Seasonal Change of Rice-mediated Methane Emission from a Rice Paddy under Different Water Management and Organic Amendments

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Methane emission was measured in a rice paddy under different water management and organic amendments. Methane emission from planted chambers and unplanted chambers was monitored to evaluate the rice-mediated methane emission. In flooding methane emission from planted chambers with NPK, NPK(+P), was 0.174 g CH₄ m⁻² d⁻¹, while that from unplanted chambers with NPK, NPK(-P), was 0.046 g CH₄ m⁻² d⁻¹. Methane emission from planted chambers with rice straw compost amendment, RSC(+P), was 0.214 g CH₄ m⁻² d⁻¹, while that from unplanted chambers with rice straw compost amendment, RSC(-P), was 0.076 g CH₄ m⁻² d⁻¹. Methane emission from planted chambers with rice straw amendment in February, RS2(+P), was 0.328 g CH₄ m⁻² d⁻¹, while that from unplanted chambers with rice straw amendment in February, RS2(-P), was 0.1 g CH₄ m⁻² d⁻¹. Methane emission from planted chambers with rice straw amendment in May, RS5(+P), was 0.414 g CH₄ m⁻² d⁻¹, while that from unplanted chambers with rice straw amendment in May, RS5(-P), was 0.187 g CH₄ m⁻² d⁻¹. In intermittent irrigation methane emission from NPK(+P) was 0.115 g CH₄ m⁻² d⁻¹, while that from NPK(-P) was 0.041 g CH₄ m⁻² d⁻¹. Methane emission from RSC(+P) was 0.137 g CH₄ m⁻² d⁻¹, while that from RSC(-P) was 0.06 g CH₄ m⁻² d⁻¹. Methane emission from RS2(+P) was 0.204 g CH₄ m⁻² d⁻¹, while that from RS2(-P) was 0.09 g CH₄ m⁻² d⁻¹. Methane emission from RS5(+P) was 0.273 g CH₄ m⁻² d⁻¹, while that from RS5(-P) was 0.13 g CH₄ m⁻² d⁻¹. Methane transport via rice plant under flooding for NPK plot, RSC plot, RS2 plot and RS5 plot was 73.6%, 64.5%, 69.5% and 54.8%, respectively, and mean was 65.6%. Methane transport via rice plants under intermittent irrigation for NPK plot, RSC plot, RS2 plot and RS5 plot was 64.3%, 59.2%, 55.9% and 52.4%, respectively, and mean was 58.0%.

Key Words: Water management, Organic amendments, Methane, Rice paddy.

Introduction

Methane is an important greenhouse gas and it affects the chemistry and oxidation capacity of the atmosphere (Bolle et al., 1986; Rasmussen and Khalil, 1986; Thompson and Cicerone, 1986). Rice fields are one of the major atmospheric CH₄ sources (Cicerone and Shetter, 1981; Wassmann et al., 1998). Rice plants are actively implicated in CH₄ production, oxidation
and transport (Seiler et al., 1984; Holzapfel-Pschorr et al., 1985; Schutz et al., 1989; Neue et al., 1997). It is imperative to evaluate the contribution of rice plant on transport of methane gas to the atmosphere. There have been several researches on CH$_4$ emission from Korean rice field; water management and organic amendments (Shin et al., 1996) and rice cultivars (Shin and Yun, 2000). However, the role of rice plant in transporting methane from soil to the atmosphere had not been studied in Korea.

The objectives of this study were to characterize and quantify the rice-mediated methane emission under different water management and organic amendments during cropping season of rice.

**Materials and Methods**

Two chambers in duplicates, one with rice and the other without rice plant, were used to evaluate the effects of rice plants on methane emission to atmosphere during the entire growth of rice under different water management and organic amendments.

