otherwise the fertilizer methods was ploughing immediately after fertilization (PIAF). Fields G/M1, G/M2, G/M3, G/M4 suggested grass and maize rotation. Field M5 was maize and barley rotation. Fields R1 and R4 were one season of rice. R5 was forage rice and barley rotation.

**Table 1:** The range of soil chemical and physical properties, CO<sub>2</sub> and N<sub>2</sub>O fluxes.

9.26 kg N ha<sup>-1</sup> yr<sup>-1</sup> in uplands and 1.28 to 1.91 kg N ha<sup>-1</sup> yr<sup>-1</sup> in paddy rice fields (Figure 2). According literature review, the N<sub>2</sub>O emission of no fertilizer and soil was 1.27 ± 1.19 kg N ha<sup>-1</sup> yr<sup>-1</sup> in uplands. The emission factor was 0.08% to 1.14% with an average 0.48 ± 0.41% and 0.13-0.64% with an average 0.43 ± 0.27% of applied fertilizer for uplands and paddy rice fields, respectively. In rice systems, rice/fallow with 0.54% to 0.64% with an average 0.59 ± 0.07% of input N showed

much higher N<sub>2</sub>O emission than forage rice/barley rotation only 0.13% of total N. Compared to the PIAF method, the FKSSL showed much higher N<sub>2</sub>O emission, which contributed to 0.85 ± 0.79% of applied N that equivalent to 3.4 times PIAF (0.25 ± 0.31%). Considering the manure type, the slurry application trended to stimulated more N<sub>2</sub>O emission with a range of 0.46% to 1.14% of input N than the dry composted manure in 0.08% to 0.64% of total N (Figure 2).



**Figure 2:** The cumulated N<sub>2</sub>O emissions over all fields. (The N<sub>2</sub>O emission from No fertilizer Andosols were from literature review, where all data were conducted in uplands covered whole year measurements across Japan. Winter included October to April, and summer was from May to September. PIAF and FKSSL indicated the fertilizer methods with Ploughing Immediately after Fertilization and Fertilizer Keeping on Surface Soil for a Long time, respectively. Error bars indicated the standard error of average values. Different lowercase letters suggested the significant difference for the annual N<sub>2</sub>O emission in each fields (p>0.05). Fields G/M1, G/M2, G/M3, G/M4 suggested grass and maize rotation. Field M5 was maize and barley rotation. Fields R1 and R4 were one season rice. R5 was forage rice and barley rotation.)

Uplands (n=105)	NH <sub>4</sub> <sup>+</sup>	NO <sub>3</sub> <sup>-</sup>	CO <sub>2</sub>	T <sub>soil</sub>	T <sub>air</sub> -T <sub>soil</sub>	Moisture
	kg N ha <sup>-1</sup> day <sup>-1</sup>		mg C m <sup>-2</sup> h <sup>-1</sup>	°C		%
	0.14	0.2*	-0.12	-0.27**	0.14*	0.24*
Paddy flooding (n=24)	0.17	-0.15	0.54*	0.01	0.25	-
Paddy un-flooding (n=32)	0.70*	0.25	-0.33	-0.61**	0.18	0.37*
Whole region <sup>s</sup> (n=137)	0.21	0.29*	-0.18	-0.08	0.11*	0.24**

T<sub>soil</sub> and T<sub>air</sub> suggested the temperature of soil and air. & indicated the whole region which included the uplands and un-flooding values. \*and \*\* suggested the significant correlation level in p<0.5 and p<0.001 levels, respectively

**Table 2:** Correlation of N<sub>2</sub>O fluxes with the soil chemical and physical properties (Pearson's R).

In the whole year, the N<sub>2</sub>O emission factors from this study were mostly lower than the factor reported by IPCC 2007 except field G/M3 with 1.14% of input N (Figure 2) [16]. Consider the IPCC emission factor used in Japan, most of factors from uplands showed in the same range except fields G/M3, but only one rice field R5 was in the range of Japanese IPCC factor. The emission factor from fields R1 and R4 which with rice/fallow in 0.59 ± 0.07% were higher than that used by Japan IPCC 0.31 ± 0.31% (Figure 2).

