Journal of Agricultural Science; Vol. 5, No. 9; 2013
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Effects of Fertilizers and Mushroom Residues on Soil N_2O Emission Under Rice-Wheat Rotation in Chengdu Plain

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Received: May 30, 2013 Accepted: July 17, 2013 Online Published: August 15, 2013

doi:10.5539/jas.v5n9p102 URL: http://dx.doi.org/10.5539/jas.v5n9p102

Abstract

Nitrous oxide (N_2O) is a greenhouse gas, and agricultural landscapes are major sources of atmospheric N_2O. In this study, different types and levels of fertilization were applied to rice and wheat plants, including full crop straw, pure synthetic fertilizer and spent agro-residues from mushroom cultivation. N_2O flux measurements were performed once a week using gas static chromatography-chamber between 2008 and 2009. In order to find out the effect of MR application on N_2O emission, soil samples, environment-monitoring factors including soil moisture and temperature and biomass were also determined. Soil nitrate and ammonia were measured in soil extracts. The results showed that the total N_2O emission decreased to 19,066 kg ha^{-1} in the rice stage and 45,312 kg ha^{-1} in the wheat stage under the mushroom residue (MR) application. This observation indicated that MR application (22,656.40 kg for rice and 9,533.33 kg for wheat) induced a decrease of N_2O emission by 62.52% and 67.55% as compared with fertilizer and straw application, which are 6328.77 ± 740.81^b g ha^{-1}, 7310.60 ± 279.73^b g ha^{-1} respectively. Therefore, MR application could be one of the most effective ways to reduce soil N_2O emissions.

Keywords: mushroom residue, nitrous oxide, rice-wheat rotation

1. Introduction

Nitrous oxide (N_2O) is an atmospheric trace gas contributing to global warming (IPCC, 1996). The major anthropogenic source of N_2O has been attributed to agriculture, which is responsible for 50% of current anthropogenic emissions (IPCC, 2001). Furthermore, the ultimate cause of N_2O emission is nitrogen (N) enrichment due to nitrogen fertilizer application tillage, crop residue incorporation and many other organic matter applications (Dobbie et al., 1999; IPCC, 2001; Zou et al., 2005; Miller et al., 2008; Xu et al., 2009).

Many studies reported that N_2O emissions are increased with the application of N (IPCC, 2001; Hellebrand et al., 2003; Miller, 2008). Regarding tillage, N_2O emissions from soil are higher under no-tillage (NT) than those under conventional-till (CT) (Skiba et al., 2002). However, other studies showed that the N_2O emission is decreased under NT (Passionato et al., 2003). Similarly, Elmi et al. (2003) and Grandy et al. (2006) reported the similar level of N_2O emission between CT and NT. Furthermore, there are also conflicting results for the effect of crop straw incorporation on N_2O emissions. Crop straw can cause N loss through denitrification and N_2O emissions (Baggs et al., 2000; Huang et al., 2004). However, Hao et al. (2001) and Yao et al. (2009) observed that the N_2O emission is decreased when crop residues are retained. In addition, the positive effects of other agricultural organic matters (such as animal manure) on soil N_2O emissions have been reported (Stevens & Laughlin, 2001; Khalil et al., 2002; Ding et al., 2007). Cattle manure reduces N_2O emissions compared with ammonium sulfate (Velthof et al., 2002, 2003). Field measurements in Northeast and North China showed that there is no significant difference in N_2O emissions between organic manure and urea (Chen et al., 2002; Meng et al., 2005). However, few studies have described the effects of mushroom residues (MR) on soil N_2O emissions. Relevant studies mainly focus on relationships between soil physic-chemical, chemical and biological properties in soil amended with mushroom residues.

MR is the leftover agro-residue from mushroom cultivation. It is a compost mixture of cereal straw, manure (poultry and/or cattle manure), calcium sulphate, soil, and residues of inorganic nutrients and pesticides (Williams et al., 2001). The residues contain not only abundant organic matter, nitrogen, phosphorus, potassium and other nutrients, but also a considerable amount of bacterial proteins (Chen, 2001; Li, 2003). In Chengdu Plain, the annual production of mushroom culture was 1.06 Mt in 2007, leading to a total of 0.28 Mt of fungal residues. Over 80% of fungal residues are disposed without recycling (Hu, 2008). This is not only a waste of resources, but also causes environmental problems, such as surface water pollution. Therefore, it is detrimental for mushroom cultivation, such as *mycete* and *ácaro* (Mi et al., 2005; Li & Cheng, 2008; Wang et al., 2008). MR recycling is one of the most effective ways to solve these problems.

