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Different responses of nitrogen fertilization on methane emission in rice plant included and excluded soils during cropping season

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ABSTRACT

Since nitrogen (N) fertilization is the most efficient practice for increasing rice production, N fertilizer consumptions have continued to increase globally. Therefore, the effects of N fertilization on CH_4 emission characteristics have been extensively studied. However, no consistent conclusions to N fertilization on CH_4 cycles have been drawn so far. In order to evaluate the effect of N fertilization on CH_4 fluxes in rice fields, N fertilizer (urea) was applied at different levels (0–180 kg N ha^{-1}) in a typical temperate paddy soil, and CH_4 emissions were characterized under two different soil conditions during cropping seasons (rice plant included and excluded soils). Seasonal CH_4 fluxes responded differently to N fertilization between the rice plants included and excluded soils. In rice plant excluded soils, total CH_4 fluxes significantly increased with increasing N fertilization levels. However, in rice plant included soils, seasonal CH_4 fluxes changed with a quadratic response. Total CH_4 fluxes increased with increasing N fertilization by 115–137 kg N ha^{-1} and later decreased. The difference in seasonal CH_4 fluxes between the two soils might be caused by rice rhizospheric activities and this difference could be defined as the minimum CH_4 oxidation potentials of rice rhizosphere. This CH_4 oxidation potential significantly increased with increasing N fertilization levels, and is highly correlated with total biomass, straw and root biomass productivities. Therefore, the decrease in CH_4 fluxes by high levels of N fertilization in rice plant included soils might be caused by the increasing N fertilization-induced CH_4 consumption.

1. Introduction

Methane (CH_4) is recognized as one of the most important greenhouse gases (GHG). It has 34 times higher global warming potential (GWP) than carbon dioxide (CO_2) at per molecule level horizon (Myhre et al., 2013) and contributes approximately 20% of the total global warming (Schulze et al., 2009; Kirschke et al., 2013; Wei et al., 2015). Rice cultivation is a major source of global CH_4 emissions, contributing about 11% of the total global CH_4 emissions (Smith et al., 2014). Rice production should be increased by 60% in the next few decades to meet rice demands for the world's growing population (Cassman et al., 1998). The intensification of rice cultivation each year may considerably contribute about 1–2% to the observed gradual increase of the atmospheric CH_4 mixing ratio (Rasmussen and Khalil, 1981).

Globally, intensive fertilization has been widely adopted in order to increase rice production. Therefore, the effect of high N fertilization on CH_4 gas emission is critical to manage GHG emission in rice-growing areas. Given the importance of the N fertilization effect on CH_4 emissions in paddy ecosystem, numerous studies have been conducted (Cai et al., 1997; Bodelier et al., 2000a; Bodelier and Laanbroek, 2004; Shrestha et al., 2010; Banger et al., 2012; Pittelkow et al., 2013). However, no consistent conclusions have been drawn in this regard (Cai et al., 1997; Dong et al., 2011; Shang et al., 2011; Banger et al., 2012).

The net N fertilization effect on CH_4 emissions has been shown to depend on the balance between the N-induced increase in CH_4 production and consumption (Xu and Inubushi, 2004; Olefeldt et al., 2013). Some studies have shown that N fertilizations increased CH_4 emissions in paddy soils (Schimel, 2000; Zheng et al., 2006; Cai et al., 2007; Yang et al., 2010). In general, N fertilization can increase rice plant biomass productivities, including root biomass. Higher rice plant biomass is found to provide more organic substrates for methanogens through biomass litter decomposition and root exudation, in particular, the labile carbon (C) concentration in the rhizosphere (Jia et al.,

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2001), and subsequently increased CH_4 production (Bodelier et al., 2000a; Schimel, 2000; Zheng et al., 2006).

In contrast, few other studies demonstrated that N fertilization significantly decreases CH_4 emissions by 30–50% in paddy soils during rice cultivation (Xie et al., 2010; Dong et al., 2011; Yao et al., 2012). Nitrogen fertilization could stimulate rhizosphere development in rice and subsequently improve root oxygen transport in the extremely reduced soil, as well as increase CH_4 consumption through enhanced methanotrophic microbial activities (Bodelier et al., 2000a; Bodelier et al., 2000b). However, thus far, the interaction between CH_4 production and consumption which increases in relation to rice plant development under N fertilizations is not clear in paddy fields. Some studies also show that N fertilization has the little effect on CH_4 emissions (Lindau et al., 1991; Wang et al., 2012; Pittelkow et al., 2014).

In this view, in order to evaluate the effect of N fertilization on CH_4 fluxes, N fertilizer (urea) was applied in a typical mono-rice paddy soil with different levels (0–180 kg N ha^{-1}), and CH_4 emission characteristics were investigated in rice plant included and excluded soils during the two year cropping season.

2. Materials and methods

2.1. Experimental field preparation and rice cultivation

The study was conducted at an agronomy field belonging to the *Gyeongsang National University* (35° 06′ N and 128° 07′ E), Jinju, South Korea between 2014 and 2015. The soil belonged to the *Pyeongtaeg* series (fine-silty, mixed, non-acid, mesic, Typic haplaquent with somewhat impeded drainage). Organic C and total N contents of the soil were 8.9 ± 0.6 g kg^{-1} and 0.65 ± 0.08 g kg^{-1}, respectively. Other chemical properties include: soil pH 5.6 ± 0.2 (1:5 with H_2O), available phosphate (P_2O_5) 73 ± 4.2 mg kg^{-1}, exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+) 6.7 ± 0.3, 1.07 ± 0.04 and 0.37 ± 0.04 $cmol^+$ kg^{-1}, respectively.

