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Methane and nitrous oxide emissions from flooded rice fields as affected by water and straw management between rice crops

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ABSTRACT

Rice fields in the tropics can vary in water regime before production of rice on flooded soil, but relatively little is known about the effects of soil water regime and crop residue management between rice crops (i.e., fallow period) on methane (CH_4) and nitrous oxide (N_2O) emissions during a subsequent rice crop. We measured CH_4 and N_2O emissions during two cropping seasons in the Philippines from field plots exposed to contrasting treatments during the fallow before land preparation for rice cultivation. The fallow treatments were continuous soil flooding (flooded), soil drying with exclusion of rainfall (dry), soil drying with dry tillage (dry + tillage), and a control with soil drying and wetting from rainfall (dry and wet). All plots were subdivided into removal of all aboveground rice residues from the previous crop (without residue) and retention of standing biomass after harvest of the previous rice crop (with residue). Emitted gas was collected weekly using chambers. Fallow treatments greatly influenced greenhouse gas (GHG) emissions during rice growth. Methane emissions and global warming potential (GWP) in both cropping seasons were highest following the flooded fallow, intermediate following the dry and wet fallow, and lowest following dry and dry + tillage fallows. The GWP was higher with than without residue across all fallow treatments. Nitrous oxide emissions were small during the season, and CH_4 emissions contributed more than 90% of the cumulative GWP during the rice crop regardless of fallow and residue management. Soil drying between rice crops in the tropics can reduce CH_4 emissions and GWP during the subsequent rice crop.

1. Introduction

The agricultural sector contributes about 10–12% of the total global anthropogenic emissions, and of these total anthropogenic emissions, 47% of CH_4 and 58% of N_2O emissions have been attributed to agriculture (Smith et al., 2007). Methane emissions from rice production have been predicted to increase substantially by 42% with an increase of atmospheric CO_2 concentration to levels between 550 and 743 ppm (van Groenigen et al., 2013), predicted to be reached between 2050 and 2080 (IPCC, 2001).

Rice production is one of the major agricultural undertakings responsible for increased CH_4 emissions. Many studies, as reviewed by Linquist et al. (2012), have measured high fluxes of CH_4 and relatively low fluxes of N_2O in production of rice on flooded soil. However, CH_4 emissions are reduced when the rice field undergoes drying periods such as mid-season drainage, but N_2O fluxes are increased (Bronson et al., 1997a; Cai et al., 1997; Chen et al., 1997; Zou et al., 2007). The application of nitrogen (N) fertilizers can increase N_2O emissions (Denmead et al., 1979; Ma et al., 2007; Mosier et al., 1989; Zou et al., 2009). Based on similar studies of Mosier et al. (1989) and Zou et al. (2007) about 0.02% to 0.42% of the N applied at 100 to 200 kg N ha^{-1} was emitted as N_2O.

Several mitigation strategies to decrease CH_4 and N_2O emissions especially from irrigated rice systems have been studied and proposed (Ahmad et al., 2009; Epule et al., 2011; Horwath, 2011; Ma et al., 2010; Majumdar, 2003; Wassman et al., 2000; Yan et al., 2005). Such strategies include the use of no tillage, single or multiple mid-season drainage events, application of rice straw as compost, off-season straw incorporation, alternative rice cultivars, and modified fertilizers (i.e., nitrification inhibitors, urease inhibitors, and slow-release fertilizers).

In a double-rice cropping system, a fallow period exists between the two cropping seasons. A limited number of studies (Bronson et al., 1997b; Zhang et al., 2011) have measured the magnitude of CH_4 and N_2O fluxes during the fallow period. In most cases, the rice field is untended during this period with no interventions. The field can be exposed to variable weather conditions, which can influence soil water regime and hence CH_4 and N_2O emissions during the period between crops. Few studies have related the condition of the field during the fallow period to the CH_4 and N_2O emissions in the following rice cropping

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season (Cai et al., 2003; Kang et al., 2002; Xu et al., 2000; Zhang et al., 2011). In addition, the management of the rice residue also influences CH_4 and N_2O emissions.

Rice residues remaining in the field after harvest are generally incorporated into the soil during land preparation. According to Watanabe et al. (1994) rice straw is the primary source of C for CH_4 production during the early growth period of rice plants. Hence when rice straw is incorporated to the soil, the emissions of CH_4 can increase during the rice-growing period. But incorporated rice residues also provide benefits such as a source of nutrients, especially potassium, to subsequent rice crops. The timing of residue incorporation, however, can be managed to reduce CH_4 emissions during the rice growing season (Xu et al., 2000).

The CH_4 and N_2O emissions in rice production as affected by mitigation strategies can be assessed by GWP relative to grain yield, which is important in order to account for differences in management practices on productivity of rice. This study was conducted to assess the influence of water management and crop residue management between rice crops (i.e., fallow period) on CH_4 and N_2O emissions in the succeeding cropping season and to quantify the yield-scaled GWP of rice as affected by fallow and residue management practices.

2. Materials and methods

2.1. Site characteristics, treatment, and experiment description

Measurements were taken from a field experiment in the Experiment Station of the International Rice Research Institute, Los Baños, Philippines (14° 10′ 07.1″ N, 121° 15′ 23.9′ E), with an elevation of 21 m above msl and mean yearly rainfall of 1992 mm (2000–2012). The field was managed from 2003 to 2012 with two rice crops per year. The study was conducted during the 2011 wet season (WS) and the 2012 dry season (DS). The soil was classified as Aquandic Epiaquoll (Soil Survey Staff, 1994) with a clay content of 62%. The soil properties include pH = 6.6, Olsen P = 17–18 mg kg^{-1}, exchangeable K = 0.7–0.9 $cmol_c\ kg^{-1}$, organic C = 18 g kg^{-1}, total N = 1.3–1.5 g kg^{-1}, and cation exchange capacity >40 $cmol_c\ kg^{-1}$ (Thuy, 2004).

