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SHORT COMMUNICATION

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Rice yield reduction by chamber enclosure: a possible effect on enhancing methane production

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Abstract Major rice growth characteristics and grain yield were compared between inside and outside of a chamber coverage area after a seasonal CH_4 and N_2O flux measurement using a closed chamber technique. Results show that only grain yield was significantly ($P<0.01$) reduced by chamber enclosure. There was no significant difference ($P>0.05$) in plant height, total straw weight, spike length, and average grain weight. Temperature increase during the gas flux measurement was likely the major cause for the observed grain yield decrease by sterilizing rice reproductive organs. Methane flux rates from rice fields were likely overestimated by using closed chamber technique because decreasing grain yield by chamber enclosure may result in more plant photosynthesis products released into soils to enhance CH_4 production. Analyzing CH_4 and CO_2 emission ratio from the rice field, after cutting the above-water part of rice plants, indicated that CH_4–C emission accounted for approximately 13% of the total CO_2 and CH_4–C emission during the major rice growing season.

Keywords Chamber technique · Methane · Photosynthesis · Rice yield · Temperature

Introduction

The increasing concentration of radiatively active trace gases in the atmosphere, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), has caused wide concerns over their impacts on global climate change. Most field information for estimating global greenhouse gas inventory is obtained by using chamber techniques to measure gas fluxes from different ecosystems. There are two types of chambers: closed (also called static) and open (also called dynamic) chamber (Hutchinson and Livingstone 1993). For open chamber technique, the difference in concentration of an interested gas between inlet and outlet of the chamber is used for calculating the gas flux rate. Closed chamber technique has been much more widely applied because of its simple design, low cost, and high mobility and sensitivity. In the following discussion, chamber refers to closed chamber unless it is described specifically. When a chamber is in place over a certain area (usually <1 m^2) of a field, gas samples can be taken from the headspace of the chamber at certain times. The change of gas concentration in the chamber over time is used to calculate the gas flux rate. A chamber can be operated manually, where the whole chamber body is covered and removed by hands, and automatically, where the chamber body is equipped with a lid that can be opened and closed by an electronic device (Schutz et al. 1989).

Micrometeorological techniques for gas flux measurement have the advantage of covering a larger area of measurement, and not disturbing plant microclimate. There is some evidence showing that, despite the spatially and temporally heterogeneous conditions in fields, N_2O flux measurement, using a small enclosure chamber technique, is quite comparable to field scale measurements using micrometeorological techniques (Smith et al. 1995; Christensen et al. 1996). Therefore, chamber technique probably provides a reasonable estimate for N_2O fluxes. In an earlier attempt to compare CH_4 fluxes from rice fields using different techniques, the results obtained by the micrometeorological techniques were consistently higher than those obtained by the chamber method over a four-day campaign in March (Kanemasu et al. 1995). A more recent comparison of CH_4 fluxes over a major rice-growing season (May to August) showed that chamber measurements were 60–90% higher than micrometeorological measurements (Werle and Kormann 2001). The later results might be more reliable due to longer period of

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comparison and improvement of the techniques (especially the CH_4 detector).

Flooded rice fields are a major source of CH_4, the second most important atmospheric trace gas (only next to CO_2), contributing to 20% of the global radiative forcing increase from 1750 to 2000 (Intergovernmental Panel on Climate Change (IPCC) 2001). Extensive studies have been conducted using chamber techniques on flooded rice fields. As a part of the carbon cycle, methanogenesis occurs under strictly reducing conditions and is closely related with plant photosynthesis activity. Studies using isotope tracer technique indicated that a large fraction of the organic matter (OM) that supported CH_4 production was derived from recently fixed carbon (Minoda and Kimura 1994). It can be expected that CH_4 flux rate will be significantly biased if rice plant growth and grain yield are affected by chamber enclosure during the measurement. In this study, major rice growth characteristics and grain yield inside the chamber were compared with those outside the chamber (as control) after a seasonal measurement of CH_4 and N_2O emissions from the rice fields (Yu et al. 2004). The implication of grain yield change on CH_4 production and emission and a possible side effect of chamber technique on CH_4 flux measurement are discussed.

Materials and methods

The field measurement was conducted at Shenyang Experimental Station of Ecology, Chinese Academy of Sciences (41°32′ N, 122°23′ E). Rice (*Oryza sativa*) was cultivated once a year with a growing season of about 120 days. Rice seedlings were transplanted after flooding the field in late May, and the fields were drained in late September for harvest in early October. Detail information on soil characteristics, field management, and variations of N_2O and CH_4 emissions were included in previous publications (Chen et al. 1995, 1997; Yu et al. 2004).

