Geoderma 209-210 (2013) 41–49

Contents lists available at SciVerse ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Toposequential variation in methane emissions from double-cropping paddy rice in Northwest Vietnam

Aung Zaw Oo [a], Lam Nguyen [b], Khin Thuzar Win [a,c], Georg Cadisch [d], Sonoko Dorothea Bellingrath-Kimura [a,*]

[a] Tokyo University of Agriculture and Technology, Saiwaicho 3-5-8, Fuchu, Tokyo 183-8509, Japan
[b] Hanoi University of Agriculture, Trau Quy, Gia Lam, Hanoi, Viet Nam
[c] Yezin Agricultural University, Yezin, Naypyitaw, Myanmar
[d] University of Hohenheim, Garbenstr 13, 70599 Stuttgart, Germany

ARTICLE INFO

Article history:
Received 5 December 2012
Received in revised form 16 May 2013
Accepted 22 May 2013
Available online 28 June 2013

Keywords:
Cascade position
Double-cropping rice
Methane emission
Paddy soil
Toposequence

ABSTRACT

Understanding the spatial and temporal variations in toposequential methane (CH_4) emission is essential for assessing and mitigating CH_4 emission from rice cascades in mountainous watersheds. To assess the toposequential variation in CH_4 emission among different field positions, two cascades of double-cropping paddy rice fields were investigated in Yen Chau district, Northwest Vietnam. The cascades were divided into fertilized and non-fertilized parts and CH_4 measurements at 10 days intervals were conducted at top, middle and bottom fields of each part. The results showed that the rate and cumulative amount of CH_4 emissions in non-fertilized part were higher than that of fertilized one in both spring and summer rice seasons due to the stimulation of CH_4 oxidation by urea and sulfate containing fertilizers. The spatial variation in CH_4 emissions among the field positions was high in both cropping seasons with the highest emissions in the bottom fields and the lowest emissions were found in the top fields (i.e. bottom field CH_4 emissions 1.8–3.0 times higher than the top field). The differences among field positions were influenced by clay content, total nitrogen and total carbon content which showed toposequential differences. The average CH_4 fluxes ranged from 1.0 to 5.1 mg CH_4 m^{-2} h^{-1} being largest at later growth stages for spring rice and during early growth stages for summer rice. Cumulative CH_4 emissions for spring rice ranged from 3.1 to 13.7 g CH_4 m^{-2} and that for summer rice from 4.3 to 23.5 g CH_4 m^{-2}. 61.7% was emitted during summer rice season and 38.1% from spring rice season. The higher values for summer crops were due to higher availability of fresh organic substrates under higher soil temperature during the early growing period. The average total CH_4 emissions from double-cropping paddy rice fields were 14.8 g CH_4 m^{-2} for cascade 1 and 27.3 g CH_4 m^{-2} for cascade 2. The higher emission for cascade 2 might be due to the lower soil Eh and higher clay content especially in the lower lying fields. The results highlight that large toposequence differences in CH_4 emissions require different site specific management practices for each toposequence position in order to mitigate CH_4 emission in paddies in mountainous watersheds.

1. Introduction

In Northern Vietnam, 0.7 million ha is under paddy rice cultivation, of these 60% are located in hilly areas on terrace forming interconnected cascades. Within cascades, the lower positioned fields are influenced by upper positioned field including sediment deposits from uplands (General Statistics Office of Vietnam, 2008). The downward movement and deposition of sediments derived from erosion of intensively cultivated upland fields play a key role for lowland rice production. Soil fertility parameters, such as soil organic carbon (SOC) content, and related rice yield tend to increase with descending position of paddies in the landscape (Schmitter et al., 2010; Tsubo et al., 2006). The study by Schmitter et al. (2011) demonstrated that spatial variation of rice production within cascades could be linked to sediment induced soil fertility and textural changes in the topsoil. Furthermore, the yearly amount of organic C entering paddies with the irrigation water was estimated at 0.8 Mg ha^{-1} as well as 0.7 Mg N ha^{-1} (Schmitter et al., 2012) which might foster elevated greenhouse gas emissions.

