Methane Emission Peak observed at Predawn in Tropical Paddy Field : A Case Study of Hainan Island, China

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Abstract Paddy fields is significant source of methane (CH_4), a major greenhouse gas. Therefore, agro-technological developments to inhibit CH_4 emission from paddy fields are required. However, little information is available on CH_4 emission from paddy fields in tropical Asia. We measured CH_4 gas emission to observe its diel change in a permanently flooded paddy field in which a high-yielding hybrid rice variety was established and no organic fertilizer was applied. The field study was conducted on Hainan island (latitude : 19°31'N, altitude : 168m) from September 21 to 26, 2006. The rice developmental stage was booting, and the leaf area index was 5.0. The CH_4 flux was calculated by the eddy correlation method. The CH_4 concentration was measured using a laser gas detector. The vertical wind speed was measured using an ultrasonic anemometer and atmospheric density. The CH_4 flux peaks were observed at predawn, which decreased rapidly after sunrise with an increase in temperature. This diel oscillation pattern of methane flux was similar to that observed in August 2006 in a highland area of central Japan. The CH_4 flux seemed to be suppressed by the photosynthesis of the rice canopy. The oxygen flux from plant top to rhizosphere increased due to photosynthesis during the daytime and inhibited methanogen activity under the ground.

Key word : greenhouse gases, methane, oxidation, oxygen, photosynthesis, tropical area

Introduction

Paddy fields are significant sources of atmospheric methane (IPCC, 1992 ; Neue and Sass, 1998), which is one of the greenhouse gases. At the same time, paddy fields have played important roles in sustainability and productivity of human beings. Therefore, there is a need to maintain their productivity and to mitigate methane emission.

Closed systems like chamber methods to cover rice plants are widely used for measurement because gases in low concentration can be quickly collected and measured. Chamber methods, however, alter the experimental conditions. Field investigations in tropical areas have been limited, although approximately 70% of global paddy fields exist in tropical Asian countries. Therefore, the present research was conducted to precisely estimate the methane emission from tropical paddy fields without using a closed system.

The objective of this study was to observe the diel change of methane flux from actual paddy fields in tropical areas using a new micrometeorological technique.

Materials and Methods

Observation point and cultivation condition

(1) Observation site : a farmer's paddy field beside South China University of Tropical Agriculture, College of Agriculture, on Hainan island (latitude 19°31', longitude 109°35', and altitude 168m)

(2) Observation period : September 20-26, 2006

(3) Cultivar : Shen nong dao No. 1. Hainan people often cultivate this high yielding hybrid rice variety registered in April 2006. It belongs to the late maturing class.

(4) Growth and developmental condition of rice: the developmental stage, leaf area index (LAI) at the observation time, and tiller number were booting stage, 5.0, and 250 per $1m^2$, respectively.

(5) Fertilizer application: Urea (N46%, 30g per $1m^2$) was applied on August 19, 2006 and chemical complex fertilizer (N14%, $P_2O_5$7%, K_2O9%, 75g per $1m^2$) was applied on September 13. No organic fertilizer was applied even in last year's rice straw. In addition, midseason drainage was not retained.

Experimental apparatus and instruments

(1) Laser methane gas detector, SA3C15A (Anritsu Co. Ltd., Japan): Measuring atmospheric methane concentration at 120cm above the ground every 0.5 sec. The distance between the detector and a reflection board was 30m.

(2) Ultra sonic anemometer, CGY-81000 (Climatec limited private company, Japan): Measuring vertical wind speed every 0.1 s. The anemometer was placed at the median center of the detector and the reflection board. Due to the performance requirements of the eddy correlation method mentioned below, wind speed data needed to be synchronized with methane concentration data. Then, the wind speed data for 10 s prior to the output of the methane concentration data at a given time was averaged.

(3) Actinograph: KADEC-UP (Kona System Co. Ltd., Japan): Measuring photosynthetic active radiation (PAR) every minute.

(4) Temperature gauge and humidity instrumentation, SK-L200TH (Sato Keiryoki Co. Ltd., Japan): Measuring air temperature and humidity every 15 sec.

Eddy correlation method

Methane concentration (C) and vertical wind speed (W) are expressed as follows:

$$W=\overline{W}+W',$$

$$C=\overline{C}+C',$$

where $\overline{C}$, C', $\overline{W}$, and W' indicate mean methane concentration, deviation of methane concentration at any time, mean vertical wind speed, and deviation of vertical wind speed at that time, respectively.

Methane flux (QC) can be expressed as follows:

$$QC=\rho\cdot(\overline{W\cdot C})$$

$$=\rho\cdot(\overline{(\overline{W}+W')\ (\overline{C}+C')})$$

$$=\rho\cdot(\overline{\overline{W}\,\overline{C}}+\overline{\overline{W}C'}+\overline{W'\overline{C}}+\overline{W'C'}),$$

Where ρ is the atmospheric density.

