The impact of land uses on N_2O emission in an intensive dairy farming region, Japan

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Abstract
Nitrous oxide (N_2O) emission from agricultural soils highly depends on the land use and management methods. We investigated an intensive dairy farming region (upper Naka river watershed, East-Japan) to evaluate the N_2O emission from soil for different land uses and different soil textures. Nitrous oxide flux from 8 agricultural fields was taken by static chamber method from January 2008 to February 2009 with bimonthly intervals. Nitrous oxide flux ranged from -9.1 to 205.6 µg N/m^2/h in upland crop systems and from -13.0 to 283.3 µg N/m^2/h in paddy fields. It was mainly influenced by soil moisture, applied fertilizer and special weather conditions. Nitrous oxide emission from rice fields was higher than that of upland soils, especial during the non-flooding period. Summer season had a significant lower N_2O emission than winter season. The controlling factors changed with different scales. The concentrations of ammonia (NH_4^+ -N) and nitrate (NO_3^- -N) in soil were the most important parameters for N_2O flux for paddy and upland systems at field scale, respectively. The soil moisture was the main controlling factor for N_2O flux at the regional scale.

Key Words
Land uses, N_2O, agricultural soils, scale.

Introduction
The livestock sector grew rapidly to meet the increasing demand in meat and dairy productions. As a result, the increased manure applied to soil became one of the most important sources of N_2O emission from agricultural soils (Mosier *et al.* 1998). Nitrous oxide flux from agricultural soils was strongly influenced by different crop systems, especially whether they are paddy or upland fields (Li *et al.* 2004). Many researchers have studied N_2O emission at field scale. It was difficult to find the main influence factors and to establish strong predictive relationships between field fluxes and field scale parameters such as temperature, soil moisture, soil texture and so on (Groffman 1991). This study was conducted at an intensive dairy farming area, where high amount of manure is applied. The data of N_2O flux from a field scale was analysed at regional scale, which contains different soil textures and different crop systems. The objectives of this research were (i) to explore the character of N_2O fluxes from different crop systems, and (ii) to evaluate the N_2O emission at the whole target region.

Methods
This study was conducted from January 2008 to February 2009 at upstream of Naka River watershed in Japan (36^{o}49`- 37$^o$01`N, 139^{o}54`-139$^o$59`W). In this region, major crop systems are one season cultivation of rice (R), maize (M), and a rotation of grass and maize (G/M). Dairy cow manure is the main fertilizer source. Five sampling sites (marked with I-V) were chosen according to different land uses, soil textures and location. There are 8 sampling fields in total. Three samples were taken at each field 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; the rice seedlings were transplanted in May and harvested in October. N_2O fluxes in the fields were measured using static chambers. The basic information about soil and fertilizer for all the sampling sites are shown in Table 1.

Results
N_2O fluxes in whole region
N_2O flux ranged from -9.1 to 205.6 µg N /m^2/h in M and G/M systems and from -13.0 to 283.3 µg N /m^2/h in R systems (Figure 1a and 1b). The highest N_2O fluxes were found in January, 2008, and then it decreased with the time. The fluxes were less than 50 µg N/m^2/h in March 2008 for M and G/M systems and in May 2008 for R systems. An exception was the G/M system on loam and R system on silt loam in December of 2008 and sandy loam in February 2009, which had high N_2O fluxes of 121.3, 128.5 and 142.9µg N /m^2/h, respectively. The cumulative N_2O emission of winter period from November to April ranged from 1.7 to 5.3

kg N /ha/ period and was significantly higher than that of summer period from May to October which ranged from -0.1 to 1.7 kg N /ha/period (Figure 2) ($p<0.01$). R systems had significantly higher N_2O emission than G and G/M systems ($p<0.01$). Significant interactions were found between the period and land uses, and between land uses and soil types ($p<0.01$). As a result, the annual N_2O emission of M and G/M systems ranged from 2.0 to 3.4 kg N /ha/yr with an average of 2.8 kg N /ha/yr, and that for R systems ranged from 2.5 to 6.0 kg N /ha/yr with an average of 4.1 kg N/ha/yr.