### Soil properties analysis

Peaks of soil mineral N concentration generally followed the fertilization events (Figure 1). Both soil NO<sub>3</sub><sup>-</sup>-N and NH<sub>4</sub><sup>+</sup>-N contents showed higher peaks after winter fertilization rather than summer fertilization events (Figure 1 and Table 1). For uplands, the peaks of NO<sub>3</sub><sup>-</sup>-N in winter and summer periods respectively varied in 422-849 mg N kg<sup>-1</sup> and 112-263 mg N kg<sup>-1</sup>, and that of NH<sub>4</sub><sup>+</sup>-N was 17.4-482 mg N kg<sup>-1</sup> for winter season and 5.44-20.7 mg N kg<sup>-1</sup> for summer season. Fields G/M1, G/M3 and G/M4 showed much higher mineral N content than other fields; the following is G/M2 and M5. In case of paddy rice fields, significantly lower soil mineral N content was observed, NO<sub>3</sub><sup>-</sup>-N and NH<sub>4</sub><sup>+</sup>-N was only 9.20-269 mg N kg<sup>-1</sup> and 0.19-30.1 mg N kg<sup>-1</sup>, respectively. The highest value was found in field R5, while field R1 showed much lower soil N content than other paddy fields. Anyway, NH<sub>4</sub><sup>+</sup>-N contents were much lower than NO<sub>3</sub><sup>-</sup>-N concentration in both uplands and paddy rice fields over the whole year. The Pearson correlation test showed NO<sub>3</sub><sup>-</sup>-N content was significantly correlated with N<sub>2</sub>O emission in all uplands and both regional un-flooding soils,

and NH<sub>4</sub><sup>+</sup>-N concentration positively correlated with N<sub>2</sub>O emission in paddy rice field during un-flooding period (Table 2).

The soil respirations (CO<sub>2</sub> fluxes) were 26.6-2094 mg C m<sup>-2</sup>h<sup>-1</sup> and 0-351 mg C m<sup>-2</sup>h<sup>-1</sup> for uplands and paddy soils, respectively (Figure 1 and Table 1). The uplands showed significantly higher CO<sub>2</sub> emissions than paddy fields. In uplands, the summer season have greater CO<sub>2</sub> fluxes than winter season. Manure application significantly stimulated CO<sub>2</sub> in both summer and winter season in all upland fields. In each upland field, the highest flux was observed in field G/M2 and the lowest CO<sub>2</sub> emission was found in M5. For paddy rice system, there was no significant difference in CO<sub>2</sub> emissions over all paddy fields. Even through, the CO<sub>2</sub> fluxes in paddy rice fields during flooding season showed significant positive correlation with field N<sub>2</sub>O emission (Table 2).

Soil temperature showed a typical seasonal pattern with a range from 1.82 to 29.1°C. The highest value was found in August and the lowest value near the end of January (Figure 1). For uplands and paddy rice in un-flooding period, negative correlations was observed between soil temperature and soil N<sub>2</sub>O fluxes. But, the daily N<sub>2</sub>O emission from uplands and in regional scale un-flooding soils still had a significant positive correlation with the difference of air temperature and soil temperature (Table 2).

The volumetric soil moisture ranged from 6.83% to 61.5% for all uplands fields and in paddy un-flooding period. Field G/M4 and M5 showed much lower water content than other fields, which were less than 38.9%. Soil moisture has a positive relation with N<sub>2</sub>O fluxes for all uplands and paddy rice un-flooding period (Table 2).