In this equation,

$$\overline{W'}=0,\ \overline{C'}=0,\ \text{and}\ \overline{W}=0.$$

Therefore, the formula can be simplified as follows:

$$QC=\rho\cdot(\overline{W'\cdot C'}).$$

[mg/m^2s] [mg/ml] [ml/m^3] [m/s]

Thus, methane flux can be calculated from the methane concentration, the deviation of vertical wind, and the atmospheric density at any time. The atmospheric density is given by ρ = y/0.082 (273+x). Here, y is the molecular weight of methane (16), and x is air temperature.

This measurement method is called the eddy correlation method and has the preferred characteristics because the dynamics of greenhouse gases above the crop canopy can be observed directly under natural conditions.

Results and Discussion

The peak of methane flux from rice canopy

Methane concentration was only observed for 2 days due to a typhoon, which narrowly missed the island. Before the typhoon, it was possible to measure methane concentrations, which were higher at night than in the day (Fig.1). The peak

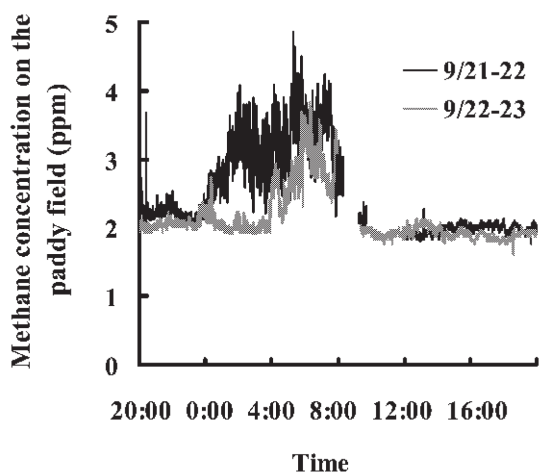

Fig 1. Methane profile on the paddy field in Hainan Island.

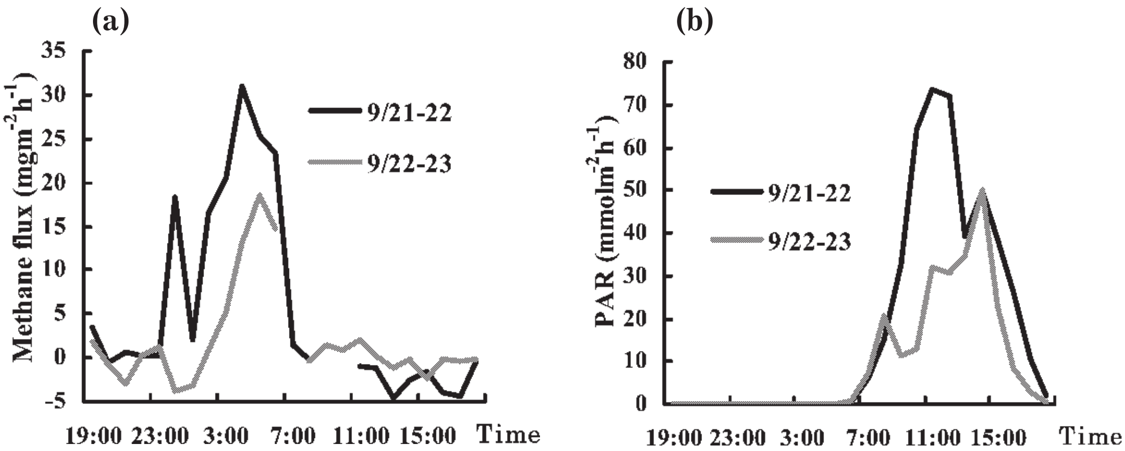

Fig 2. Diel change of (a) methane flux (b) PAR.

level of methane concentration was about 2 times higher compared to the data obtained by Yoshikawa *et al.* (2006) on the highland of Nagano in Japan. The diel oscillation pattern was similar to the data obtained in Japan.

Fig.2 (a) shows the diel variation of CH_4 flux during the observation period. The CH_4 flux peaked at predawn and decreased rapidly after sunrise. In an earlier study using a chamber method, Seiler *et al.* (1984) observed a peak of CH_4 flux during daytime. On the other hand, Minami and Yagi (1988) reported that there seemed to be no peak of CH_4 flux in diel variation when using a closed chamber for observation. In contrast to their results, we observed an obvious peak of methane flux at predawn on the open field. In closed system observations, rice plants were covered with chambers for 30-60 min in the former study and for 20 min in the latter. Therefore, the photosynthetic rate of the rice plants would be influenced by the chambers that shut off the wind. In addition, microbial activity would be increased because of the rapid temperature elevation. In other words, temperature elevation in the chamber might activate CH_4 producing anaerobic bacteria. In fact, the environment inside the chamber during measurement was considered to be different from the outside environment. As mentioned above, the difference of measurement environments is responsible for the difference between the present and previous results.

