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Greenhouse Gas Emissions from Paddy Fields with Different Organic Matter Application Rates and Water Management Practices

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Global warming associated with emissions of greenhouse gases (GHGs) is one of the most important environmental issues because its potential to impact on human life is severe. In this study, we investigated the effect of organic matter applications and water management on the fluxes of GHGs and yields of rice from paddy fields, a major source of anthropogenic CH_4 emissions. We found that the treatment effects on fluxes of GHGs differed among the gases and that the treatments affected rice yields. High CH_4 fluxes and high rice yields were associated with organic matter amendments. CH_4 gas fluxes were high during summer season especially in manure compost plot. Maintaining low water levels resulted in low rice yields and low emissions of CH_4. CO_2 is sunk into the soil through rice crop during daytime under any water management in this experiment.

Key words: greenhouse gases, organic matter application, paddy fields, rice yields, water management

Introduction

Global warming is one of our biggest concerns because its potential impact on human life is so severe. Global warming potential is calculated by using conversion factors of 1, 23, and 296 mg for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), respectively, to express GHG emissions in mg of CO_2 equivalent per kg of dry soil per hour (IPCC, 2001). Therefore, a contribution ratio of CH_4 and N_2O to global warming would be high even if their emission rates are small. Rice paddies are considered to be a major source of anthropogenic CH_4 emissions (Jacobson, 2005), and a large proportion of the world's paddy fields are located in Asian countries, including Japan. The emissions of GHGs from paddy fields need to be controlled. Various factors that affect GHG emissions from paddy fields include water management (Xiong *et al*., 2007), fertilizer management (Lindau and Bollich, 1993), organic matter application (Yagi and Minami, 1990), and soil type (Xiong *et al*., 2007).

Eusufzai *et al*. (2011) and Naser *et al*. (2007) have shown that CH_4 emissions from paddy fields increased with increases in rice straw application rates. On the other hand, management of water in a paddy field is one of the most useful ways to control emissions of GHGs from paddy fields (Cai *et al*., 1997; Hadi *et al*., 2010; Nishimura *et al*., 2004; Yagi *et al*., 1997). Yu and Patrick (2004) have reported that there was a range of oxidation–reduction potentials (ORPs) suitable for minimizing emissions of CO_2, CH_4, and N_2O. Furthermore, gas emissions are primarily made through rice crop's aerenchyma so that the volume of CH_4 emission reached the 35–62% of the total emission during the cultivation period (Wassmann *et al*., 1996).

In this study, we investigated the effects of organic matter application and water management on fluxes of

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GHGs from paddy fields. We evaluated gas emissions from the bare soil surface mainly as well as gas emissions through rice crop in the experiment among different water managements. Finally, we compared the effects of the different treatments on GHG emissions and rice yields.

Methods

Organic matter application

The paddy fields used to study the effects of different organic matter treatments on GHG fluxes and rice yields were located in Iitate Village, Fukushima Prefecture. We established three different organic matter application treatments: (1) rice straw, (2) no amendments (i.e. control), and (3) manure compost. We transplanted one japonica rice seedling (cv. Hitomebore) per hill with 30×18 cm spacing. We measured CH_4, CO_2, and N_2O gas fluxes (mg m^{-2} h^{-1}) two times per month during the rice-growing season (9 June 2013 to 5 October 2013) using the closed chamber method. Samples for GHGs were collected with a 40×40×50 cm acrylic chamber in bare soil areas. The concentrations of GHGs were analyzed with GC-FID for CH_4 and CO_2 and GC-ECD for N_2O (GC-8A, Shimadzu co.). In addition, we measured CO_2 fluxes from three bare soil areas with the Automated Soil CO_2 Flux System (LI-8100A, LI-COR, USA).

