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Research paper

Comparison of net global warming potential between continuous flooding and midseason drainage in monsoon region paddy during rice cropping

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ABSTRACT

Midseason drainage is regarded as a key practice to suppress methane (CH_4) emission from paddy soil during rice cultivation, but it can increase carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions. However, the influences of midseason drainage practice on the net global warming potential (GWP) and greenhouse gas intensity (GHGI) of rice cropping systems is not well documented in the East monsoon region. In this field study, the effect of a 30-day midseason drainage practice from the 28th day after transplanting (DAT) to the 57th DAT on the three major greenhouse gas (GHG) fluxes and yield properties were compared with those of a continuous flooding system during rice cultivation in 2011 and 2012. The impact of midseason drainage on changing three GHG emissions was compared using the GWP value and GHG intensity (GHGI). Midseason drainage significantly reduced the net GWP scale by 46–50% of the continuous flooding, mainly due to 50–53% reduction of seasonal CH_4 fluxes. Midseason drainage significantly increased N_2O flux by 20–37% over the conventional flooding, but the influence of N_2O emission increase on the net GWP scale was negligible. Midseason drainage significantly decreased soil C sequestration capacity by around 60% of continuous flooding, and then increased net GWP by 0.25–0.32 Mg CO_2-eq. ha^{-1} during rice cultivation. There was no significant difference of rice yield between two irrigation systems, and then midseason drainage can reduce GHGI by 50–56% of the continuous flooding. In conclusion, the midseason drainage practice during rice cultivation could be very useful soil management strategy to reduce GHG emission impact from lowland rice fields without impacting rice productivity.

1. Introduction

Rice is one of most important food crops in the world and is mostly cultivated under flooded soil condition. However, these flooded rice fields are major anthropogenic source of methane (CH_4), which has a 34 times higher global warming potential (GWP) than carbon dioxide (CO_2) over a 100-year time horizon (IPCC, 2013). The anthropogenic CH_4 emissions were globally estimated by using a bottom-up approach, showing approximately 331 Tg CH_4 year^{-1} in 2000–2009. CH_4 emission from rice paddies was accounted for 36 Tg CH_4 year^{-1} on average (IPCC, 2013), which contributes to approximately 10% of the total anthropogenic CH_4 emission. Using the population projections from the United Nations and income projections from the Food and Agricultural Policy Research Institute (FAPRI), global rice demand is estimated to rise from 439 million tons (milled rice) in 2010–496 million tons in 2020 and further increase to 555 million tons in 2035 (GRiSP, 2013). With the intensification of rice cultivation by the adoption of modern agronomic practices, the impact of CH_4 emissions might be expected to increase further. Therefore, soil management strategies which can reduce CH_4 emission from rice paddy fields should be developed.

Since CH_4 can be produced only under the strictly anaerobic conditions with a low soil redox potential (Eh) (Vogels et al., 1988; Neue, 1993), CH_4 emission from rice paddy fields can have a close

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relationship with water management condition. Improvements in water-management techniques such as midseason or intermittent drainage are expected to suppress CH_4 emissions by changing soil redox conditions (Yagi et al., 1997; Yan et al., 2005; Minamikawa et al., 2006; Kim et al., 2014). For example, midseason drainage and intermittent drainage during the rice-growing season reduced seasonal CH_4 emissions relative to continuous flooding in Asia by 40% and 48%, respectively (Yan et al., 2005). However, many studies have also shown that midseason drainage and intermittent drainage significantly increased nitrous oxide (N_2O) emissions (Yan et al., 2000; Nishimura et al., 2004; Zou et al., 2005, 2009; Kim et al., 2014). Midseason or intermittent drainage practices may stimulate N_2O emission via both nitrification and denitrification processes (Xiong et al., 2007). A recognizable amount of N_2O emission is expected during a drained period (Bronson et al., 1997; Cai et al., 1997, 1999). Since N_2O has 298 times higher GWP than CO_2 over a 100-year time horizon (IPCC, 2013), the small increase of N_2O emission by floodwater drainage could significantly increase total GWP scale.

In IPCC guideline (IPCC, 2013), CO_2 emitted from agricultural lands was not counted as a greenhouse gas (GHG), because soil is regarded as a carbon (C) sink. However, since water content and temperature are the most important environmental factors controlling soil respiration rates (Howard and Howard, 1993; Curiel Yuste et al., 2007), water management in rice paddy might significantly affect soil basal respiration rates. Therefore, in order to evaluate properly the impact of midseason or intermittent drainage practices on GHG emission impact in paddy soil, the trade-off relationships between the reduced CH_4 emission and the increased CO_2 and N_2O emissions might be properly evaluated in water controlled rice fields.

