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SHORT COMMUNICATION

Relationship between nitrous oxide emission and winter wheat production

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Abstract A 3-year field study in southeast China was performed to examine the relationship between N_2O emission and winter wheat production. Over the 2002–03, 2003–04 and 2004–05 wheat-cropping seasons, N_2O emissions depended on nitrogen addition, plowing practice, and preceding crop type treatments, and showed a pronounced inter-annual variation. N_2O–N emission factor, the proportion of fertilizer N released as N_2O–N from the wheat field, varied from 1.33% to 2.97%. The relationship between N_2O emission (y) and crop yield (x) was well explained by the function $y=3.773\mathrm{Ln}(x)+1.46$. Similarly, the function $y=4.445\mathrm{Ln}(x)-3.52$ can be employed to address the relationship between N_2O emission (y) and above ground biomass (x). About 84% and 87% of variation in seasonal N_2O emission were explained by the two functions, while only 66% of the variation was represented by the N input with a linear relationship. The results of this study suggest that seasonal N_2O emission of soil under winter wheat could be better predicted by crop yield and biomass than by N input.

Keywords Agricultural practice · Crop yield · Crop biomass · N_2O · Relationship

Introduction

Nitrous oxide (N_2O) is an important trace gas that contributes to the global warming and leads to the depletion of stratospheric ozone. The atmospheric concentration of N_2O continues to rise at a rate of approximate 0.26% per year and has reached a concentration of 319 ppb (10^{-9} mol mol^{-1}) in 2005 (IPCC 2007a). Globally, agricultural N_2O emissions have increased by nearly 17% from 1990 to 2005, and they account for about 60% of global anthropogenic N_2O emissions (IPCC 2007b).

The understanding of factors controlling agricultural N_2O emissions would allow a better estimation of global balance. The default methodology proposed by the IPCC estimates direct N_2O emissions from soils as a constant fraction of the N input (Bouwman 1996). This emission factor approach is based on a limited number of data and is applied worldwide for agricultural ecosystems regardless of variations in agricultural practices (Roelandt et al. 2005). However, some studies suggest that the relationship between N input and N_2O flux may be more complex (Nägele and Conrad 1990; Mcswiney and Robertson 2005). Indeed, N_2O flux often exhibits a different response to N inputs under various agricultural managements and climates (Conen et al. 2000; Bouwman et al. 2002a, b).

Agricultural management regime and weather condition are believed to be important in N_2O production and emission (Bouwman et al. 2002a, b; Lu et al. 2006). For example, tillage practice can affect soil water content, and thus N_2O emissions (Passianoto et al. 2003). The preceding

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cropping practice has a far-lasting effect on N_2O emissions during the following cropping season (Zou et al. 2004). Weather condition can change soil temperature and moisture that are important factors influencing soil N_2O emission. Temperature controls several soil processes, such as organic matter decomposition, denitrification, and nitrification (Bouwman et al. 2002a). High soil water content often restricts gas diffusion and limits oxygen supply, which can cause a temporary accumulation of N_2O with possible considerable emissions.

Agricultural management practices, e.g., N application, plowing practice, and crop rotation regime determine the grain yield and plant biomass (Lafond et al. 1996). Crop production generally increases with N addition within a certain range (Mcswiney and Robertson 2005). Krupinsky et al.(2006) reported that the preceding crop had different effects on following crop production. It is well-established that crop production is closely related to weather condition. Given that both N_2O emission and crop production depend on management regime and weather condition, we hypothesize that the relationship between N_2O emission and crop production could be significant in arable soils.

From 2002 to 2005, we measured N_2O fluxes from soil differing in N input, plowing depth, and preceding crop type treatments, and sampled crop biomass and grain yield under winter wheat in southeast China. We examined the effects of agricultural management treatments on seasonal N_2O emissions and its inter-annual variations. The aim was to study the relationship between N_2O emission and crop production or plowing so as to verify that seasonal N_2O emission could be better predicted by crop production than N input to soil in winter wheat.

Materials and methods

Site and soil description

In the 2002–05 cropping seasons, field plots (100×30 m) with winter wheat were set up at the experimental farm of the Jiangsu Academy of Agricultural Sciences (32.0°N, 118.8°E) in southeast China. Annual rotations such as paddy rice (*Oryza sativa*)–wheat (*Triticum aestivum*), soybean (*Glycine max*)–wheat and maize (*Zea mays*)–wheat are the main crop production regimes in the area. Annual average temperature is 15.6°C and annual rainfall averages at about 1,100 mm. The soil was classified as hydromorphic, and contained 29.1% sand, 16.0% silt, and 54.9% clay. It had an initial pH (H_2O) of 6.1. Total organic matter and nitrogen contents before the experiment were 16.7 g kg^{-1} and 1.1 g kg^{-1}, respectively.