In the present study, the optimal proportion of MR and synthetic fertilizers are determined for the analysis between different fertilization and N_2O emission. This paper also presents the possible beneficial effects of MR application on soil N_2O emissions by field experiments with a rice (Oryza sativa)-wheat (Triticumaestivum) rotation compared with a crop straw application.

2. Materials and Methods

2.1 Site Description and Materials

The experimental site was located in Hanchang County (latitude 30°27′ N, longitude 103°41′ E, altitude 483.7 m) in Chengdu Plain with a mean annual precipitation of about 1,098.2mm and a mean annual temperature of 16.0 °C. The soil at the experimental site is a *Fe-accumuli-StagnicAnthrosols* with long-term NT derived from grey alluvium of the MinjiangRiver. The basic physicochemical properties of the topsoil layer (0-10 cm) were listed in Table 1.

Table 1. Physicochemical properties of the topsoil layer (0-10 cm)

Physicochemical properties	Data
Soil pH	6.85
Bulk density	1.13 $g\cdot cm^{-3}$
Sediment concentration	21.73%
Salinity	49.76%
Clay fractions	28.51%
Organic matter content	57.90 $g\cdot kg^{-1}$
Total N contents	2.90 $g\cdot kg^{-1}$
Total P contents	1.05 $g\cdot kg^{-1}$
Total K contents	21.20 $g\cdot kg^{-1}$
Available N contents	124.92 $mg\cdot kg^{-1}$
Available P contents	20.36 $mg\cdot kg^{-1}$
Available K contents	270.47 $mg\cdot kg^{-1}$
Soil/water extract	1:2.5

The mushroom residues used in the experiment were produced in the standard cultivation house of one local edible fungi company. All the residues came from agaricus-bisporus which were fertilized by the mixture of cattle manure and rice straw. Before the experiment, the basic nutrient content of mushroom residues applied in rice and wheat season were measured and they were listed in Table 2.

Table 2. The nutrientcontent of mushroom residues applied in rice and wheat season

Nutrient content	Rice season	Wheat season
moisture	6.60 %	31.20 %
Organic matter content	382.10 $g\cdot kg^{-1}$	466.80$g\cdot kg^{-1}$
Total N contents	16.20 $g\cdot kg^{-1}$	8.70$g\cdot kg^{-1}$
Total P contents	0.61 $g\cdot kg^{-1}$	1.70 $g\cdot kg^{-1}$
Total K contents	2.47 $g\cdot kg^{-1}$	11.80 $g\cdot kg^{-1}$

Rice, GangYou 94-11, was transplanted by hand at intervals of 13 cm in lines and 26 cm in rows on May 10th, 2009 and harvested on August 31st, 2009. Wheat, RongMai 2, was seeded on November 1st, 2008 and harvested on May 1st, 2009. After the rice or wheat was harvested, the stubble height was less than 5 cm.

2.2 Experimental Design

Six different treatments were conducted in the investigation, including chemical fertilizer only (CF), chemical fertilizer with a full dose of rice or wheat straw returned (CFS), or a mixture of 50% MR and 50% chemical fertilizer. Table 3 shows six different kinds of fertilization applied in the field. The percentages of total N and CF in the MR were 50% and 100% respectively. The ratio was 0.5:1 (50% MR). When a full dose of mushroom cultivation residues was returned, the percentage of total N and that in the MR were both 100%. The ratio was 1:1 (100% MR); the percentage of total N and CF in the MR were 150% and 100% respectively. The ratio was 1.5:1 (150% MR). Each test was performed in triplicate. MR treatments were fertilized with the same dose of urea for N, single super-phosphate for P, and potassium chloride for K as for the CF treatments, and they were arranged in a randomized complete block design. The length and breadth of the plot was 5 m and 6 m respectively.

The soil N_2O efflux under different fertilization was measured using the static chamber technique. The sampling boxes are cubical in shape and made by steel. In order to avoid temperature change inside the boxes caused by solar radiation, the outer flank of every box was wrapped up by sponge and then by a thin layer of silver paper.

Before the rice blooming stage, 45 kg ha^{-1} of K fertilizer was applied to the field surface. The remainder was applied to the field surface on the 4th day after the rice transplantation. In the wheat season, all fertilizers were applied to the surface before sowing. In the rice and wheat season, the major nutrient contents of mushroom cultivation residues returned to the field were 396.70 and 428.40 g per kg of organic matter, 16.20and 18.10 g per kg of N, 0.61 and 0.81 g per kg of P, and 2.47 and 2.99 g per kg of K, respectively.