Chamber and measurement

Physiological characteristics of rice plant and grain yields were investigated after a seasonal N_2O and CH_4 measurement that has been reported (Yu et al. 2004). A major rice cultivar (Liaokai 79) of this region was studied under four treatments: (A) No OM addition, flooded; (B) No OM addition, non-flooded; (C) OM addition, flooded; (D) OM addition, non-flooded. Treatment C was the conventional management practice in this region. For the OM-added plots, organic manure was applied at approximately 30 ton ha^{-1} before rice cultivation. Each treatment had three replicate plots. Methane and N_2O emissions in the rice fields were measured at least once a week using a manually operated chamber. The chamber is 1 m high, with a base area of 0.8×0.8 m. Inside the chamber, a battery-operated fan was mounted on the top. The chamber body was constructed of Plexiglas of 90% transparence to sunlight. For every measurement, rice plants and field within a stainless steel base unit were covered by the chamber for 40 min, and sealed with water. Gas samples inside the chamber were collected at 0, 20, and 40 min upon chamber closure after rotating the fan for 1 min. Immediately after gas sampling, temperatures inside and outside the chamber were recorded, and then the chamber was manually removed from the field. At time of harvest, an undisturbed field (0.8×0.8 m) outside the chamber was randomly selected to compare the physiological characteristics (rice plant height, total straw weight, spike length, weight per thousand grain) of the rice plant and grain yield with those inside the chamber.

Ratio of CO_2 and CH_4 emissions

Carbon dioxide and CH_4 are the two major C-containing gaseous products in the soil carbon cycle. To determine the ratio of CO_2 and CH_4 emission from the rice fields, rice plants were cut at 5 cm above the water surface to eliminate interference of rice plant photosynthesis on CO_2 concentration inside the chamber. We hypothesized that the CO_2 and CH_4 emission ratio would remain approximately the same before and after cutting the rice plants, as most of the gases produced in soils were emitted through the aerenchyma system of rice plants (Yu et al. 1997). Three rice cultivars (Liaokai 79, 294, and Youza) cultivated in the conventionally managed field (treatment C) were used to compare the CH_4 flux rate before and after cutting rice plants. The experiment was conducted seven times in the major rice-growing season with three replicates. For each measurement, CH_4 and CO_2 emissions were measured twice in the same day using the same chamber technique. The first measurement was conducted at 11:00 in the morning. Then the rice plants in the same plot were cut at 5 cm above water surface, for the second measurement at 14:00 in the afternoon. Previous observation on the diurnal pattern of CH_4 emission indicated that CH_4 emission rate was close at these two points of the day (Chen et al. 1995). The chamber base was removed after these two measurements to another location with the same treatment preparing for the next measurement (about 2 weeks later after equilibrating base).

Data analysis

Gas measurement and analysis was as previously documented (Yu et al. 2004). Statistical analysis was conducted using SAS (SAS Institute. Cary, NC, USA). Analysis of variance (ANOVA) using PROC GLM was used to determine if there was a statistically significant difference (α=0.05) between different treatments. Simple linear regression using PROC REG was conducted to test if the slope of a regression was significantly different from a theoretical model.

Results and discussion

In total, 16 measurements of N_2O and CH_4 emissions from the rice fields under the four different treatments were conducted within the period from panicle initiation (end of June) until harvest (early October). The results of rice growth characteristics and grain yield after harvest are summarized in Table 1. Regardless of effects of different treatments on rice growth and grain yield, only the grain yield was significantly (P=0.0038) reduced by chamber enclosure. There was no significant difference in the rice plant height (P=0.30), total straw weight (P=0.59), spike length (P=0.84), and average grain weight (P=0.32). On average of the four treatments, grain yield was decreased by 29%, while the other rice growth characteristics were decreased by 1 to 6%. Rice yield reduction was also observed in a study using an automatic chamber for gas flux measurement. Bronson et al. (1997) reported that the rice yields inside the chamber were decreased by 43 and 30%, respectively, in the dry and wet season of 1993, and by 10% in the dry season of 1994.

There could be multiple reasons for the observed grain yield decrease by chamber enclosure. The most likely reason is the temperature increase inside the chamber during the measurement. We found that the temperature increase at the end of a 40-min measurement ranged from several degrees in a cloudy day to 18°C in a sunny day (with a final temperature inside the chamber up to 46°C). Matsui et al. (1997) concluded that the high temperature during flowering resulted in increased pollen sterility. Increasing temperature can increase the number of panicles per rice plant but the number of seeds per panicle declined sharply (Baker et al. 1992). A similar study by Kim et al. (1996) reached the same conclusion that the grain-yield decline at higher temperatures was primarily due to an increase in the number of sterile spikelets and slightly due to the increase in imperfectly ripened grains. The spikelet sterility was most closely related to the daily maximum temperature averaged over the flowering period.