**Cultivation of rice**  Rice cultivar Ilpoombyeo (Oryza sativa L. japonica type) was cultivated on three plots at Suwon in 1994: (i) Nitrogen-Phosphorus-Potassium (NPK) (N-P$_2$O$_5$-K$_2$O = 110-70-80 kg ha$^{-1}$); (ii) NPK plus rice straw (5 Mg ha$^{-1}$); and (iii) NPK plus rice straw compost (10 Mg ha$^{-1}$) (RSC). Rice straw was incorporated at two different times, on February (RS2) and on May (RS5), to study the effect of early application of rice straw on methane emission. The paddy field belongs to the Hwadong series - a fine clayey, mixed, mesic family of Aquic Hapludalfs. The soil pH was 5.9, content of soil organic matter was 10 g kg$^{-1}$, content of available phosphorus 20 mg kg$^{-1}$, and content of exchangeable potassium 0.26 cmol kg$^{-1}$.

Rice seedlings were transplanted on 23 May, 1994. The planting density was 15 x 30 cm. Water in the experimental plots was managed by flooding and intermittent irrigation. For both water management all plots were flooded until 30 days after transplanting. Thereafter, in flooding plots the paddy was flooded until two weeks before harvest; in intermittent irrigation plots remained without any irrigation until small cracks were noticed in the soil surface and then flooded.

The fresh rice straw incorporated contained 0.5% of total nitrogen and 35.3% of total carbon, resulting in a 66.6 C/N ratio; these quantities for the rice straw compost were 1.69, 29.6 and 17.5%, respectively. Basal dressing occurred just before transplanting and top dressings occurred on June 9 and July 26.

**Analytical techniques**  Gas samples were collected by using the closed static chamber method (Shin et al., 1995; Shin et al., 1996) in which eight rice plants were enclosed in a transparent polycarbonate plastic chamber with inner dimensions of 60 x 60 x 100 cm. Two chambers were installed in each experimental plot (area was 41 m$^2$). Gas samples were collected from 9 a.m. till noon once a week from 31 May through 11 October. Gas samples were collected in a 60 ml polypropylene syringe fitted with a Mininert valve. The samples were analyzed for CH$_4$ by using gas chromatograph (Varian Star 3400, USA) equipped with an FID. The analysis column used was a stainless steel column (0.3 cm x 2 m) packed with Porapak N (80/100 mesh). The temperatures of the column, injector, and detector were 45, 70 and 120°C, respectively.

**Calculation of methane flux**  Flux (F = mg or $ug$ m$^{-2}$ hr$^{-1}$) was calculated:

$$F = \rho \cdot \frac{V/A}{(H)} \cdot \frac{\Delta c}{\Delta t} \cdot 273/T$$  (1)
\[ \rho = \text{gas density (CH}_4 = 0.714 \) } \\
V = \text{volume of the chamber (m}^3) \\
A = \text{area of the chamber (m}^2) \\
H = \text{height of the chamber (m)} \\
\Delta c / \Delta t = \text{average increase of gas concentration in the chamber} \\
T = 273 + \text{mean temperature in chamber (°C)}

**Results and Discussion**

**Rice-mediated methane emission under flooding**  Methane emission from flooding with or without rice plants was measured in flooding conditions. Methane emission in NPK plot ranged from -0.15 to 12.95 mg CH\(_4\) m\(^{-2}\) h\(^{-1}\) for planted chambers and ranged from -0.06 to 5.16 mg CH\(_4\) m\(^{-2}\) h\(^{-1}\) for unplanted chambers. Daily methane emission was 0.174 g CH\(_4\) m\(^{-2}\) d\(^{-1}\) for planted chambers, while that was 0.046 g CH\(_4\) m\(^{-2}\) d\(^{-1}\) for unplanted chambers; methane emission through rice plant was calculated to 73.6% (Fig. 1).

Methane emission in rice straw compost (RSC) plot was in the range of -0.04 to 15.02 mg CH\(_4\) m\(^{-2}\) h\(^{-1}\) for planted chambers and in the range of -0.10 to 8.52 mg CH\(_4\) m\(^{-2}\) h\(^{-1}\) for unplanted chambers. Daily methane emission was 0.214 g CH\(_4\) m\(^{-2}\) d\(^{-1}\) for planted chambers, while that was 0.076 g CH\(_4\) m\(^{-2}\) d\(^{-1}\) for unplanted chambers; methane emission through rice plant was calculated to 64.5%.