Table 3. The overview of different fertilization for field (kg ha^{-1})

Treatment	wheat					rice				
	Crop straws	MR	N	P_2O_5	K_2O	Crop straws	MR	N	P_2O_5	K_2O
CF	-	-	163.79	26.33	31.60	-	-	93.30	15.00	18.00
CFS	5000.00	-	163.79	26.33	31.60	5250.00	-	93.30	15.00	18.00
50%MR	-	11328.20	81.67	10.32	-	-	4766.67	46.74	13.20	10.00
100%MR	-	22656.40	-	-	-	-	9533.33	-	11.60	4.00
150%MR	-	33984.60	-	-	-	-	14300.00	-	17.20	6.00
200%MR	-	45312.80	-	-	-	-	19066.67		22.80	8.00

2.3 Measurement of Soil Temperature, Moisture, Biomass Measurement and NH_4^+-N, NO_3-N Determination

Concerning the law of growth cycle of wheat and rice, factors (temperature, moisture, NH_4^+ and NO_3^-) affecting soil N_2O emissions were monitored every 10 days during the wheat stage and once a week during the rice stage.

The top soil temperature at different depths (5 cm, 10 cm, 15 cm and 20 cm) both inside and outside of the gas chamber was measured by JM portable electronic thermometer. The measurement could be divided into two parts: routine determination and diurnal variation measurement. The coldest, the hottest and the most moderate soil temperatures in one day were measured in each plot at 7:00, 13:00 and 18:00 respectively in the routine determination. While in diurnal variation measurement, the soil temperature was observed every 2 hours between 7:00 and 9:00 during the growth stage of wheat and rice.

The top soil moisture was measured in each plot using the method of oven drying in aluminum-boxes. During the incubation, the initial soil moisture was measured and expressed as soil water content (%).

Soil NH_4^+ and NO_3^- contents were measured by a KCl extraction method as follows. Briefly, 5.00 g of moist soil (0-10 cm) was added to 50 ml of 1 M KCl solution, and the mixture was then vortexed for 1 h to fully extract NH_4^+ and NO_3^- contents. Subsequently, the extract solution was analyzed by an auto analyzer (Foss, FIAstar5000, Danish). Soil NH_4^+ and NO_3^- contents were expressed as follows:

$$NH_4^+(NO_3^-) = solution\ contents\ (mg/ml) \times 10 \times (1+water\ content) \tag{1}$$

2.4 N_2O Flux Measurement

N_2O flux was simultaneously measured using a static chamber. The plant density inside the flux chamber (0.5 m × 0.5 m × 0.5 m), covering four hills of rice and 30 hills of wheat in the field, was the same as that outside the chamber. In all plots, stainless steel bases were installed into the chambers before the rice transplantation and kept there until the next harvest season. In order to avoid soil disturbances during the sampling and measurements, removable wooden boardwalks (2 m of length) were set up at the beginning of the rice season. Gas samples were collected during a 10-day period post-fertilization with a 4- or 5-day interval. Moreover, gas samples were also collected during the next 4 months of rice growth with a 7-day interval. Four gas samples from each chamber were collected during the rice growth stage with a 5-min intervaland during the wheat growth stage with an 8-min intervalusing 60-ml vacuum vials. Due to the law of plant respiratory metabolisms, the photosynthesis of plant is strongest between 09:00 and 11:00AM and most of greenhouse gases are released during that time. Samples were collected between 09:00 and 11:00 AM on every sampling day.

The N_2O concentration was measured using a gas chromatograph (GC) instrument (HEWLETT Packard 5890, seriesⅡ, USA) equipped with an electron capture detector (FID) through automatic injection (CA-5, Institute of Atmospheric Physics, China). Chromatography conditions were set up as follows: column temperature of 35°C, injection temperature of 55°C, and detection temperature of 200°C. A N_2O peak was detected at a specific retention time. Before the sample analysis, the GC was calibrated with different dilutions of 10 mg kg^{-1} span N_2O gas, and the chamber volume was then determined. Total N_2O emissions were calculated as follows:

$$T_{N_2O} = \sum_{i=1}^{n} (F_i \times D_i) \tag{2}$$

Where D_i is the number of days, F_i is the measured efflux in the *i*th sampling interval, and *n* is the number of sampling intervals.

