Contribution of plants to $\text{N}_2\text{O}$ emissions in soil-winter wheat ecosystem: pot and field experiments

Jianwen Zou$^{1,3}$, Yao Huang$^{1,2}$, Wenjuan Sun$^1$, Xunhua Zheng$^2$ & Yuesi Wang$^2$

$^1$College of Resources and Environmental Sciences, Nanjing Agricultural University, Nanjing, 210095, P.R. China. $^2$LAPC, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 10029, P.R. China. $^3$Corresponding author*, present address: Department of Ecology and Evolutionary Biology, Rice University, Houston, TX 77005, USA

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Abstract

Outdoor pot and field experiments were conducted to assess the role of growing plants in agricultural ecosystem $\text{N}_2\text{O}$ emissions. $\text{N}_2\text{O}$ emissions from plants were quantified as the difference in soil-crop system $\text{N}_2\text{O}$ emissions before and immediately after cutting plants during the main growth stages in 2001–02 and 2002–03 winter wheat seasons. Emissions of $\text{N}_2\text{O}$ from plants depended on biomass within the same plant developmental status. Field results indicated that the seasonal contribution of $\text{N}_2\text{O}$ emissions from plants to ecosystem fluxes averaged 25%, ranging from 10% at wheat tillering to 62% at the heading stage. The fluxes of $\text{N}_2\text{O}$ emissions from plants varied between 0.3 and 3.9 mg N$_2$O-N m$^{-2}$ day$^{-1}$ and its seasonal amount was equivalent to 0.23% of plant N released as N$_2$O. A N$_2$O emission coefficient ($\text{N}_2\text{O}_E$, mg N$_2$O-N g$^{-1}$ C day$^{-1}$), defined as N$_2$O-N emission in milligrams from per gram carbon of plant dry matter within a day, was represented by a 5-fold variation ranging from 0.021 to 0.004 mg N$_2$O-N g C$^{-1}$ day$^{-1}$. A linear relationship ($y = 0.4611x + 0.0015$, $r^2 = 0.9352$, $p < 0.001$) between N$_2$O$_E$ ($y$) and plant dark respiration rate ($x$, mg CO$_2$-C g C$^{-1}$ day$^{-1}$) suggested that in the absence of photosynthesis, some N$_2$O production in plant N assimilation was associated with plant respiration. Although this study could not show whether N$_2$O was produced or transferred by winter wheat plants, these results indicated an important role for higher plant in N$_2$O exchange. Identifying its potential contribution is critical for understanding agricultural ecosystem N$_2$O sources.

Introduction

Nitrous oxide is an atmospheric trace gas that contributes to global warming and the depletion of stratospheric ozone (IPCC, 1996), but its global budget remains poorly understood at present (IPCC, 2001). Perhaps the most important reason for the current uncertainty is the difficulty in measuring fluxes due to extraordinary spatial and temporal variability (Brumme et al., 1999; Khalil, 2000). Some studies have suggested that N$_2$O input to the atmosphere from agricultural production as a whole has been previously underestimated (Kroeze et al., 1999; Mosier et al., 1998; Robertson et al., 2000). Understanding the role of plants will help show the nature and extent of N$_2$O emissions from agricultural ecosystem, and minimize the uncertainty in global N$_2$O budget.