Paddy field is known to have a high capacity for soil C sequestration (Pan et al., 2004; Zheng et al., 2008; Lu et al., 2009; Shang et al., 2010). Converting atmospheric CO_2 into stable organic C pools in the soil can sequester CO_2. However, the changes in soil C storage depend on the balance between C input and output. Therefore, net CO_2 emission impact can be evaluated by C balance analysis. In general, the net exchanges of CO_2 could be measured by soil organic C (SOC) changes over a sub-decadal or decadal timescale (Pan et al., 2004; Lu et al., 2009). However, the method is not sensitive enough to detect seasonal or annual changes (Zhang et al., 2008). The net ecosystem C budget (NECB) analysis is developed as a powerful tool to estimate soil C balance between C sequestration and CO_2 emission (Chapin III et al., 2006; Smith et al., 2010).

In this experiment, in order to compare the impact of water management on GHG emission in rice paddy soil, rice was cultivated under both continuous flooding and midseason drainage conditions. The fluxes of CH_4 and N_2O emissions which can be significantly changed by soil water managements were simultaneously monitored during rice cultivation. Soil organic C sequestration changes were quantified by NECB analysis. Finally, the impact of GHG emission was compared by net GWP and GHGI scale.

2. Materials and methods

2.1. Experimental plot installation

In order to investigate the effect of midseason drainage on three GHGs emission characteristics during rice cultivation season in a temperate mono-rice paddy soil, two treatments having the continuous flooding and the midseason drainage systems were installed at *Gyeongsang* National University Experimental Farm (36° 50′ N and 128° 26′ E), *Jinju*, South Korea in the early May 2011. The texture of the soil in selected plot was silt loam and the soil was classified as typic Haplaquents with somewhat impeded drainage. Some selected chemical properties of initial soil were pH 6.9 ± 0.3, total organic C 8.5 ± 0.6 g kg^{-1}, total N 1.41 ± 0.08 g kg^{-1}. In Korea rice cultivation system, most of rice straw is removed for cattle feeding. In this study, rice straw was removed at the previous rice harvesting stage. The 10 m × 10 m treatment plots were in a randomized block design and replicated three times. The concrete barrier was laid down between each treatment as buffer zones (0.6 m) to avoid mixing effect.

The recommendation rates of chemical fertilizers (N-P_2O_5-K_2O = 90-45-57 kg ha^{-1}) were applied in both treatments for rice cultivation (RDA, 1999). The basal mineral fertilizers applied one day before transplanting were 45 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, and 40 kg K_2O ha^{-1}. Thirty day old seedlings (3 plants per hill) of rice (*Dongjinbyeo* cultivar, Japonica) were transplanted with a spacing of 30 cm × 15 cm by hand in the early June 2011 and 2012. Tillering fertilizer (18 kg N ha^{-1}) was broadcasted on the 15th day after transplanting and panicle fertilizer (27 kg N ha^{-1}, 17 kg K_2O ha^{-1}) on the 60th day. The rice was harvested on the early October 2011 and 2012, and its productivities were recorded following the RDA methods (RDA, 1995).

The two water management practices namely continuous flooding and midseason drainage were adopted during this study. The treatments were arranged in randomized block design with three replications. In the continuous flooding treatment, the water level was maintained at a depth of 5–7 cm above the soil surface using an automatic water level controller, and then drained 3 weeks before rice harvesting. In comparison, except for during the midseason drainage period, the water was identically controlled with that in the continuous flooding during rice cultivation. The flooded water was drained out for 30 days from the active stage (28 days after transplanting) to the maximum growing stage (57 days after transplanting) and thereafter the soil was flooded.

2.2. Gas sampling and analysis

A closed-chamber method (Ali et al., 2008, 2009; Haque et al., 2013) was used to estimate CH_4, respiration (CO_2), and N_2O emission rates as described in Fig. S1. Two different types of closed chambers were installed at different position during rice cultivation. A type of transparent glass chambers which have surface area 62 cm × 62 cm and height 112 cm were placed permanently in the flooded soil after rice transplanting for monitoring CH_4 and N_2O emission rates. Eight rice plants were enclosed in a chamber. In addition opaque acrylic column chambers which have diameter 24 cm and height 25 cm were placed inner plant excluded soil surface between rice plants for evaluating heterotrophic respiration rates during rice cultivation (Lou et al., 2004; Xiao et al., 2005; Iqbal et al., 2008). The bottom 20 cm of chamber was interred inner soil to prevent plant root intrusion, and weeds inner the chamber were continually removed to minimize plant CO_2 uptake loss during the investigation. There were 2–4 holes in the bottom of the chambers to maintain the water level 5–7 cm above the soil water interface during rice cultivation. All chambers were kept open in the field throughout the investigation period except during the gas sampling. The chamber was equipped with a circulating fan for gas mixing and a thermometer inside to monitor the temperature during the sampling time.

Air gas samples were collected using 50 mL gas-tight syringes at 0 and 30 min after chamber placement. Gas samplings were carried out at three times (8:00–12:00–16:00) in a day to get the average GHGs emission rates. Three gas samples in each replicate of each treatment were then drawn off from the chamber headspace equipped with 3-way stop cock. Collected gas samples were immediately transferred into 30-mL air-evacuated glass vials sealed with a butyl rubber septum for gas analysis.

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