2.5 Calculations and Statistics

All data were analyzed using the General Linear Model of SPSS13.0. Independent variables are six different fertilization including CF, CFS, 50%MR, 100%MR, 150%MR, 200%MR while dependent variables are soil NO_3^-, soil NH_4^-, soil NO_3^-/NH_4^-,soil moisture, soil biomass and soil temperature. All non-normal data were log-transformed. Means were determined using the Uniform Minimum Variance Unbiased Estimators. Results were similar to the arithmetic means. Therefore, treatment means and standard errors presented in tables and figures were obtained from untransformed data. Comparisons of total N_2O emissions were performed using the Least Significance Difference (LSD) test since comparisons are significant. Treatment means were compared using a protected LSD test. Pearson correlation coefficients were determined for soil NO_3^-, NH_4^+ contents, temperature of surface soil and soil at 5 cm blow the surface, soil moisture and N_2O emissions. $P<0.05$ was considered as statistically significant.

The effects of environmental conditions on N_2O efflux were analyzed by a series of single and Multiple Regression Analyses (MRA). Multiple regression analysis has been widely used to model the cause-effect relationship between inputs and outputs and has predicting function. It can be generally expressed as

$$\mathrm{Y} = f(X_1, \dots X_n; \theta_1, \dots, \theta_p) + \varepsilon \tag{3}$$

where Y is a dependent variable (i.e., output variable), $X_1, \dots, X_n$ are independent or explanatory variables (i.e., input variables), θ_1–θ_p are regression parameters, ε is a random error, which is assumed to be normally distributed with zero mean and constant variance σ^2, and f is a known function, which may be linear or nonlinear. If f is linear, then (3) becomes a multiple linear regression model and can be expressed as

$$\mathrm{Y} = \mathrm{b_o} + \mathrm{b_1X_1} + \mathrm{b_2X_2} + \cdots + \mathrm{b_nX_n} + \varepsilon \tag{4}$$

where b_0 is a constant and called intercept. Different functional forms decide different MRA models.

The regression parameters θ_1–θ_p or b_0–b_n are usually estimated using the least squares method (LSM), which can be expressed as an unconstrained optimization problem:

$$\text{Minimize J} = \sum_{t=1}^{T} \left(\mathrm{Y_t} - f(X_{1t}, \dots, X_{nt}; \theta_1, \dots, \theta_p)\right)^2 \tag{5}$$

where t = 1, … , T represent T different sample points. Once the regression parameters are determined, the corresponding regression model can be utilized for prediction.

3. Results

3.1 Effect of MR Application on N_2O Emission

3.1.1 Effect of MR Application on Seasonal N_2O Emission

Average N_2O emission ranged from -0.133 to 4.093 mg m^2 h^{-1} under CF, -0.079 to 2.061 mg m^2 h^{-1} under CFS, -0.173 to 3.261 mg m^2 h^{-1} under 50% MR, -0.310 to 1.125 mg m^2 h^{-1} under 100% MR, -0.173 to 0.793 mg m^2 h^{-1} under 150% MR, and -0.313 to 2.650 mg m^2 h^{-1} under 200% MR. Figure 1 shows that two N_2O efflux peaks were observed after the fertilization during the winter wheat seeding stage and maturity stage, respectively. The first peak appeared due to the fertilization, and the second one was caused by the acute alteration of soil moisture. However, the soil moisture changed only during the first several months in the cold winter and during the wheat growth season.

Furthermore, two influx peaks during the tillering stage (around June 24th, 2009) and flowering stage (around July 27th, 2009) and two efflux peaks during the drained stage within the tillering stage (around November 9th, 2008) as well as during the maturity stage (around May 4th, 2009) were observed during the rice growing season though they were not very obvious (Figure 1). The first N_2O efflux peak was observed after the fertilization, and the second one appeared on June 30th when all field water was drained in order to prevent the rice from over-tillering until the heading stage. The third efflux peak occurred during the maturity stage after the drainage (Figure 1). Finally, the two influx peaks bothappeared during the flooding period.