Effect of photosynthesis on methane flux

Fig.2 (b) shows the diel variation of photosynthetic active radiation (PAR). It was shown that CH_4 flux decreased rapidly as PAR increased after sunrise (Fig. 2 (a) (b)). The oxygen concentration in the rice plant body increased with photosynthesis after sunrise. The increase in oxygen concentration would generate a concentration gradient between plant body and rhizosphere. Then, a supply of oxygen from the plant top to the rhizosphere would occur, thus increasing the oxygen concentration in the rhizosphere. In short, an oxygen-rich condition in the rhizosphere developed by photosynthesis produced the above-mentioned result.

Holzapfel-Pschorn et al. (1986) reported that up to 80% of the methane produced was oxidized. Methane oxidation is a significant sink of produced methane. Holzapfel-Pschorn *et al.* (1985) also reported that some of the methane is

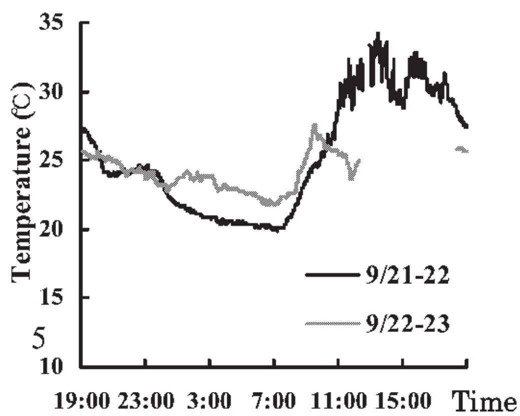

Fig 3. Diel variation of air temperature.

oxidized through the oxidized zone surrounding the rice roots. The rhizosphere is one of the locations where methane oxidation occurs. Oxygen supply to the paddy soil relating to photosynthesis appeared to induce methane oxidation in rhizosphere.

At the same time, the activity of CH_4 producing anaerobic bacteria (methanogens) is considered to decrease if oxygen concentration in rhizosphere increases, which would restrain the methane production.

Both of these factors may inhibit methane flux during daytime. In this regard, however, the data base is so limited at present that we cannot be conclusive. From current results, a low level of methane flux during daytime is assumed to be due to photosynthesis of rice plants. These results may contribute to the development of new rice breeding objectives for the mitigation of global warming.

Temperature factor

The diel variation is shown in Fig.3. It is clear that the temperature rises during daytime. It has been reported that the methane flux is correlated with soil temperature at 5 cm depth (Holzapfel-Pschorn and Seiler, 1986 ; Schütz *et al*., 1990). In general, air and soil temperatures have a similar pattern of diel variation. Therefore, the present result does not agree with the previous reports. From the present result, it was clarified that there is no distinct correlation between methane flux and soil temperature.

Comparison of observation sites

Yoshikawa *et al*. (2006) observed methane flux using the same measurement method in a mountainous area of central Japan in August 2006. The diel oscillation pattern of methane flux at that time was similar to that observed in the present study. The peak of methane flux was obtained from late night to predawn.

Comparison with other previous studies

Various studies have been conducted to clarify the predominant factor of diel oscillation of methane flux. Wassmann and Aulakh (2000) reported that methane production in rice fields largely depends on root exudates. If there is a diurnal fluctuation in the rate of root exudates, the diel pattern is expected to be the highest during daytime due to the increased activity of the plants. Our current results do not agree with theirs.

In addition, Frenzel *et al*., (1992) reported that the photosynthesis of rice plants had no effect on methane emission. They conducted their experiment using a microcosm and planted rice seedlings into the microcosm (a small box) with extremely higher plant density and poor nutrient conditions. Therefore, the data was measured under conditions far from actual paddy fields, which might reduce the influence of rice plants on the soil environment. Differences in plant canopy size, population size, and measurement systems are responsible for the difference between the present and previous results.

Conclusions

(1) The methane flux peaked at predawn in this study, which is different from the previous studies that either obtained the peak during daytime or obtained no peak.

(2) The pattern of diel variation of methane flux was similar to that observed at a paddy field in highland of Japan in August 2006.

(3) The methane flux seemed to relate to rice photosynthesis. Oxygen supply to the paddy soil relative to photosynthesis appeared to facilitate methane oxidation in the rhizosphere and inhibit the activity of CH_4 producing anaerobic bacteria. Both the reasons suggest that the methane flux would be inhibited during daytime.

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