## Discussion

### Effects of manure managements on N<sub>2</sub>O emissions

Fertilization by providing available nitrogen for nitrification and denitrification is a key factor for soil N<sub>2</sub>O emission. Similar with the previous researches, we observed that high N<sub>2</sub>O peak with high soil mineral N content followed the fertilization events (Figure 1) [17-19]. The ending of elevated N<sub>2</sub>O flux was around one month after manure fertilization. In un-flooding period, lower N<sub>2</sub>O fluxes in paddy field could be attributed to the lower fertilizer application rate in winter season than uplands, which is supported by a significantly lower soil mineral N content in paddy rice un-flooding season (Figure 1). For all the uplands soils, a significantly positive correlation between N<sub>2</sub>O fluxes and soils NO<sub>3</sub><sup>-</sup>-N concentration was found (Table 2). This result indicated that nitrification was a process responsible for N<sub>2</sub>O production rather than denitrification. However, the soil NH<sub>4</sub><sup>+</sup>-N content in un-flooding paddy rice soil was significantly correlated with soil N<sub>2</sub>O emission (Table 2). This phenomenon can be regarded as an evidence to prove that N<sub>2</sub>O emission from those soils was stimulated by denitrification process.

Manure type with different aerobic condition would also be a significant factor to control soil N<sub>2</sub>O emissions. Aerobic condition is one of the major factors to regulate soil nitrification and denitrification processes [20,21]. Higher N<sub>2</sub>O emission has been found in pig slurry than compost for maize crop fields [22]. Deng also reported that slurry application stimulated greater denitrification capacity than dry compost manure. In the present research, higher N<sub>2</sub>O emission was found in slurry fields rather than dry compost (Figure 2), which confirmed again that slurry fertilizer can promote denitrification process [14].

The different manure application methods showed significant different N<sub>2</sub>O fluxes. In uplands winter cropping season, the fertilizer generally has been applied on the surface of soil after the summer crop harvesting and would plough the soil over 10 days later (FKSSL). The higher concentration of soil NO<sub>3</sub><sup>-</sup>-N and NH<sub>4</sub><sup>+</sup>-N in G/M1, G/M2, G/M3, G/M4 in winter fertilization was confirmed that the available N of top soil could keep high level for long time (Figure 1). On the other hand, the temperature in fields G/M1, G/M2, G/M3, G/M4 were still around 20°C that denitrifies and nitrifies can keep high activities. Consequently, the high N<sub>2</sub>O could be stimulated. For summer crop season, the applied fertilizer has been mixed immediately with soil and then seeding (PIAF). The growth of summer crops was also very quick and the nutrient requirement was very high. As a result, the available N of N<sub>2</sub>O emission was lower than winter crop season. Yonemuna also found that significant high N<sub>2</sub>O peak around November from 2002-2004 was due to the soybean seeds with high N content incorporated into soil and the experiment site was very nearby our study area [23]. For paddy rice fields R1 and R4, due to the manure were applied in winter fallow season by keeping on the surface soil long time and the tillage did in the next year just before rice translation, high level available N and good aerobic condition caused higher N<sub>2</sub>O emissions.

Due to the influence of aforementioned manure application methods, it mad that the soil temperature was not the main factor to direct N<sub>2</sub>O emission in this study, which showed a negative relation (Table 2). However, the difference between air temperature and soil temperature was significantly positively correlated with soil N<sub>2</sub>O fluxes (Table 2). This phenomenon could be explained by that the big difference of air and soil temperature can stimulate the diffusion of N<sub>2</sub>O gas from soil to air.

### Effects of land-uses on N<sub>2</sub>O emissions

Considering the differences of N<sub>2</sub>O emission in uplands and paddy rice, the main reason was the different soil aerobic state. Many studies reported that the paddy rice fields have significantly lower N<sub>2</sub>O fluxes than uplands, especially in the flooding period [24,25]. The N<sub>2</sub>O emission from paddy rice during the flooding period was near zero or negative value [18,26]. Our results were consistent with those previous reports and N<sub>2</sub>O flux in flooding soils was near negligible (Figure 1). The weaker soil respiration in flooding soil was positive correlated with N<sub>2</sub>O emission and this result showed again that there is a very low aerobic condition for paddy rice in flooding season. For un-flooding soils, soil moisture showed significant correlation with soil N<sub>2</sub>O fluxes (Table 2). This result also provide that the soil aerobic state was the main driver for N<sub>2</sub>O emission.