Water management experiment

We used six 2×2×2 m lysimeters installed in the Ikuta Campus of Meiji University (Fig. 1) to measure GHG fluxes. The experimental design involved duplication of three different water management practices: (1) continuous flooding (CF1&2) as a control, (2) mid-season drainage (MD1&2), and (3) low water level (LW1&2). We maintained a groundwater level at 20 cm below the soil surface to study the effect of low water level on GHG fluxes from paddy fields. We transplanted one japonica rice seedling (cv. Kinuhikari) per hill with 20×20 cm spacing. We measured fluxes of CH_4, CO_2, and N_2O (mg m^{-2} h^{-1}) once per week during the rice-growing season (11 June 2010 to 17 September 2010) using the closed chamber method. In this experiment, we also investigated the gas emission through rice crops beside from the bare soil area. Samples for GHGs were collected in rice-growing areas with a 30×60×106 cm acrylic chamber and in a bare area with a 50-cm-high acrylic cylindrical chamber with an inside diameter of 25.6 cm. To collect GHG samples in the rice-growing area, we covered six plants with a chamber. The concentrations of GHGs were analyzed by gas chromatograph flame ionization detection (GC-FID) for CH_4 and CO_2 and by gas chromatograph electron-capture detection (GC-ECD) for N_2O (6890N, Agilent technologies). The ORP of the soil was measured with a reference (PRN-41, Fujiwara Scientific Company Co., Ltd.) and platinum electrodes inserted into the soil.

Results and Discussion

The effect of organic matter application on GHG fluxes

We observed higher emissions of CH_4 during the summer season (except on July 28) from the rice straw and manure compost treatments than from the control plot (Fig. 2). The CO_2 fluxes measured with the automated gas sampling system (Fig. 3) were large on September 8 and 15. This time interval is indicated by the shaded area in Fig. 3. We installed the automated