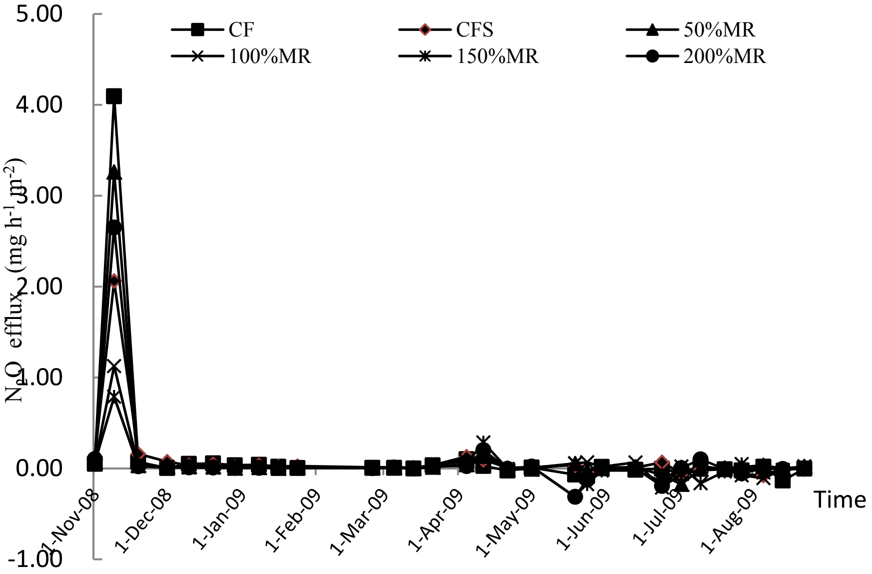

Figure 1. N_2O emission in the rice-wheat growth season

3.1.2 Effect of MR Application on Total N_2O Emission

Table 4shows that the total soil N_2O emission ranged from 3,659.11 kg ha^{-1} to 9,174.78 kg ha^{-1} after a wheat-rice rotation during the incubation with a following sequence: 200% MR > CFS > CF > 150% MR > 50% MR > 100% MR. Compared with CF, the N_2Oemission was decreased by 62.52% under 100% MR, 43.61% under 50% MR and 42.18% under 150% MR. However, the N_2O emission was increased by 44.97% under 200% MR and 15.51% under CFS. With the MR application, the predicted annual N_2O emission was decreased to 19,066 kg ha^{-1} in the rice stage and 45,312 kg ha^{-1} in the wheat stage, respectively.

Annual N_2O efflux under CF, 100%, 50%, and 150% MR treatments was significantly decreased ($p < 0.05$) from November 2008 to September 2009. During this period, the cumulative N_2O emission from plots with crop straw applications and chemical fertilizer was greater than that from plots fertilized with mineral fertilizer. Moreover, it was two times greater than that from plots with MR application, except for the 200% MR application.

Table 4. Total N_2O emission under different fertilization at rice and wheat season

Treatment	N2O efflux of the rice season (g ha-1)	N2O efflux of the wheat season (g ha-1)	Total N2O flux (g ha-1)
CF	-698.49±70.32b	7027.26±626.27b	6328.77±740.81b
CFS	-270.47±56.98a	7581.07±222.96b	7310.60±279.73b
50%MR	-784.72±90.66bc	4353.54±125.34bc	3568.82±168.78c
100%MR	-702.83±119.83b	3074.99±119.84d	2372.16±201.68c
150%MR	-1043.78±5.94d	4702.89±43.51c	3659.11±48.62c
200%MR	-718.15±61.26bc	9892.93±781.35a	9174.78±775.95a

Values are the mean ± SE of three individual replicates. Values in the same column followed by the same letter do not differ significantly by LSD ($p< 0.05$).

3.2 Factor Effect on N_2O Efflux

3.2.1 Correlation Between N_2O Efflux and Soil NH_4^+, NO_3^-, NO_3^-/NH_4^+ Fertilizer

The correlation between the N_2O efflux and topsoil NO_3^-/NH_4^+ content was analysed. Data showed that except for the chemical fertilization treatment, other treatments were significantly different at the $p < 0.05$ level, and the 150% MR treatment was significant at the $p < 0.01$ level (Table 5). Therefore, although the N fertilizer was the factor affecting the soil nitrification and denitrification, a striking correlation could be found between the soil N_2O efflux and soilat neither the rice stage nor the wheat stage. However, the N_2O efflux was positively correlated with the NO_3^-/NH_4^+ content.

3.2.2 Correlation Between N_2O Efflux and Soil Moisture

The effects of environmental conditions on N_2O efflux were investigated by a series of single and multiple regression analyses. Consistent with previous studies,no significant correlation between the soil moisture and N_2O efflux was found for any treatment (Table 5). However, the two leaps of N_2O efflux emerged at the period when soil was with high moisture level, which was also during the flooding time at the rice transplanting and wheat maturation stage (Figure 3).