Rice yield is directly correlated with cumulative sunlight. For every 1% reduction in total sunlight, a 2.2% reduction in grain yield was observed over a 5-year period in Texas US (Stansel 1975). In our study using a 90% transparence Plexiglas chamber, 16 measurements could only reduce the cumulative sunlight by about 0.1%. Therefore, reduction of sunlight by chamber enclosure was negligible for the grain yield decrease inside the chamber. Physical disturbances when operating the chamber (including rotating the electric fans before gas samplings) might be unfavorable for the rice plant growth. The chamber height is close to a matured rice plant (Table 1), which partially explained the more obvious decreases in the plant height and grain yields of taller rice plants (in the plots of treatment C and D).

The carbon dioxide concentration inside a chamber will decrease rapidly upon chamber enclosure due to plant photosynthesis activity. However, rice plant growth was not significantly affected in this study (Table 1) because the total enclosure time was only 11 h during the entire growing season. Photosynthesis potential of rice plants inside and outside of the chamber was likely close if not the same. The implication of decreasing rice yield by chamber enclosure on methane production is that more plant photosynthesis products may be released into the soils to enhance CH_4 production. By artificially removing rice spikelets to reduce the rice plants' capacity to store fixed C in grains, CH_4 emissions were significantly increased due to extra C inputs to the soils for methanogenesis (van der Gon et al. 2002). It was estimated that, on average, 11±4% of the C not allocated to rice grains was emitted as CH_4 (Sass et al. 1994). Results using an isotope labeled organic C to a wetland rice soil revealed that 12±4% of the added C was recovered as CH_4 (van der Gon 2000).

Primary production has a significant relation with CH_4 production in wetland (both natural and flooded rice) ecosystems. Whiting and Chanton (1993) estimated that about 3% of the daily net ecosystem production (net primary production minus soil and microbial respiration) was emitted back to the atmosphere as CH_4. If the net primary products (such as rice grains) were reallocated into the soils (such as by chamber enclosure), CH_4 production and emission would be enhanced. Assuming CO_2 and CH_4 as the only end gas products from mineralization of soil organic C, we estimated the percentage of organic C conversion to CH_4 from the rice fields by calculating emission ratio of CO_2 and CH_4. By analyzing CH_4

Table 1 Comparison of rice plant growth characteristics and grain yield between chamber covered and non-covered field plots

Sample location and treatment	Inside the chamber				Outside the chamber			
	A	B	C	D	A	B	C	D
Plant height (cm)	82.6	84.2	91.6	84.7	82.3	86.5	95.3	97.4
Total straw weight (g m^{-2})	890	859	1,140	1,141	940	850	1,220	1,330
Spike length (cm)	16.0	16.3	17.9	15.6	15.9	16.7	17.3	16.4
Weight/thousand grain (g)	27.7	29.0	26.7	25.8	28.6	29.0	27.5	27.5
Total grain yield (g m^{-2})	688	680	750	781	970	880	1,090	1,150

Treatment: *A* No OM addition, flooded; *B* No OM addition, non-flooded; *C* OM addition, flooded; *D* OM addition, non-flooded
Data represent means of the measurements with standard deviations between 3 and 12%. For plant height and rice spike length measurements, n=10; for weight per thousand grain, total straw weight, and total yield measurements, n=3
In comparing the measurements between those inside and outside the chamber, only the average grain yield under the four treatments was significantly different (P=0.0038, n=4)

emissions from the fields with three rice cultivars, we found that the CH_4 emission rates were quite comparable before and after cutting the rice plants (Fig. 1a). The average 9% decrease in CH_4 emission after cutting the rice plants was probably due to (1) the small difference in CH_4 emission rate at these two points of the day, and (2) a slight increase of chamber volume after removing the rice plants that was not considered in calculation of the CH_4 emission rates. No other plant physiological activities but photosynthesis were known to significantly consume CO_2. It is possible that CO_2 and CH_4 emission rates would remain the same after cutting the above-water part of the rice plants because the venting systems of the rice plants remained functioning as before. Without the interference of photosynthesis after cutting rice plants, the emission ratio of CO_2 to CH_4 from rice fields can be determined (note: this also eliminates respiration from the above-ground part of the rice plant). We found a large variation in CO_2–C to CH_4–C emission ratio from the rice fields, ranging from 4 to 2,300. Carbon dioxide was the dominant C gas when CH_4 emissions were low, resulting in higher CO_2 to CH_4 emissions ratios (Fig. 1b). Regression analysis indicated that, on average, CO_2–C emission rate was about 6.45 times higher than that of CH_4–C emission from the studied rice fields. This is equivalent to 13.4% of the soil organic C converted to CH_4, similar to the estimates of Sass et al. (1994) and van der Gon (2000) by using different approaches. We conclude that grain yields reduction by chamber enclosure will considerably enhance CH_4 production and emission from rice fields. In other words, using the current chamber technique has overestimated the actual CH_4 emission rate from a flooded rice ecosystem, as supported by the study of Werle and Kormann (2001), because grain yields unanimously decreased inside a chamber than in undisturbed rice fields. However, how much the reallocated organic C from rice grains contributes