The character of N_2O emission from different land uses

Land uses strongly influenced the N_2O fluxed in the fields. The N_2O emission from paddy fields was 1.5 times higher that of upland field. Winter period from November to April showed 10 and 3 times higher N_2O emission compared to summer period from May to October for rice fields and upland systems, respectively. Those results may be due to the different soil moisture, the application of fertilizer and special weather condition. Davidson *et al.* (2000) showed that soil water-filled pore space (WFPS) is an import factor to control N_2O emission from soil. Nitrous oxide flux mainly occurs when WFPS is between 40% and 80%. When WFPS exceeds 80%, N_2O consumption occurs and di-nitrogen (N_2) becomes the major end product of denitrification. In this study, the paddy fields were kept flooding from early May to end of August 2008, leading to low N_2O emissions. However, during non-flooding time, WFPS was around 46% and promoted N_2O emission. For uplands, the WFPS was less than 40% during the whole season, and only little N_2O emission from nitrification might have occurred. High N_2O emission can happen after fertilizer application (Mori *et al.* 2008). In this region, the fertilizer is generally applied in paddy fields in winter period around November. Thus, N_2O emission can be stimulated during that time. For silt loam soil, slurry with the same amount N as winter period has been applied in August 2008, few days before sampling. However, no high N_2O emission was found during that time (Figure 1a). It can be explained that the main end product of denitrification was N_2 rather than N_2O. In uplands, the manure was applied both in winter and summer seasons. For the summer period, farmers applied manure around end of May to early June in all G and G/M systems. Thus, high N_2O flux during this time might not be captured since no sampling was conducted after manure application. Thus, the N_2O emission during summer period might be underestimated. Comparing different soil textures, there was no significant correlation between N_2O emission and soil texture parameters through the whole year for all of the crop system. However, a significantly high N_2O emission was observed in silt loam soil at R system (Figure 2). It may be due to the 2 times higher fertilizer application rate compared to clay loam and sandy loam fields (Table 1). Many studies have shown that high N_2O emission can occur during special weather conditions such as freezing-thawing period or rain events (Neilsen *et al.* 2001). The high N_2O fluxes during winter were coincided due to freezing-throwing event in surface soils.

The character of N_2O emission from whole region

The present study showed different influence parameters at different scales (Table 2). At field scale, the influence factors of N_2O flux included the concentration of soil NO_3^- -N and soil temperature (0-10cm). But for regional scale, it is also the concentration of NH_4^+ -N, CO_2 emission, the difference between air and soil temperature, the WFPS, contentment of silt and organic C and the ratio of C/N. As expected, NO_3^- -N availability was found to limit N_2O flux at M and G/M systems (Table 2). Unlike upland soils, NH_4^+ -N of soil significantly influenced the N_2O emission at R systems (Table 2). However, the NO_3^- -N concentration with an average of 95 mg N/kg was much higher than that of NH_4^+ -N, which had an average of 9.3 mg N/kg at both flooding and non-flooding period. This result suggests that there are different processes to control N_2O emission in upland systems and rice systems. Carbon dioxide emission was significantly positively correlated to N_2O flux at R systems during non-flooding period (Table 2). It indicates that microbe activities are closely related to N_2O emission for rice flooding period. A negative correlation between CO_2 emission and N_2O fluxes was also found in all R systems for all season. High CO_2 flux from soil in August 2008 was stimulated by high temperature, which promoted the soil microorganisms' activities, soil animal and crop root respiration. Since N_2O emission in soil is produced by microbial processes of nitrification and denitrification, soil temperature affects N_2O flux by regulating those microbial activities (Granli and Bøckman 1995). In this study, a significant negative correlation was found between soil temperature and N_2O fluxes (Table 2). It may be masked by other factors such the amount of applied fertilizer and the freezing-thawing event. The difference between air and soil temperature can drive N_2O diffusion from soil (Granli and Bøckman 1995). The difference between air and soil temperature was also significantly correlated with N_2O flux in this study. All of the results indicated that N_2O emission at this region was controlled by the mineralization N of soil, microbe activities, temperature, water regime, soil texture and the turnover of soil nitrogen and carbon.

Table 1. The basic informations of soils of the 8 study fields.

Land uses	I	II		III	IV		V	
	G/M	G/M	R	G/M	G/M	R	G/M	R
TN(mg N/g)	0.85a	0.87a	0.48b	0.80a	0.43bc	0.36b	0.37c	0.87a
TC(mg C/g)	11.85a	12.17a	6.64c	10.41b	4.62de	3.83e	5.23d	9.61b
pH	6.15	6.95	6.56	6.27	5.69	6.1	6.16	6.15
Fertilizer(kg N/ha)								
Winter (Nov-Apr)	430	455	100	315	410	295	250	250
Summer(May-Oct)	430	455	100	415	470	0	250	270
Soil texture	Clay loam			Loam	Sandy loam		Silt loam	

Table 2. Coefficients factors for the linear model of N_2O at different spatial scales.