3.2.3 Correlation Between N_2O Efflux and Soil Temperature

Table 3 shows that the temperature of surface soil and soil at 5 cm blow the surface were both positively correlated with the N_2O emission at the wheat stage. However, at the rice stage, a negative correlation was observed between the soil N_2O emission and the temperature of surface soil or soil at 5 cm blow the surface. This difference was mainly resulted from different soil moistures between the wheat stage and rice stage.

3.2.4 Correlation Between N_2O Efflux and Crop Biomass

The correlation between the soil N_2O efflux and crop biomass during the wheat-rice rotation was analyzed. Data in the correlation matrix showed that the soil N_2O efflux was significantly correlated with the crop fresh weight and dry weight, except for the dry weight under CFS and 200% MR (Table 5).

Table 5. Correlation matrix of N_2O emission with soil temperature, NO_3^-, NH_4^+, NO_3^-/NH_4^+, soil moisture and biomass under different fertilization

Treatments	NO_3^-, NH_4^+ and NO_3^-/NH_4^+			Soil moisture	Biomass		Temperature							
	NO_3^-	NH_4^+	NO_3^-/NH_4^+		Fresh	Dry	Rice stage	flowering	Wheat stage	tillering	Wheat stage	jointing	Wheat stage	flowering
							Pa	Pb	Pa	Pb	Pa	Pb	Pa	Pb
CF	0.284	-0.085	0.686^{*}	0.420	0.833^{**}	0.770^{**}	-	-	0.832^{*}	0.786^{*}	0.944^{**}	0.956^{**}	-	-
CFS	0.083	-0.374	0.716^{*}	0.590	0.825^{**}	0.524	-0.784^{*}	-0.724	-	-	0.912^{**}	0.942^{**}	0.85^{5**}	0.769^{*}
50%MR	0.584	-0.148	0.722^{*}	0.150	0.685^{**}	0.600^{*}	-	-	-	-	-	-	-	-
100%MR	0.653^{*}	-0.34	0.721^{*}	0.500	0.778^{**}	0.567^{*}	-0.760^{*}	-0.760^{*}	0.855^{*}	0.813^{*}	-0.106	-0.44	0.811^{**}	0.728
150%MR	0.331	-0.515	0.828^{**}	-0.100	0.657^{*}	0.860^{**}	-	-	-	-	-	-	-	-
200%MR	-0.103	0.283	-0.096	-0.200	0.571^{*}	0.471	-	-	-	-	-	-	-	-

* Correlation is significant at the 5% level, **correlation is significant at the 1% level.

Moisture value means 0-10 cm depth soil moisture.

The corretion between N_2O emission and biomass, which countents fresh weight and dry weight.

p_a means the correlation between N_2O emission and soil surface temperature.

$p_b$means the correlation between N_2O emission and soil temperature 5cm under surface.

\- means didn't measured.

4. Discussion

4.1 Effect of Soil Moisture, Temperature, Biomass and NH_4^+/NO_3^- Content on N_2O Emission

Microbial denitrification and nitrification are responsible for the majority of N_2O emissions under many soil environmental conditions (Fireston & Dowids, 1989), such as soil moisture, temperature and mineral fertilizer. A series of multiple regression analysis was used to investigate the effects of environmental conditions on soil N_2O emissions. Data indicated that the soil temperature (especially the surface temperature), crop biomass and NO_3^-/NH_4^+ content could affect the N_2O emission, whereas the soil moisture could not (Table 5). Significant correlation between the soil moisture and N_2O emission was not found in the study, which was consistent with the results of Jones et al. (2007) but different from Liu et al. (2007) and Beare et al. (2009). Liu et al. reported that favorable soil moisture can increase the N_2O emission.

Other results showed that the N_2O emissions are significant increased when the soil moisture is increased from 30% to 50%. Reinhard Well et al. (2008) and Liu et al. (2007) concluded that the nitrification greatly contributes to the N_2O emission when the soil moisture is favorable. N_2O is mainly derived from denitrification since nitrification can be depressed by higher soil moisture. However, significant correlation between the N_2O emission and topsoil moisture was not found in this study. On the contrary, the three main N_2O pulses, which occurred at the wheat maturity stage, the rice tillering stage and the maturity stage, occurred during the period when the soil moisture was acutely altered.