The experimental field consisted of 12 plots, each 100 m^2, and was laid out using a randomized block design. A concrete barrier was installed between each pair of treatments as a buffer zone (0.5 m) to prevent mixing effects. Four treatments with different levels of urea fertilization were installed (0, 45, 90 and 180 kg N ha^{-1}). However, following the recommended doses for Korean rice cultivation, the same levels of P_2O_5 (45 kg ha^{-1}) and K_2O (58 kg ha^{-1}) were applied in all treatments (RDA, 1999). We applied 50% of N, 100% of P_2O_5 and 70% of K_2O as the basal fertilizers a day before transplanting. Split doses of fertilizers were applied on the 15th (20% of N) and the 42nd day (30% of N and K_2O) after transplanting.

Thirty day old seedlings (3 or 4 plants per hill) of rice (*Dongjinbyeo* cultivar, Japonica) were transplanted with a spacing of 30 cm × 15 cm by hand in late May, 2014 and 2015. Irrigation water was maintained at 5–7 cm depth throughout the cropping season and drained 3 weeks before rice harvesting. Rice was harvested by early October and its productivities were recorded following the RDA methods (RDA, 1995).

2.2. Gas sampling and analysis

A closed-chamber method was used to estimate CH_4 fluxes during the rice cultivation period (Rolston, 1986; Ali et al., 2008, 2009; Kim et al., 2013). In order to estimate the CH_4 fluxes from the rice plant included and excluded soils during the cropping season, two different types of chambers were installed in each plot. To monitor the rates of CH_4 emissions in rice plant included soils, a six hexahedron transparent acrylic chamber (width 62 cm, length 62 cm, and height 112 cm) was set up permanently on the flooded soil after rice transplantation and three acrylic chambers that could accommodate eight rice plants inside each were used. Aside these chambers, sets of acrylic column chambers (ID 24 cm × H 25 cm), were placed on the soil surface between rice plants to evaluate the rates of CH_4 emissions from rice plant excluded soils. The chambers were kept open in the field throughout the rice cultivation period, except during the days of gas sampling. The movement of water was controlled by two holes at the bottom of each chamber. The accurate height of each chamber was recorded before each gas sampling because the air volume inside the chamber could be slightly different depending on the level of flooding and on the depth of the inner chamber in the soil. The chamber was equipped with a circulating fan to ensure complete mixing of gases and a thermometer to monitor the temperature during the sampling.

After chamber placement, gas samples were collected with 50 ml gas-tight syringes at 0 and 30 min. To obtain the average CH_4 emission rates, gas samplings were conducted three times daily (08:00, 12:00 and 16:00). The collected gas samples were immediately transferred into 30 ml air-evacuated glass vials sealed with a butyl rubber septum for gas analysis.

The CH_4 concentrations were measured with a gas chromatograph (GC-2010; Shimadzu, Japan) packed with a Porapak NQ column (Q 80–100 mesh) and flame ionization detector (FID). The temperature of the column, injector and detector were adjusted at temperatures of 70 °C, 150 °C and 200 °C, respectively. Helium and H_2 gases were used as the carrier and burning gases, respectively.

2.3. Calculation of methane emission and oxidation rate

Methane fluxes from rice paddy fields were calculated within a specific time interval following the increase in CH_4 concentrations per unit surface area of the chamber (Rolston, 1986; Lou et al., 2004) from Eq. (1).

$$F = \rho \times (V/A) \times (\Delta c/\Delta t) \times (273/T) \quad (1)$$

where, F is the CH_4 emission rate (mg m^{-2} d^{-1}), ρ is the gas density of CH_4 under a standardized state (0.714 mg cm^{-3}), V is the volume of the chamber (m^3), A is the surface area of the chamber (m^2), $\Delta c/\Delta t$ is the rate of CH_4 increase in the chamber (mg m^{-3} d^{-1}) and T (absolute temperature) is the 273 + mean temperature in °C of the chamber.

The seasonal CH_4 flux for the entire rice cropping period was computed, as reported by Singh et al. (1999) (Eq. (2)).

$$\text{Seasonal } CH_4 \text{ flux} = \sum_i^n (F_i \times D_i) \quad (2)$$

Where, F_i is the rate of CH_4 emission (g m^{-2} d^{-1}) in the i^{th} sampling interval, D_i is the number of days in the i^{th} sampling interval and n is the number of sampling.

2.4. Investigation of meteorological, soil and rice yield properties

Weather data were corrected from the automatic weather station (**AWS**) at the field and soil temperatures were constantly recorded using a thermometer placed at a 3–5 cm depth in the soil during rice cultivation. The platinum Eh electrode (EP-201, Fujiwara, 24 cm) was installed permanently at 3–5 cm soil depth in each plot, and soil redox potential (Eh) was measured in each treatment during gas sampling, using Eh meter (PRN-41, DKK-TOA Corporation).

Rice growth and yield characteristics were investigated at the maturing stage. Yield components were determined following Korean standard methods (RDA, 1995). Rice root biomass yields were calculated as 10% of the aboveground biomass yields (Huang et al., 2007).