Methane emission in RS2 plot was in the range of 0.01 to 30.1 mg CH\(_4\) m\(^{-2}\) h\(^{-1}\) for planted chambers and in the range of 0.05-11.80 mg CH\(_4\) m\(^{-2}\) h\(^{-1}\) for unplanted chambers. Daily methane emission was 0.328 g CH\(_4\) m\(^{-2}\) d\(^{-1}\) for planted chambers, while that was 0.1 g CH\(_4\) m\(^{-2}\) d\(^{-1}\) for unplanted chambers. Based on the investigated results, methane emission through rice plant was calculated to 69.5% (Fig. 2).

Methane emission in RS5 plot was in the range of - 0.05 to 42.37 mg CH\(_4\) m\(^{-2}\) h\(^{-1}\) for planted chambers and in the range of 0.02 to 20.56 mg CH\(_4\) m\(^{-2}\) h\(^{-1}\) for unplanted chambers. Daily methane emission was 0414 g CH\(_4\) m\(^{-2}\) d\(^{-1}\) for planted chambers, while that was 0.273 g CH\(_4\) m\(^{-2}\) d\(^{-1}\) for unplanted chambers; methane emission

![Graph showing seasonal changes of methane emissions from flooded paddy field with rice plant (+P) or without rice plant (-P) in both plots of NPK and RSC.](image-url)
through rice plant was 54.8%. For flooding proportion of methane emission through rice plant was highest in NPK plot (73.6%), while lowest in RS5 plot (54.8%).

**Rice-mediated methane emission under intermittent irrigation**  Methane emission from intermittent irrigation with or without rice plants was measured. Methane emission in NPK plot was in the range of -0.04 to 11.29 mg CH$_4$ m$^{-2}$ h$^{-1}$ for planted chambers and in the range of 0.04 to 3.99 mg CH$_4$ m$^{-2}$ h$^{-1}$ for unplanted chambers. Daily methane emission was 0.115 g CH$_4$ m$^{-2}$ d$^{-1}$ for planted chambers, while that was 0.041 g CH$_4$ m$^{-2}$ d$^{-1}$ for unplanted chambers; methane emission through rice plant was 64.3% (Fig. 3). Methane emission in RSC plot was in the range of -0.05 to 12.53 mg CH$_4$ m$^{-2}$ h$^{-1}$ for planted chambers and in the range of -0.13 to 5.86 mg CH$_4$ m$^{-2}$ h$^{-1}$ for unplanted chambers. Daily methane emission was 0.137 g CH$_4$ m$^{-2}$ d$^{-1}$ for planted chambers, while that was 0.06 g CH$_4$ m$^{-2}$ d$^{-1}$ for unplanted chambers; methane emission through rice plant was 59.2%. Methane emission through rice plant in NPK plot and RSC plot showed lower proportion in early stage of rice growth, while higher proportion in later stage of growth period when rice growth was vigorous.

Methane emission in RS2 plot was in the range of 0.004 to 16.69 mg CH$_4$ m$^{-2}$ h$^{-1}$ for planted chambers and in the range of -0.09 to 9.97 mg CH$_4$ m$^{-2}$ h$^{-1}$ for unplanted chambers (Fig. 4). Daily methane emission was 0.204 g CH$_4$ m$^{-2}$ d$^{-1}$ for planted chambers, while that was 0.09 g CH$_4$ m$^{-2}$ d$^{-1}$ for unplanted chambers; proportion of methane emission through rice plant was 55.9%. Methane emission in RS5 plot was in the range of -0.09 to 28.53 mg CH$_4$ m$^{-2}$ h$^{-1}$ for planted chambers and in the range of -0.09 to 16.71 mg CH$_4$ m$^{-2}$ h$^{-1}$ for unplanted chambers. Daily methane emission was 0.273 g CH$_4$ m$^{-2}$ d$^{-1}$ for planted chambers, while that was 0.13 g CH$_4$ m$^{-2}$ d$^{-1}$ for unplanted chambers; methane emission through rice plant was calculated to 52.4%. For intermittent
irrigation proportion of methane emission through rice plant was highest in NPK plot (64.3%), while lowest in RS5 plot (52.4%).