Field experiments

The experimental design, shown in Table 1, included six treatments in the 2002–03 (November 10, 2002~June 4, 2003), 2003–04 (October 29, 2003~May 29, 2004), and 2004–05 (November 1, 2004~May 30, 2005) seasons. Random plots were set up and each treatment was replicated three times. In each season, a winter wheat cultivar Yangmai 158 was planted. Root and about 8-cm stubble of preceding crops were retained in fields in all the treatments. Nitrogen fertilizer was added as urea with or without crop residue in the three seasons. Preceding cropping consisted of paddy rice, soybean, and maize crops, abbreviated as R, S, and M, respectively. Plots were plowed at the depth of 0, 12, and 25 cm, coded as N, P, and DP, respectively.

N_2O measurements, crop yield, and biomass

The N_2O flux from the soil–wheat system was measured using a closed-chamber technique (Zou et al. 2005). During each crop-growing season, boardwalks were installed to randomly selected sites to reduce soil and crop disturbance during gas sampling. Base frames made of steel (50×50 cm) for the gas collection chambers were installed in each plot. The steel chamber was 50×50×50 cm, and its height increased with the growth of wheat. Steel chambers were equipped with circulating fans to ensure complete gas mixing and wrapped with sponge and stannum foil to prevent temperature exchanges with the atmosphere. Each chamber was closed when a groove on the top edge of the frame was filled with water. Flux measurements were made once or twice a week. Gas samples were transferred to laboratory for analysis within 5 h.

Gas samples were analyzed by a modified gas chromatograph (Agilent 4890D, Agilent corporation) equipped with an electron capture detector (ECD) (Wang and Wang 2003; Zou et al. 2005). The oven was at 55°C and the ECD at 330°C. The flux of N_2O was determined from the slope of the mixing ratio change with values at 0, 10, and 20 min after chamber closure (Zou et al. 2005). Almost all samples sets yielded a linear regression value with $R^2>0.90$. At the end of each cropping season, the above ground crop biomass and grain yield were harvested, dried at 75°C for 3 days, and weighed.

Data analysis

The seasonal N_2O emissions were calculated by multiplying the average flux of two consecutive measurements by the intervals between these two measurements. The difference in seasonal N_2O among treatments was analyzed

Table 1 Field experimental treatments and seasonal N_2O emissions

Cropping season	Code	Preceding crop	Plowing depth (cm)	Nitrogen application (kg N ha^{-1})			N_2O emission (kg N ha^{-1})[a]	EF (%)[b]
				Fertilizer	Crop residue	Total		
2002–03	RP0	Rice	12	0	0	0	2.60±0.08	
	RP1	Rice	12	100	0	100	5.57±0.24	2.97
	RP2	Rice	12	150	47	197	5.97±0.21	1.71
	RP3	Rice	12	200	0	200	7.54±0.18	2.47
	RP4	Rice	12	225	23	248	7.44±0.28	1.95
	RP5	Rice	12	300	0	300	7.74±0.31	1.71
2003–04	SP0	Soybean	12	0	0	0	3.67±0.08	
	SP6	Soybean	12	200	0	200	6.45±0.40	1.33
	MP0	Maize	12	0	0	0	3.93±0.08	
	MP6	Maize	12	200	0	200	6.52±0.40	1.36
	RN6	Rice	0	200	0	200	6.90±0.17	1.54
	RP6	Rice	12	200	0	200	6.85±0.66	1.52
2004–05	MP7	Maize	12	180	0	180	8.51±0.34	2.33
	MN7	Maize	0	180	0	180	9.29±0.25	2.77
	RN7	Rice	0	180	0	180	8.55±0.34	2.35
	RDP7	Rice	25	180	0	180	8.33±0.17	2.23
	RP7	Rice	12	180	0	180	8.19±0.40	2.15
	RP0	Rice	12	0	0	0	4.32±0.28	

EF The emission factor of N for N_2O

[a] Mean±1SE

[b] EF calculated by the difference between seasonal N_2O emissions from fertilized plots and unfertilized plots in a certain season

by one-way ANOVA in SYSTAT 10.0. Regression analyses of seasonal N_2O emission versus crop production and of N_2O emission versus N addition were conducted by Microsoft Excel.