Nitrous oxide is produced from denitrification and nitrification processes in soils, and nitrification-denitrification activity was sensitive with temperature (Maag & Vinther, 1996). The daily N_2O emission measured at each growth stage of rice or wheat was significantly associated with the soil surface temperature as well as the temperature of soil at 5 cm blow the surface. However, temperature played the opposite role in N_2O emissions at wheat and rice stages. As the N_2O efflux was positively correlated with the temperature at the wheat stage, it was decreased at the rice stage due to the flooding and dry environment.

Microbial denitrification and nitrification are responsible for the majority of N_2O emissions in many soil environments. The elevated N_2O emission induced by the addition of ammonia is mainly due to denitrification rather than nitrification (Clough et al., 2004). There wasn't any significant correlation between the N_2O emission and soil NO_3^- or NH_4^+ content respectively in the this study, which was consistent with results of previous study (Miller et al., 2008). However, there exists significant correlation between soil N_2O emission and soil NH_4^+/NO_3^-. When taken together, the soil NO_3^-/NH_4^+ content played an important role during the denitrification-nitrification period, at least under a wheat-rice rotation.

4.2 Effect of MR Application on Soil N_2O Emission

Although MR consisted of many types of organic matters, its application decreased the soil N_2O emission at both wheat and rice stages. Compared with mushroom residues, the crop residues also affected the N_2O emission at both wheat and rice stages, which was consistent with previous study (Miller et al., 2008). Bacterial denitrification plays an important role in the global nitrification cycle, and it is a principal contributor of N_2O to the atmosphere (Miller et al., 2008). Many studies have shown that the available C increases the microbial activity and O_2 consumption, leading to conditions favorable for denitrification.

Although higher N_2O fluxes can resulted from the application of organic matters (such as manure, sewage, slurry and crop residue), the MR application still induces a reduction trend of soil N_2O emission compared with the chemical fertilizer treatment (Christensen, 1983; Clayton et al., 1997; Scott et al., 2000). This difference can be caused by the following reasons. First, the organic matter within the mushroom cultivation residue contains a great deal of unavailable organic matter, which is retained after the mushroom cultivation. Therefore, the available organic matter in soil is not increased by the MR application. Second, N_2O fluxes are decreased by the MR application mainly due to the decrease in [NO_3^-/NH_4^+], which is positively correlated with the N_2O emission. Finally, lower soil moisture is found in MR-treated plotsunder the same environmental condition. This is the direct reason for denitrification, which is more important for soil N_2O effluxes than for nitrification.

Fertilization dominates the temporal variation in N_2O emissions (Weitz, 2001). In summary, the soil N_2O emission was decreased by MR application because there was little available organic matter in the MR. Moreover, MR application also reduced the wheat-rice soil N_2O emissions (Figure 1) , soil NO_3^-/NH_4^+ content (Figure 2), soil moisture content (Figure 3) and cumulative temperature (Figure 4) under a wheat-rice rotation.