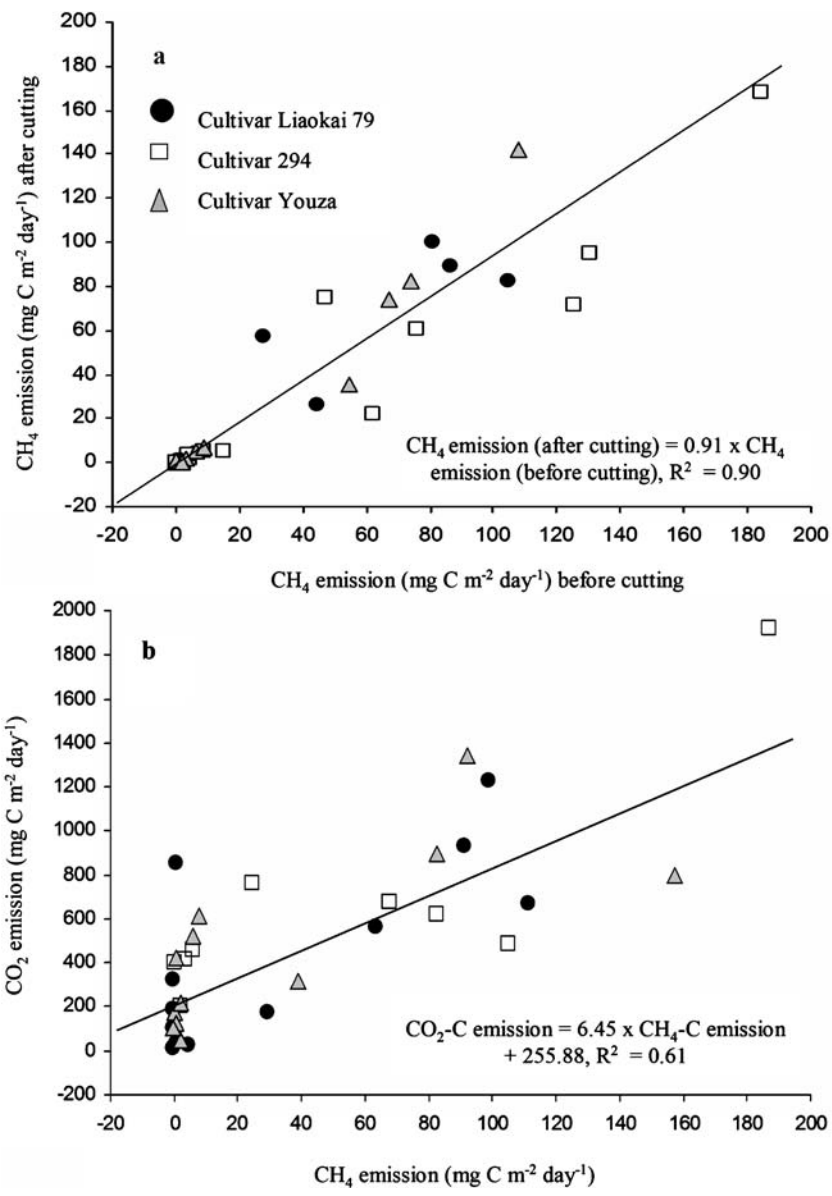

Fig. 1 **a** CH_4 emissions from field plots before and after cutting rice plants. The regression showed no significant difference (*P*=0.06) than the theoretical model [CH_4 emission (after cutting) = 1xCH_4 emission (before cutting)]; **b** CO_2 and CH_4 emissions from the rice fields after cutting the rice plants. The regression showed a significant correlation (*P*<0.001) between CH_4 and CO_2 emissions

to CH_4 production in soils remains uncertain. Part of such additional organic C may still remain in the soils when CH_4 production is terminated after draining the fields at end of the season.

The chamber design and operation described in this study has been widely used. Improvement in chamber technique to avoid rice yield reduction is strongly needed. Regardless of all possible reasons of grain yield reduction by chamber enclosure, this study reveals a biological mechanism of enhancing CH_4 production and emission from rice fields. Previously published CH_4 flux rates using similar technique deserve careful evaluation.

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