Results

Over the 2002–03, 2003–04 and 2004–05 cropping seasons, seasonal N_2O emissions differed significantly among different treatments ($P<0.001$, Fig. 1). Seasonal N_2O emissions were the lowest (2.60 kg N ha^{-1}) for the RP0 treatment in the 2002–03 season and highest (9.29 kg N ha^{-1}) for the MN7 treatment in the 2004–05 season (Table 1). Seasonal N_2O emission was generally greater in the no-plowing than in the plowing treatments (Table 1). Higher N_2O emissions were found in the 2004–05 than in the 2002–03 and 2003–04 seasons, although fertilizer was applied at lower rate in the 2004–05 season (Table 1).

Nitrogen application increased N_2O emission. Nitrogen emission factor (EF) for N_2O, the proportion of fertilizer N released as N_2O–N, was calculated by the difference

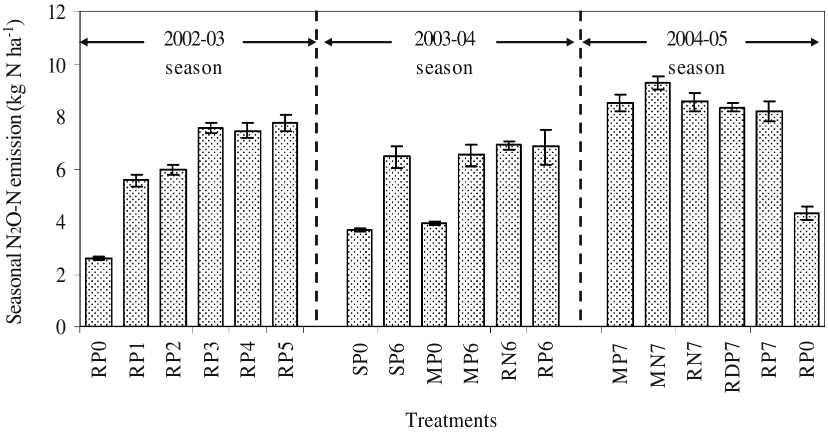

Fig. 1 Seasonal N_2O emission across different treatments in three wheat cropping seasons of 2002–03, 2003–04 and 2004–05. Error *bars* represent standard error (n=3)

between seasonal N_2O emissions from fertilized and non-fertilized plots. The EF value depended on the amount of applied N with the lowest N (100 kg N ha^{-1}) addition producing the highest EF value (2.97%) in the RP1 treatment (Table 1). The lowest EF value (1.33%) occurred at the N application rate of 200 kg N ha^{-1} in the 2003–04 season. By keeping constant the N addition, the EF value depended on management practice (preceding cropping regime and plowing practice) (Table 1). For example, when N was applied at the rate of 200 kg N ha^{-1}, the EF value ranged from 1.33% in the SP6 treatment to 2.47% in the RP3 treatment, and this range was due to the differences in preceding crop regime and plowing depth. Although the RP3 and RP6 treatments had similar N addition and management practice, the EF value was 2.47% and 1.52% in these two treatments, respectively, suggesting an inter-annual variation of the EF (Table 1).

The grain yield and the above ground biomass of winter wheat ranged from 1.19 t ha^{-1} to 7.51 t ha^{-1} and from 3.66 t ha^{-1} to 16.26 t ha^{-1} in three cropping seasons, respectively (Fig. 2a, b). The seasonal N_2O emission (y) was correlated with grain yield (x) by the relationship y=3.77Ln(x)+1.46 (R^2=0.84, P<0.001) (Fig. 2a), and it was correlated with the harvested above ground biomass (x) by the relationship y=4.45Ln(x)−3.52 (R^2=0.87, P<0.001) (Fig. 2b). Thus, grain yield and above ground biomass can be sensitive predictors for N_2O emissions from soil under winter wheat when various management practices were considered. These two crop factors explained about 84–87% of the variation in N_2O emission.

Seasonal N_2O emissions (y) increased linearly with amount of fertilizer N (x) applied to soil according to the relationship y=0.0168x+4.01 (R^2=0.66, P<0.001) (Fig. 2c). By considering that the coefficient is 0.0168, it means that an addition of 1 kg N ha^{-1} will cause a loss of 0.0168 kg N_2O–N ha^{-1} during the whole wheat-growing season. The background N_2O–N emission from soil under wheat was 4.01 kg N ha^{-1}. The N addition significantly increased both crop yield (y=2.30 $e^{0.0034x}$, P<0.01) and aboveground biomass (y=5.76 $e^{0.0034x}$, P<0.001).