The experiment had a split-plot design with four replications. The main plots were comprised of water and tillage management treatments carried out during the fallow period between rice crops. They consisted of continuous soil flooding (flooded), soil drying by exclusion of rainfall (dry), similar soil drying but with dry tillage conducted twice (dry + tillage), and a control with soil drying and wetting from rainfall (dry and wet). The subplots were two crop residue treatments: removal of all aboveground rice residues from the previous crop (without residue) and retention from the previous crop of standing biomass after rice harvest (with residue).

In the main plot with the flooded treatment the soil was always flooded (3–5 cm) from rice harvest to land preparation for the next rice crop. The dry and the dry + tillage treatments were exposed to the sun during the day, but covered with tents during rainfall events and at night to exclude rainfall. In the treatment without residue, all the above-ground biomass was removed from the plots. In the treatment with residue, the stubbles remaining after harvest were left standing in the field during the fallow period, except for the dry + tillage treatment. The retained residue was incorporated during plowing at land preparation. The amount of residue returned was uniform at 5 mg ha^{-1} in all plots. At the end of the fallow period, all the plots were flooded, plowed, and hydro-tilled to prepare the land by puddling for transplanting of the succeeding crop.

Immediately before transplanting, 17 kg P ha^{-1}, 17 kg K ha^{-1}, and 10 kg Zn ha^{-1} were broadcast and incorporated to the soil with final harrowing and soil leveling in the 2011 WS; and 21 kg P ha^{-1}, 25 kg K ha^{-1}, and 10 kg Zn ha^{-1} were broadcast and incorporated to the soil in the 2012 DS. Two seedlings of NSIC Rc158 were transplanted per hill on a 20 cm × 20 cm spacing on 21 June 2011 and on 5 January 2012. The crop was harvested on 5–7 October 2011 in the WS and on 16–19 April 2012 in the DS.

In both seasons, N fertilizer was applied to the different treatments based on the site-specific nutrient management (SSNM) approach using the leaf color chart. Urea was split applied three times during the growing season at 7–10 days after transplanting (DAT), 25–28 DAT (tillering), and at 40 DAT (about panicle initiation stage). The rates of N fertilizer as urea applied in the different treatments at the different application times are given in Table 1.

2.2. Gas flux measurements

Gas flux measurements started at land preparation from two weeks before transplanting to crop harvest. Methane and N_2O fluxes were measured in three of the four replicates of the experiment using the static chamber method as described by Rolston (1986) every seven days starting at 0930 h. In addition to this regular gas sampling, in the 2012 DS gas flux measurements were carried out daily for four to five days after each N application time. The sampling protocol was in good agreement with common practices (Sander and Wassmann, 2014).

A stainless steel metal base, with dimensions of 40 cm length × 22 cm width × 12 cm height, served as the anchor for each chamber. The anchor was inserted about 10 cm into the soil with two rice hills on the inside. The anchors were installed in the plots at least one day before the first sample collection to allow stabilization, and they were left in the field throughout the growing period of the crop. The base height and water depth inside the metal frames were measured at each gas sampling time.

The gas collection chambers, made from a plastic box with dimensions of 40 cm length × 22 cm width were used with variable height (11, 42, and 81 cm) depending on the height of the plant inside the chamber. The chambers were equipped with a vent to allow equilibration of the pressure, a thermometer, and a sampling port in the form of a 9 cm syringe needle with stopcock that was secured with a Swagelok fitting. In the tall chambers (42 and 81 cm height), a battery-operated 12 V computer fan was installed to ensure well-mixed air inside the chamber while in the small chambers the air was mixed with the sampling syringe right before taking the sample.

At the time of sampling, the gas collection chambers were placed on the trough of the metal bases with a water seal. Gas samples inside the chambers were collected using a 60-mL syringe fitted with a stopcock at 0, 15, 30, and 45 min after chamber closure. Sixty milliliters of headspace air was immediately transferred to an evacuated 30-mL vial with gray butyl rubber septum and analyzed with a Shimadzu 14B gas chromatograph (GC) within one week. The GC was equipped with ^{63}Ni electron capture detector (ECD) for analysis of N_2O, and a flame

Table 1
Fertilizer nitrogen application rates in the 2011 wet season (WS) and the 2012 dry season (DS).

Season	Fallow management		N rates (kg N ha^{-1})			
	Water and tillage	Residue incorporation	7–10 DAT	25–28 DAT	40 DAT	Total
2011 WS	Flooded	Without	0	35	35	70
		With	0	35	35	70
	Dry	Without	20	45	45	110
		With	35	45	30	110
	Dry + tillage	Without	20	45	35	100
		With	35	45	30	110
	Dry and wet	Without	20	45	45	110
		With	35	45	30	110
2012 DS	Flooded	Without	20	45	45	110
		With	20	45	45	110
	Dry	Without	45	60	60	165
		With	60	60	45	165
	Dry + tillage	Without	45	60	60	165
		With	60	60	45	165
	Dry and wet	Without	45	60	60	165
		With	60	60	45	165