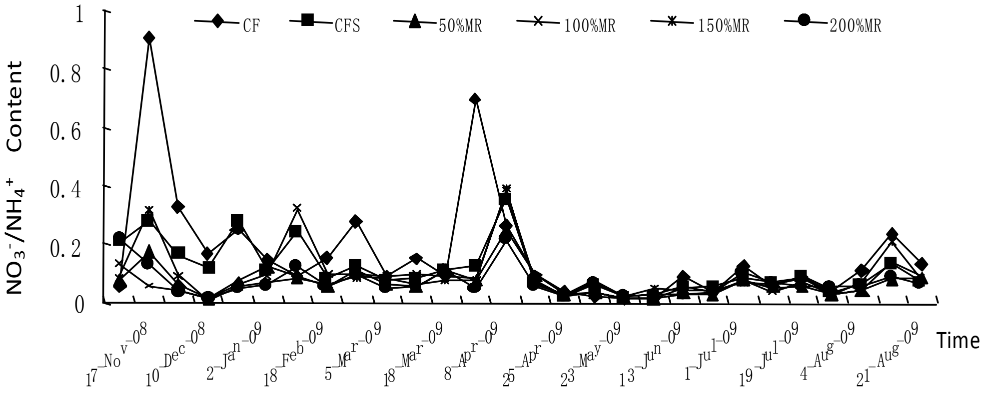

Figure 2. Weekly value of topsoil NO_3^-/NH_4^+ among the wheat-rice rotation

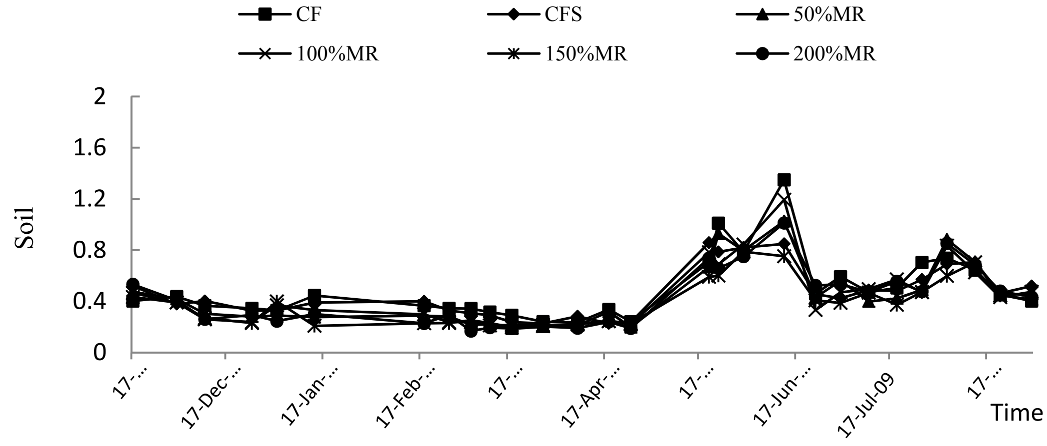

Figure 3. Topsoil moisture in the rice-wheat

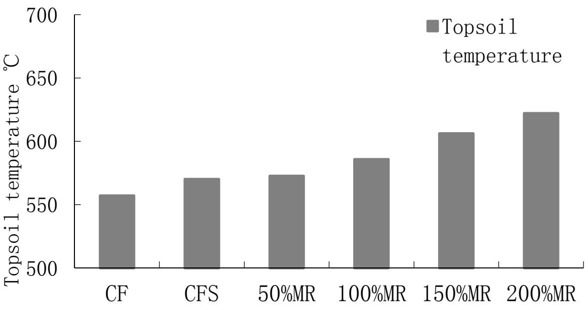

Figure 4. Amount of the top soil temperature from each treatment in wheat-rice rotation

5. Conclusions

MR application has a strong impact on both seasonal and total soil N_2O emission. Results showed that average N_2O emission ranged from -0.133 to 4.093 mg m^2 h^{-1} under CF, -0.079 to 2.061 mg m^2 h^{-1} under CFS, -0.173 to 3.261 mg m^2 h^{-1} under 50% MR, -0.310 to 1.125 mg m^2 h^{-1} under 100% MR, -0.173 to 0.793 mg m^2 h^{-1} under 150% MR, and -0.313 to 2.650 mg m^2 h^{-1} under 200% MR. The total N_2O emission was decreased to 19,000 kg ha^{-1} in the rice stage and 45,000 kg ha^{-1} in the wheat stage under the MR application, respectively. This observation indicated that MR application (22,656.40 kg for rice and 9,533.33 kg for wheat) induced a decrease of N_2O emission by 62.52% and 67.55% as compared with fertilizer and straw application, respectively. Therefore, MR application could be one of the most effective ways to reduce soil N_2O emissions.

Seasonal dynamics in N_2O emissions was largely regulated by moisture, cumulative temperature, soil NO_3^-/NH_4^+ content and crop biomass status in the soil. It is found that the N_2O efflux was positively correlated with the NO_3^-/NH_4^+ content while no significant correlation between the soil moisture and N_2O efflux was found for any treatment. Different soil moistures between the wheat stage and rice stage led to positive and negative correlations respectively between soil N_2O emission and soil temperature. Data also showed that the soil N_2O efflux was significantly correlated with the crop fresh weight and dry weight, except for the dry weight under CFS and 200% MR.

Based on previous study, this paper analyses the effect of mushroom residues on N_2O emission in Chengdu Plain. sionissionmeasure the effect of the With the popularization of rice-(straw)-edible mushroom cycling mode in Chengdu Plain and in many other rural areas, how to measure effect of the whole cycling mode and its different stages on greenhouse gasses emission like N_2O or C_2O emission need to be explored. Its impact on air environment would be a good direction of research.

As this paper simply concentrates on differences of N_2O emission under different fertilization, how C and N circulate in the farmland ecosystem and how organic matter accumulates in soil need to be deepened in further study.

Acknowledgements

The authors are grateful for funding of this research under a grant from the project of the 12th national five-year-plan of key science and technology "Breeding Industry Wastes Circular Utilization Technology Integration and Demonstration in Southwest China" (2012BAD14B18).

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