Much research has gone into assessing the role of growing plants in N$_2$O production and emissions from agricultural systems (e.g., Chang et al., 1998; Grundmann et al., 1993; Haider et al., 1985; Müller, 2003). In general, the contribution of growing plants to ecosystem N$_2$O emissions has been supported by three lines of evidence. First, plant roots facilitate N$_2$O production in the soil. General denitrification models have elucidated that N$_2$O production in soil is mainly controlled by the availability of nitrate, labile C compounds, and O$_2$ (Del Grosso et al., 2000), which is...
greatly affected by the existence of growing plants (Conrad et al., 1983). Second, some studies have been devoted toward understanding a role of plant pathway in ecosystem N₂O emissions (e.g., Li and Chen, 1993; Yu et al., 1997). Mosier et al. (1990) reported that rice plants contributed to the efflux of N₂O from paddy soil. When the soil was flooded, N₂O emission was predominately through the rice plants (Yan et al., 2000). Chang et al. (1998) indicated that plant serves as a conduit to transport N₂O produced in soil to atmosphere based on the relationship between soil solution N₂O content and N₂O flux. Finally, recent evidence suggests that plants can emit N₂O under natural conditions, or plant N₂O emissions were directly detected in some studies. For example, it has been reported that a transgenic tobacco can emit N₂O when fed with ¹⁵N-labeled nitrate or nitrite (Goshima et al., 1999). Xu et al. (2001) found that significant amounts of N₂O were released from foliage of plants since there was an above-ground vertical concentration profile of N₂O within coniferous-deciduous mixed forests. The result obtained by Smart and Bloom (2001) demonstrated that wheat leaves emit N₂O during nitrate assimilation. A study with 17 plant taxa indicated that plant N₂O emission was common in plant tissues (Hakata et al., 2003).

So far, studies have centred around the plant N₂O pathway or plant N₂O production, while relatively few have focused on the whole seasonal contribution of growing plants to agroecosystem N₂O emissions. Measuring within a single stage of plant development, however, provides very little insight into the role of plants in the ecosystem N₂O emissions. Here we present the results from winter wheat outdoor pot and field experiments that employed the cutting plant method in combination with the static opaque chamber method. Comparing the ecosystem N₂O emissions before and immediately after cutting plants offers an approach to quantifying N₂O emissions from plants. We did not attempt to partition N₂O production in soil or plants, but instead concentrated on the overall contribution of plants to ecosystem N₂O emissions and the seasonal pattern of N₂O emissions from plants.

Materials and methods

Pot and field experiments

Both pot and field experiments were used to quantify N₂O emissions from plants at similar temperatures and soil moisture, which are the main environmental factors important to N₂O emissions. We used pot experiment to minimize the differences in N₂O fluxes due to variability in soil moisture. The outdoor pot experiments were carried out at Nanjing Agricultural University, in Nanjing, Jiangsu province, China (31°52′ N, 118°50′ E) during the 2001–02 and 2002–03 wheat-growing seasons. Soil for the experiment was taken from the top 20 cm of the profile in winter wheat croplands at Jiangsu Academy of Agricultural Sciences in Nanjing. This soil consisted of 4% sand, 45% silt, and 51% clay with an initial pH of 6.1. Total organic C and N were 13.1 g kg⁻¹ and 1.1 g kg⁻¹, respectively. Pot experiments have been performed to investigate greenhouse gases emissions in rice-wheat rotation ecosystems previously and more details on methods can be found in Huang et al. (2002). Six pots were used in the 2001–02 season and 12 pots in the 2002–03 season. A local prevailing winter wheat cultivar (Triticum aestivum L.) was planted on November 5 in the 2001–02 season and on November 8 in the 2002–03 season. Nitrogen fertilizer was applied as urea at the rate of 1.1 g N pot⁻¹, with a split of 55% as basal fertilizer, 25% on 115 days and 20% on 155 days after planting. There was no difference in fertilization regime between two seasons.

The field experiment was initialized on November 8 in the 2002–03 wheat-growing season. In order to create differences in biomass inside the gas sampling chamber, there were three experimental treatments designed to represent low, normal and high planting densities. In the field, 27 pots with the bottom removed were installed as gas flux collars and evenly distributed in the three treatments. We checked the number of seedlings and tillers in the pot according to density treatments on 30 days and 110 days after planting, respectively. Urea was used at the rate of 200 kg N ha⁻¹, split as 30% as basal fertilizer, 45% on 110 days and 25% on 155 days after planting. Phosphorus and potassium were applied as the basal fertilizer at the local rate and no additional organic manure was incorporated in the field. After going through winter stages, wheat plants entered the main active growth phases at the end of February (about 120 days after planting).

Gas samples and measurements

N₂O emissions from plants are typically determined by the cutting plant method (Chen et al., 1999; Müller, 2003; Yan et al., 2000). We performed a preliminary study that showed no obvious changes in soil N₂O