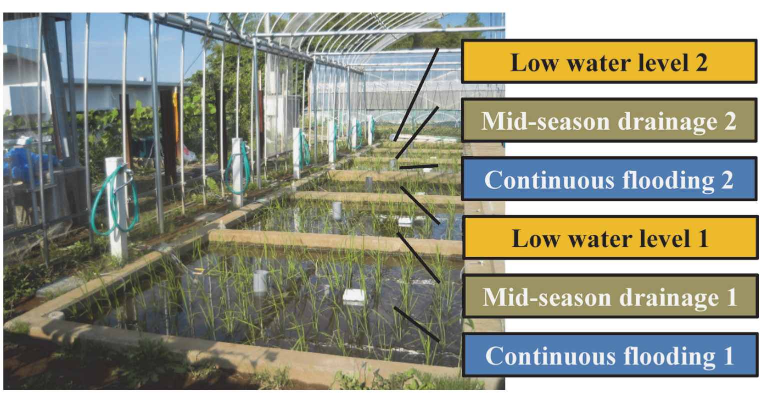

Fig. 1. Six 2×2×2 m lysimeters for experimental water management treatments

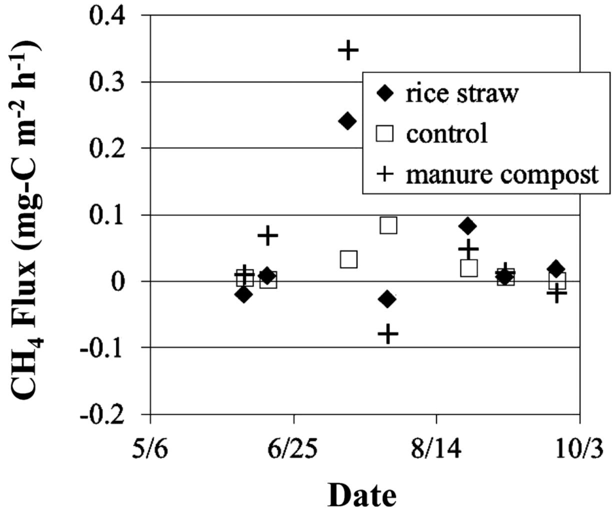

Fig. 2. CH_4 fluxes from paddy fields of organic matter application treatments

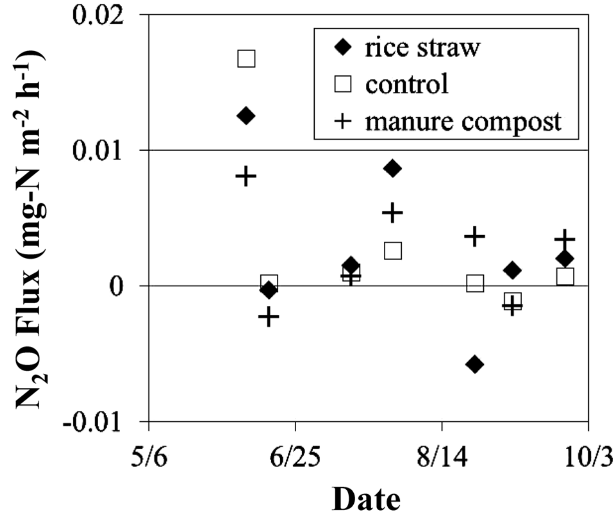

Fig. 4. N_2O fluxes from paddy fields of organic matter application treatments

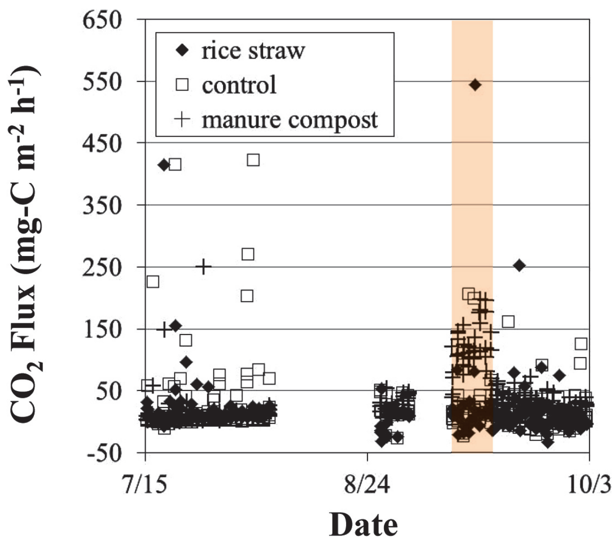

Fig. 3. CO_2 fluxes from paddy fields of organic matter application treatments measured with the Automated Soil CO_2 Flux System. The shaded area corresponds to the time interval September 8–15.

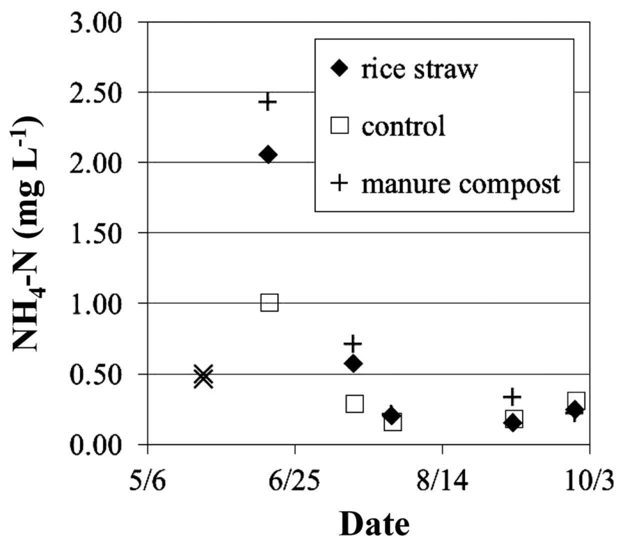

Fig. 5. Temporal changes in NH_4-N concentration in soils of organic matter application treatments

gas sampling system in the middle of our investigating period. Therefore, time scale of the horizontal axis in Fig. 3 is different from others. We did not measure CO_2 gas fluxes on those days with the closed-chamber method. Unfortunately, we couldn't compare the results of CO_2 gas fluxes between automated and closed-chamber method. The N_2O fluxes were small in the rice cropping season; the maximal N_2O fluxes were observed before rice planting on June 8 (Fig. 4). Rapid increases in NH_4-N concentrations might be associated with the high N_2O fluxes on June 8 as a result of nitrification of NH_4-N (Fig. 5).