Even though spatial differences in soil fertility and texture have been shown to occur within rice cascades, there is still limited information about the carbon (C) and nitrogen (N) cycle in the rice field cascade. For example, paddy rice fields account for up to 12% of total anthropogenic methane (CH_4) emission (IPCC, 2007). Field experiments have shown that there are large variabilities in CH_4 emissions from rice fields,

* Corresponding author at: Tokyo University of Agriculture and Technology, Graduate School of Agriculture, Department of International Environmental and Agricultural Science, Saiwaicho 3-5-8, Fuchu, Tokyo 183-8509, Japan. Tel./fax: +81 42 367 5952.
E-mail address: skimura@cc.tuat.ac.jp (S.D. Bellingrath-Kimura).

0016-7061
http://dx.doi.org/10.1016/j.geoderma.2013.05.025

both spatially, with variability between different fields, and temporally, with seasonal and diurnal variations (Holzapfel-Pschorn and Seiler, 1986; Sass et al., 1991; Schütz et al., 1989). However, to date more focus has been paid on the temporal variability, while there is very limited information about the spatial variation according to toposequential differences of paddy rice fields along cascades in mountainous watersheds. Most studies reported on large-scale spatial variation comparing sites which are far away from each other and with very different soil properties, climate and environmental conditions (Kimura et al., 1991; Yang and Chang, 2001). On the other hand, Sass et al. (2002) reported within field spatial variation in CH_4 emissions from rice fields. In particular, recent land use intensification in upland areas, construction of reservoirs and increased irrigation and management of paddies have led to enhance sediment delivery and hence exacerbated spatial heterogeneity in rice cascades in mountainous areas (Schmitter et al., 2010). However, the variations in CH_4 emission among different field positions in the cascade have not been investigated thoroughly yet. More research is necessary to understand the temporal and spatial variations among the different field positions of paddy rice cascades to be able to estimate regional CH_4 budget and identify effective mitigation measures.

It is well known that CH_4 emission is a net product of production and oxidation, both are affected by N and other nutrients directly or indirectly (Schimel, 2000). For example, several field scale studies have demonstrated that addition of N fertilizers increased CH_4 emissions in the rice soils probably due to stimulation of methanogens by greater production of crop biomass by N fertilizers than control (Banik et al., 1996; Shang et al., 2011). In contrast, others have reported inhibition of CH_4 emissions with addition of ammonia-based non-sulfate fertilizer (Dong et al., 2011) and ammonium sulfate fertilizers (Cai et al., 1997) to the rice soils. Till to date, no single consensus exists on net impact of N fertilizers on CH_4 emissions in the rice soils (Cai et al., 1997; Dong et al., 2011). In order to assess the net effect of ammonium based and sulfate containing fertilizers on CH_4 emission from paddy rice ecosystem, we used the recommended types of fertilizers by local extension services for rice production which commonly include urea and sulfur containing potassium sources. The study by Schmitter et al. (2011) showed that on average, the fertilized fields yielded continuously more than the fields without fertilizer in Chieng Khoi area. It is necessary to know the sediment induced toposequential variation in CH_4 emissions and the influence of mineral fertilizers on plant growth related CH_4 emission from the rice fields. Therefore, this experiment was conducted to evaluate (i) the spatio-temporal variation in CH_4 emission related to field positions among the paddy rice field cascades and (ii) the influence of mineral fertilizer on CH_4 emission among the field positions of paddy rice cascade from double-cropping paddy rice in Chieng Khoi Commune, Yen Chau district, Northwest Vietnam.

2. Materials and methods

2.1. Study site and experimental design

The field experiments were carried out from February until November, 2011, during two rice cropping seasons in the Chieng Khoi commune (350 masl, 21° 7′60″N, 105°40′0″E), Yen Chau district, Northwest Vietnam. The studied area is located in the tropical monsoon belt with cool and dry winter and spring with 201 mm rainfall (monitored during November, 2010–April, 2011) and very hot and rainy summer and autumn with 858 mm rainfall (May–October, 2011) amounting to an annual precipitation of 1059 mm in 2011.