Discussion

The coefficient of N_2O–N emission per 1 kg fertilizer N applied to per hectare was 0.0168, a value consistent with the recent estimate of N_2O emissions from Chinese croplands using a precipitation-rectified emission factor (Lu et al. 2006). Our background N_2O–N emission value (4.01 kg N ha^{-1}) was comparable to those of other studies in this region (Zheng et al. 2000, 2004; Zou et al. 2005), but it was significantly greater than that proposed by Bouwman (1996) on a global scale. This difference may be attributed to the higher precipitation in the experimental site (about 1,100 mm) than the averaged global precipitation used to estimate the global N_2O flux (Flynn et al. 2005; Roelandt et al. 2005; Lu et al. 2006). Probably, crop residue (root and about 8-cm stubble) from previous season retained in the field provided C and N sources for nitrification and denitrification, and thus stimulated N_2O emissions from soil under wheat (Cochran et al. 1997; Zou et al. 2005).

In this study, seasonal N_2O emission depended on plowing practice, preceding cropping type, and showed a pronounced inter-annual variation, which confirms what reported in bibliography (e.g. Mackenzie et al. 1998; Koga et al. 2004; Lei et al. 2005; Roelandt et al. 2005). Seasonal N_2O emissions were generally decreased by plowing practices, as reported by previous studies (Mackenzie et al. 1998; Koga et al. 2004). Crop residues with different C/N ratios retained in soil often induce different N_2O emission patterns (Huang et al. 2004), and this can explain the significant effect of preceding cropping on N_2O emission in this study. In addition, pronounced inter-annual variation of N_2O emissions may be closely associated with weather

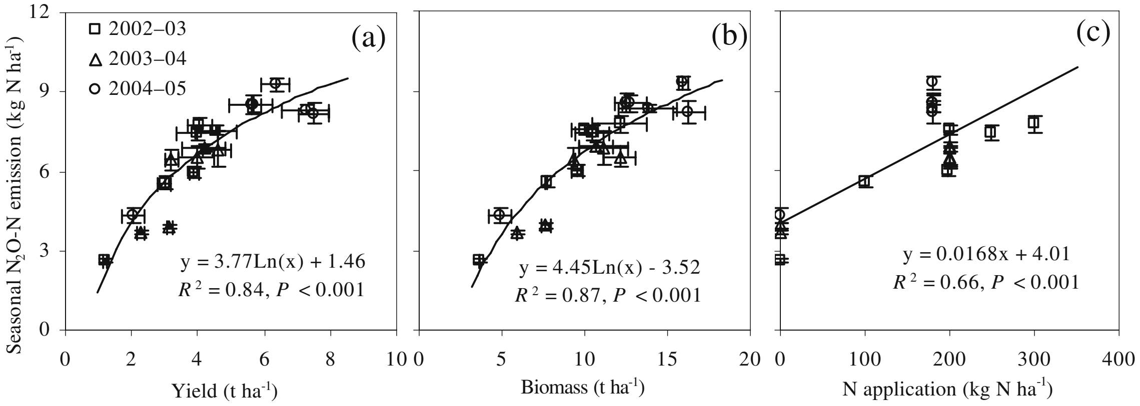

Fig. 2 Correlation of seasonal N_2O emission to wheat grain yield (**a**) and above ground biomass (**b**), and to N addition (**c**). Error *bars* represent 1 standard error (n=3)

condition, as documented by other studies (Bouwman et al. 2002a; Roelandt et al. 2005; Flynn et al. 2005).

Crop production depended on management practices such as N application, plowing practice, preceding cropping, and weather conditions. Some studies found that preceding crop had different effects on following crop yields (Krupinsky et al. 2006). Crop grain yield and biomass generally increased with N addition within the certain range, and no-plowing increased grain yield, partially due to the soil water conserved in the top 30 cm of the soil (Lafond et al. 2006). The effect of soil moisture on nitrous oxide emissions from soil and $N_2O/(N_2O+N_2)$ ratio under laboratory conditions has been studied by Ciarlo et al. (2007). High soil water conserved by no-plowing can accelerate crop residue decomposition in soils (Koga et al. 2004), and thus increases seasonal N_2O emissions.

Over the three growing seasons of wheat, seasonal N_2O emissions depended on plowing practice, preceding cropping practice, and inter-annual weather change, and were better modeled by crop production than by N addition. To our knowledge, another study has addressed the relationship between seasonal N_2O emission and maize yield (Mcswiney and Robertson 2005). In order to prove the validity of this relationship, other crops should be investigated under different environmental conditions and different soils, and with a range of N applications.

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