Mean methane flux during growing season of rice could be summarized as in Fig. 5. In general methane emission between flooding and intermittent irrigation showed little difference mostly when rice was not planted, while difference of methane emission was great when rice was planted.

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In general methane emission between flooding and intermittent irrigation showed little difference mostly when rice was not planted, while difference of methane emission was great when rice was planted.

Proportion of rice-mediated methane emission could be compiled as in Fig. 6. In flooding mediation effect for NPK plot, RSC plot, RS2 plot, RS5 plot was 73.6%, 64.5 %, 69.5% and 54.8%, respectively. In intermittent irrigation mediation effect for NPK plot, RSC plot, RS2 plot, RS5 plot was 64.3%, 59.2%, 55.9% and 52.4%, respectively.

An experiment in Taiwan showed methane emission from rice-planted soil was 0.73-15.69 mg CH₄ m⁻² d⁻¹, while that from unplanted soil was 0.11-1.45 mg CH₄ m⁻² d⁻¹ (Huang, 1991). Another experiment held in Japan estimated the emission of methane through rice plant to atmosphere in pots packed with several Japanese soils (Inubushi et al., 1989). Pots packed with Konosu soil (gley lowland soil) of LiC soil texture showed emission between 0.16 and 15.8 mg C m⁻² h⁻¹ from planted pots and that between 0.017 and 0.168 mg C m⁻² h⁻¹ from unplanted pots; plant-mediated methane emission was calculated to 98.8%. Pots packed with Ayama soil (Gley soil) of HC soil texture showed emission between 1.94 and 22.7 mg C m⁻² h⁻¹ from planted pots and that between 0.23 and 5.09 mg C m⁻² h⁻¹ from unplanted pots; plant-mediated methane emission was 85.0%. Pots packed with Ichishi soil (Gley
lowland soil) of SL soil texture showed emission between 0.52 and 3.3 mg C m$^{-2}$ h$^{-1}$ from planted pots and that between 0.33 and 0.39 mg C m$^{-2}$ h$^{-1}$ from unplanted pots; plant-mediated methane emission was 51.1%. These results suggested that plant-mediated methane differed by soil types. Another Japanese experiment showed rice-mediated methane emission was 98% in Gley lowland soil, while 70% in Andosol soil (Minami et al., 1988). An experiment in the USA studied the effect of fertilization on the emission of N$_2$, nitrous oxide and methane from Crowley silty loam soil in Louisiana, USA (Lindau et al., 1990). Maximum emission of methane under urea fertilization was 75 g CH$_4$ ha$^{-1}$ d$^{-1}$ for planted paddy, while 22 g CH$_4$ ha$^{-1}$ d$^{-1}$ for unplanted paddy; rice-mediated methane emission was calculated to 70.7%. Maximum emission of methane under ammonium sulfate fertilization was 8.5 g CH$_4$ ha$^{-1}$ d$^{-1}$ for planted paddy, while 5.3 g CH$_4$ ha$^{-1}$ d$^{-1}$ for unplanted paddy; rice-mediated methane emission was 37.6%.

Maximum emission of methane under potassium nitrate fertilization was 17.9 CH$_4$ ha$^{-1}$ d$^{-1}$ for planted paddy, while 15.4 g CH$_4$ ha$^{-1}$ d$^{-1}$ for unplanted paddy; rice-mediated methane emission was 13.9%. This shows methane emission through rice could be affected by the types of fertilizer used. 49% to 64% of total methane emission was ascribed to ebullition (Bartlett et al., 1988). A study in a Italian paddy investigated the effect of vegetation on methane emission (Holzapfel-Pschorr et al., 1986). Methane emission from unplanted paddy was mainly via ebullition, while more than 90% of methane emission from planted paddy was made through rice body. Though rice promotes the production of methane in the flooded soils, it also stimulates the methane oxidation in the root zone resulted in low methane emission out of methane production; 23%. Methane emission from unplanted paddy corresponded to about 50% of that from planted paddy and methane emission from unplanted paddy was made through
seasonal change of rice-mediated methane emission

Fig. 5. Mean methane flux during growing season of rice under different water management and organic amendments.