The observation of high CH_4 emissions from the rice straw treatment was consistent with reports by other researchers (e.g., Eusufzai *et al*., 2011; Naser *et al*., 2007; Yagi and Minami, 1990). In those studies there were two emission peaks. Eusufzai *et al*. (2011) speculated that the early-season peak during the vegetative stage was resulted from straw decomposition while the later peak during the reproductive stage was associated with root exudation. They applied rice straw in November, whereas we applied rice straw in May. The peak of CH_4 emissions from our site occurred about 30 d after rice planting, so the peak of CH_4 emissions might be attributed to the decomposition of the rice straw. The low emissions of CH_4 on July 28 may be resulted from soil oxidation associated with low water depths that were recorded with a water-level indicator and documented with photographs between (not shown). The mid-season drainage was in effect on between September 8 and 15, and hence the soil was relatively dry and oxidized. Organic matter derived from manure compost may have been decomposed while the soil was oxidized. This decomposition may have been responsible for the large release of CO_2 gas. The concentration of NH_4-N increased more rapidly on June 16 than on May 25 (Fig. 5). During those days, we applied organic matter and irrigated.

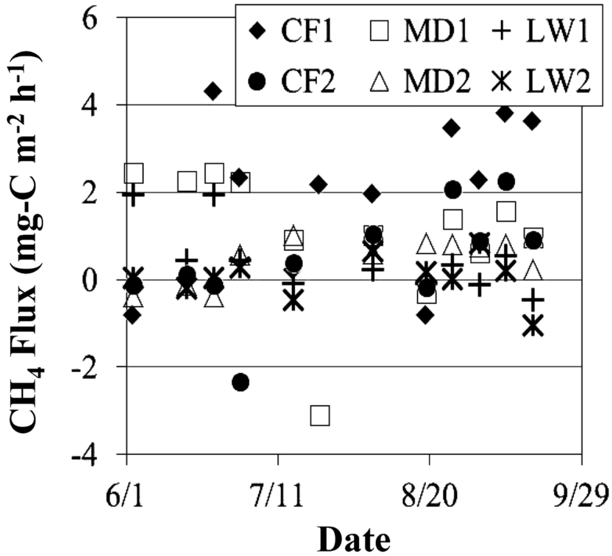

Fig. 6. CH_4 fluxes from rice-growing areas of water management treatments

The effect of water management on GHG flux

We observed larger GHG fluxes in rice-growing areas than in bare areas. The CH_4 emissions were small from the low-water-level treatment (Fig. 6). The largest emissions of CH_4 were observed from the continuous-flooding treatment, especially after the end of August. We observed large CO_2 sink in the rice-growing area, regardless of water management practices (Fig. 7). There were no specific patterns associated with the N_2O fluxes among the water management practices (Fig. 8). We intended the investigation of GHG fluxes from bare areas, but observed GHG fluxes were much smaller from bare areas than from rice-growing areas (data not shown).