In case of rice/fallow system, the manure applied in fallow season and the tillage conducted just before rice translation. The higher available N after manure applied on top soil stimulated higher N<sub>2</sub>O fluxes. In result, the N<sub>2</sub>O emission factor reached to 0.64% which significant higher than the IPCC used factor 0.31% for Japanese rice.

In general, soil texture by influencing soil aerobic state was important for regulating soil N<sub>2</sub>O emission [27]. In our study, no significant difference of N<sub>2</sub>O fluxes were found in different soil textures. The influence of soil textures on N<sub>2</sub>O emissions was weaker with others factors such as: manure type, fertilization method and land uses. So, soil texture was not the significant driver for soil N<sub>2</sub>O emission in our study fields.

### Total N<sub>2</sub>O emissions

Nitrous oxide losses observed in this study was comparable to previously study [3]. The total soil N<sub>2</sub>O emission was 1.91-9.26 kg N ha<sup>-1</sup>yr<sup>-1</sup> in uplands and 1.28-1.91 kg N ha<sup>-1</sup>yr<sup>-1</sup> in paddy rice field, within the same range of uplands (1.73-11.2 kg N ha<sup>-1</sup>yr<sup>-1</sup>) and paddy rice (0.73-2.58 kg N ha<sup>-1</sup>yr<sup>-1</sup>) reported in a global meta-analysis [3]. For the N<sub>2</sub>O emission factor, our results were 0.48 ± 0.41% in uplands which in the same range of N<sub>2</sub>O emission factor from grass lands in Andosol in Japan reported by Shimizu, but slightly lower than the Japanese uplands summery of 0.62 ± 0.48% [11,28]. However, the result in paddy rice in our study (0.43 ± 0.27%) was higher than the Japanese paddy factor of 0.31 ± 0.31% [11]. The greater N<sub>2</sub>O emission from our paddy fields could be mostly attributed of the fertilizer (manure) applied in winter fallow season while in case of the summary by Akiyama the fertilizer may be only applied in cropping season. Therefore, our research provided a new emission factor for paddy rice with manure applied in fallow winter season 0.59%.

Based on the results, it can be concluded that N<sub>2</sub>O emission factor from uplands and paddy rice was 0.48 ± 0.41% and 0.43 ± 0.27% of input manure, respectively. The slurry manure stimulated more N<sub>2</sub>O emission with 0.71 ± 0.37% of input N than that of dry compost manure with the emission factor of 0.32 ± 0.25%. For fertilization methods, it was better to plough the soil immediately after manure application (PIAF 0.25%) by reducing available N content of top soil, otherwise around 3 times N<sub>2</sub>O would be emitted with FKSSL management (0.85%).

## Conclusion

The current results suggested that manure type, manure application method, land uses are the main factors to regulate N<sub>2</sub>O emission in the study region. Manure type and land uses affect N<sub>2</sub>O emission through

influence soil moisture. Slurry manure which was used to regulating denitrification can stimulate more N<sub>2</sub>O flux than dry manure. Immediately ploughing soil is recommended after manure application to mitigate N<sub>2</sub>O fluxes, otherwise much more N<sub>2</sub>O would be produced if leaving manure on the surface soil with long time. Comparing with uplands, paddy rice fields showed much lower N<sub>2</sub>O emissions, and the total N<sub>2</sub>O emission rate were 1.91-9.26 kg N ha<sup>-1</sup> yr<sup>-1</sup> for uplands and 1.28-1.91 kg N ha<sup>-1</sup> yr<sup>-1</sup> for paddy rice field, respectively. Under intensive dairy manure application, the N<sub>2</sub>O emission factors were 0.48 ± 0.41% for uplands and 0.43 ± 0.27% for paddy rice, 0.71 ± 0.37% for slurry manure and 0.32 ± 0.25% for dry compost manure, 0.25 ± 0.31% for PIAF and 0.85 ± 0.79% for FKSSL method. Specifically, we provided a new emission factors 0.59% for paddy rice under fertilizer in winter follow season.

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