Ebullition (Schutz et al., 1989).

Methane ebullition was important in early flooded period (June to July) when rice plant was small, but vascular bundle transport became important as rice grew (August to October) (Takai and Wada, 1990). Methane emission from paddies in Zhejiang Province in China was reported that methane emission through rice plant

Fig. 6. Proportion of rice-mediated methane emission in different water management and organic amendments.
corresponded to more than 85% of total methane emission (Min et al., 1993). It has become clear that methane emission from paddies were affected by the presence of rice plants, soil type, types of nitrogen fertilizers, and also as in this experiment by water management, types and timing of organic amendments.

References


물 관리와 유기물 시용이 다른 논의에서 벼 식물체를 통한 메탄 배출의 계절변화

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물 관리와 유기물 시용이 다른 논의에서 메탄 배출을 측정하였다. 벼 식물체를 통해 배출되는 메탄을 측정하기 위하여 벼를 심은 chamber와 심지 않은 chamber를 반복으로 포장에 설치하였다. 기체사료는 벼 재배기간중 주 1회 체취하였다. 상시담수에서는 벼를 심은 NPK구, NPK(+P),는 0.174 g CH₄ m⁻² d⁻¹의 배출을 보였으나 심지 않은 NPK구, NPK(-P),는 0.046 g CH₄ m⁻² d⁻¹의 배출을 보였다. 벼를 심은 벼밀퇴비 시험구, RSC(+P),는 0.214 g CH₄ m⁻² d⁻¹의 배출을 보였으나 심지 않은 벼밀퇴비 시험구, RSC(-P),는 0.076 g CH₄ m⁻² d⁻¹의 배출을 보였다. 벼밀을 2월에 시용하고 벼를 심은 시험구, RS2(+P),는 0.328 g CH₄ m⁻² d⁻¹의 배출을 보였으나 벼밀을 2월에 시용하고 벼를 심지 않은 시험구, RS2(-P),는 0.1 g CH₄ m⁻² d⁻¹의 배출을 보였다. 벼밀을 5월에 시용하고 벼를 심은 시험구, RS5(+P),는 0.414 g CH₄ m⁻² d⁻¹의 배출을 보였으나 벼밀을 2월에 시용하고 벼를 심지 않은 시험구, RS5(-P),는 0.187 g CH₄ m⁻² d⁻¹의 배출을 보였다. 간단관계에서는 NPK(+P)는 0.115 g CH₄ m⁻² d⁻¹의 배출을 보였으나 NPK(-P)는 0.041 g CH₄ m⁻² d⁻¹의 배출을 보였다. RSC(+P)는 0.137 g CH₄ m⁻² d⁻¹의 배출을 보였으나 RSC(-P)는 0.06 g CH₄ m⁻² d⁻¹의 배출을 보였다. RS2(+P)는 0.204 g CH₄ m⁻² d⁻¹의 배출을 보였으나 RS2(-P)는 0.09 g CH₄ m⁻² d⁻¹의 배출을 보였다. RS2(+P)는 0.273 g CH₄ m⁻² d⁻¹의 배출을 보였으나 RS5(-P)는 0.13 g CH₄ m⁻² d⁻¹의 배출을 보였다. 상시담수 처리에서 벼 식물체를 통한 메탄 수송은 NPK구, RSC구 (벼밀퇴비를 5월에 시용한 구), RS2구(벼밀을 2월에 시용한 구)와 RS5구 (벼밀을 5월에 시용한 구)에서 각각 73.6 %, 61.5%, 69.5%, 54.8%였고 평균 65.6%였었다. 간단관계처리에서 벼 식물체를 통한 메탄 수송은 NPK구, RSC구, RS2구와 RS5구에서 각각 64.3, 59.2, 55.9, 52.4였다.