	Constant	NH_4^+	NO_3^-	CO_2	Soil temp.	Air-soil temp.	WFPS	Silt	C	Ratio C/N	Model	
		mg N/kg		mg C/m^2/h	ºC		%	%	mg N/g		R	P
Field scale												
IVG/M	122.29	-	-	-	-	-	-	-	-	-	0.87	<0.001
V M	-21.08	-	0.44	-	-	-	-	-	-	-	0.71	0.003
II R	171.33	-	-	-	-10.48	-	-	-	-	-	0.69	0.007
IV R	101.71	-	-	-	-5.51	-	-	-	-	-	0.72	<0.001
V R	214.27	-	-	-	-11.13	-	-	-	-	-	0.70	0.002
Regional scale												
Uplands	695.50	-	0.43	-	-9.17	-	4.66	-	-9.17	-	0.99	0.001
Non-flooding R	137.21	8.96	-	-	-12.11	-	-	-	-	-	0.76	<0.001
Flooding R	1.93	-	-	0.20	-	-	-	-	-	-	0.55	0.022
All season R	131.00	5.84	-	-9.55	-	-	-	-	-	-	0.71	<0.001
Whole region	209.31	-	-	-	-6.04	5.65	-	1.03	-	-10.65	0.53	<0.001

Conclusion

The results of this research demonstrate that N_2O emission in soils was regulated by land use types, application of fertilizer and special weather conditions. Annual N_2O emission from R systems was higher than that of upland soils. Summer season had a significant lower N_2O emission than winter season. The controlling factors changed with the different scales. For R systems, the water regime and the concentration of NH_4^+ -N in soil were the most important factor for N_2O flux. The concentration of NO_3^- -N and the WFPS in soil were the main factors of N_2O emission in G and G/M systems. At the whole region, the soil moisture was the important factor to drive N_2O emission.

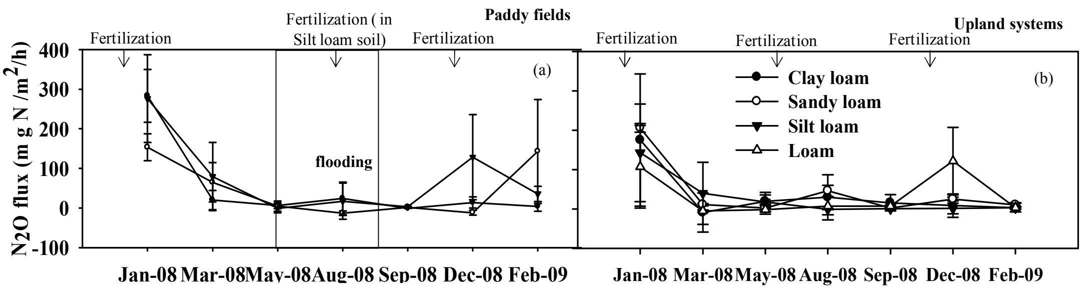

Figure 1. Seasonal patterns in N_2O emission at (a) paddy rice systems and (b) Maize and grass/maize rotation systems. Black error bar stands for standard deviation (n=3).

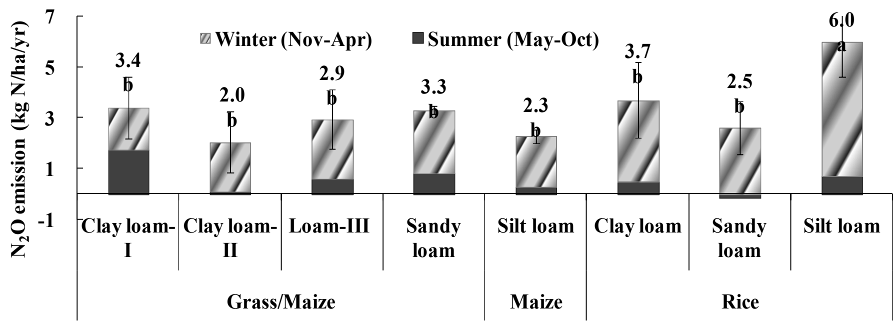

Figure 2. Annual N_2O emission from different land uses. Black error bar stands for standard deviation (n=3).

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