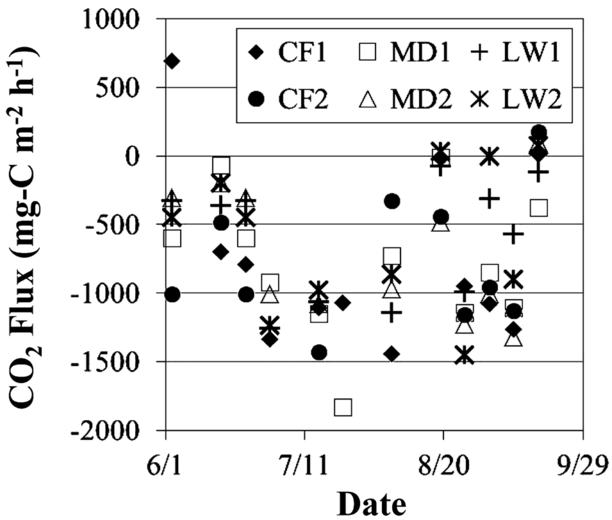

Fig. 7. CO_2 fluxes from rice-growing areas of water management treatments

The smallest emissions of CH_4 were associated with the low-water-level treatment because of the low activity of anaerobic, methane-producing bacteria in the aerobic soil environment. Hou *et al*. (2000) have reported that methane was produced in a strictly anaerobic environment by obligate anaerobic microorganisms, either through CO_2 reduction or transmethylation of acetic acid. The emission of CH_4 and uptake of CO_2 observed in this study were consistent with their results. All the GHG fluxes observed in the rice-growing areas were emitted primarily through aerenchyma, an important conduit of GHGs from the soil to the atmosphere. Photosynthesis by rice plants was a major sink of CO_2, because our flux measurements were made during the daytime. The ORP values measured in the continuous-flooding and mid-season-drainage treatments were below −200 mV throughout the experimental period. Such low ORPs might have caused the emissions of CH_4 to be higher from the continuous-flooding and mid-season-drainage treatments than from the low-water-level treatment. However, the CH_4 and N_2O emissions from the former treatments were lower than those reported by other workers (e.g., Xiong *et al*., 2007; Nishimura *et al*., 2004). Soil temperature and other soil condi-

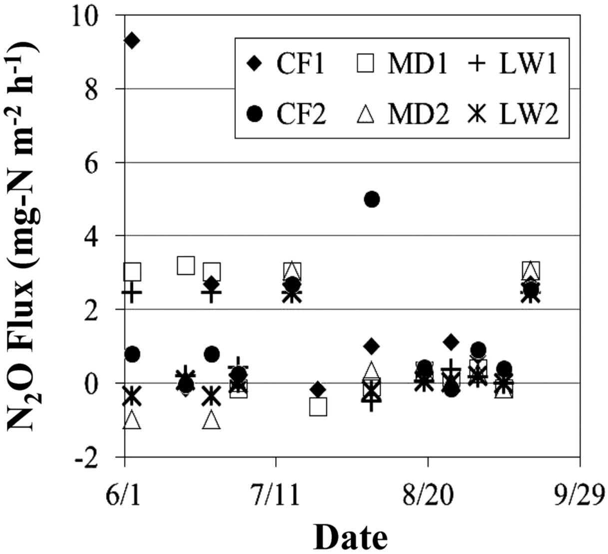

Fig. 8. N_2O fluxes from rice-growing areas of water management treatments

tions might have contributed to this result.

The effect of organic matter application and water management on rice yields

In the case of the organic matter application experiment, rice yields from the paddies with rice straw, no amendments (i.e. control), and manure compost were 513, 310, and 462 g m^{-2}, respectively. The concentrations of NH_4-N increased after the application of organic matter in the paddies amended with rice straw and manure compost. After this increase, NH_4-N concentrations gradually decreased. We expected that the NH_4-N derived from the decomposition of organic matter would be absorbed by the rice plants and influence yields. Rice yields were higher from the plots amended with rice straw than from the plots amended with manure compost. The concentration of NH_4-N was higher in soil amended with manure compost than in soil amended with rice straw. Rice plants that produced higher yields seemed to absorb more NH_4-N, so that the concentration of NH_4-N remaining in the soil was lower.

There were large variations in rice yields among the three water management treatments. Rice yields from the CF1&2, MD1&2, and LW1&2 treatments were 494 and 806; 535 and 698; and 429 and 509 g m^{-2}, respectively. Rice yields were tended to be lower in the LW1&2 treatments than in the other treatments. Further research on rice yield is needed to obtain statistically-significant results with increasing the number of data. Although daylight hours, air temperature, wind speed, and other environmental factors influence rice yields, we did not measure those factors in this study.

Conclusions

Rice is a staple food, especially in east and south Asia, and GHG emissions through rice plants are unavoidable. Higher GHG fluxes were observed from sites amended with organic matter than control from bare area, and rice yields from those sites were high. Low emissions of CH_4 were observed from low-water-level treatment, rice-growing areas. A small amount of emissions from the bare area were observed in our experiments. Larger GHG fluxes were observed in rice-growing areas than in areas with no rice plants in the water management experiment. Rice yields were also low from the low-water-level treatment. Water management and organic matter application influenced both rice yields and GHGs fluxes.

Acknowledgements

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