Two rice cascades (cascades 1 and 2) were selected for this experiment (Fig. 1). The length and altitude differences were 83 m and 7 m for cascade 1 and 87 m and 5 m for cascade 2, respectively. Both cascades contained 5–6 successive paddy fields, covering a total of 0.8 ha. The uppermost field of the cascades received water directly from the irrigation channel. All other fields received water from a single inlet from the above lying field and drained via a single outlet to the lower situated field.

The experiment was laid out in a split plot design with three replications at each site. All fields in both cascades were divided into two parts resulting in two strips per cascade. Two sets of factors included in this experiment were as follows: different toposequence positions as the main plot and with (+F) and without (−F) fertilizer application as the subplot. The investigated cascades had 5–6 fields and among them the fields at the top, middle and bottom positions were chosen as shown in Fig. 1. The applied chemical fertilizers were 213 kg N ha^{-1}, 150 kg P ha^{-1} and 93 kg K ha^{-1} per rice season with split applications according to the local recommendations by extension service. The first dressing, at transplanting, contained 56% N, 100% P and 34% K of the total amount of fertilizer applied in the form of NPK and urea. Second and third dressings contained 22% N and 33% K of the total amount of fertilizer in the form of urea and Kali (K_2SO_4–40% K_2O) which were applied at active tillering and at heading stage.

Soil type was Gleysols (silty loam in the different horizons) (UNESCO, 1974). Soil particle analysis was done by pipette method (Gee and Bauder, 1986). Total N (TN) and total C (TC) contents were analyzed by using a NC analyzer (Sumigraph NC-80; Sumika Chemical Analysis Service Co., Japan). The soil pH was measured in the supernatant suspension of a 1:2.5 soil:water mixture using a portable pH meter equipped with a combined electrode (glass:Ag/AgCl, Horiba, Japan). Electrical conductivity of the soil water was measured in the supernatant suspension of a 1:5 soil:water mixture using EC meter (OM-51, Horiba, Japan). Table 1 showed basic soil properties among the different toposequence positions of the experimental site before transplanting of spring rice, 2011. In both cascades, sand was the dominant texture in the top fields with lower TN and TC content. Middle and bottom fields showed higher silt content with higher TN and TC contents when compared to the top fields. There was no statistical difference in clay content in cascade 1 between top and bottom fields, but significantly higher clay content was found in the middle and bottom fields of cascade 2 than in the top field. Soil pH ranged from 8.0 to 8.4 in both rice cascades. A higher electrical conductivity (EC) value was found in the top field than in the others in both rice cascades.

The sticky rice variety (*Oryza sativa* L. var. Nep 87) was used in both cropping seasons for both cascades. 18 days old seedlings were transplanted into the well-puddled fields. Rice seedlings were transplanted on February 28 and harvested on June 30, 2011 for the spring rice and the corresponding dates for the summer rice were July 28 and November 7, 2011, respectively. Before transplanting the spring rice, all crop residues left from the previous summer rice were incorporated into the soil. After harvesting the spring rice, all fresh crop residue leftovers were incorporated into the soil by plowing and harrowing. All management practices were following the farmer practices in both cropping seasons. For spring rice, the field was flooded 15 days before puddling on February 7, 2011. The puddling was conducted with buffalo and basal fertilizers were mixed at that time. After transplanting, irrigation water was kept at 3–7 cm depth and the field was continuously flooded till 14 days before harvest on June 16, 2011. For summer rice, the field was flooded 21 days before puddling on July 7, 2011. The puddling was also conducted with buffalo and basal fertilizers were mixed at that time. After transplanting, irrigation water was kept at 3–7 cm depth and the field was continuously flooded till 14 days before harvest on October 25, 2011. Previous to this experiment, all fields were used similarly for continuous double-cropping paddy rice for several years.

2.2. Sample collection, soil parameters, and CH_4 analysis

Methane fluxes were measured in triplicate at 10 day intervals from 7 days after transplanting (DAT) until harvest throughout the spring and summer rice growing seasons, using the closed chamber method (Lu et al., 1999). The air inside the chamber was mixed by a fan at the top of the chamber. Gas samples were drawn from the