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Understanding and predicting the impacts of elevated CO_2 atmospheric and increased temperature on methane emission from the paddy soil
(Abstract of the Interim Report)

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1. Introduction

Currently, about a half of the world's population depend their diet on rice, which is mostly produced in the rice paddy fields. As the rice-consuming population is projected to increase, the role of paddy fields in the food supply will become more important in the future. On the other hand, rice agriculture is one of the main sources of the potent green-house gas, methane: Its concentration has increased substantially by 2.5 times from the pre-industrial level. Although the concentration has become stagnant since 1990, the future course is uncertain and the need to mitigate emissions from the anthropogenic sources will remain in the future.

One of the uncertainties about the methane emission from the paddy under future climates is that the global warming itself will promote methanogenesis and methane emission. Recently the increase in atmospheric carbon dioxide concentration also stimulates the methane emission from the paddy soils. One mechanism of the feedback effect of elevated CO_2 concentration ([CO_2]) on methane emission is that increased photosynthesis of the crop supplies carbon from the roots to the soil, which in turn is used for the substrate for carbon reduction and methane production under anaerobic conditions. The other mechanism is that elevated [CO_2] increases tiller and root number, the major pathway of methane from the soil to the atmosphere. This will reduce the methane resistance through the rice plants. However, a huge uncertainty exists about the magnitude of the effect of elevated [CO_2] on the methane emission: the reported enhancement being from 20 % to 600 %. The large variation in the reported figure in the methane emission derives largely from the different experimental settings and environmental conditions; Temperature can change the relative enhancement of methane emission due to elevated [CO_2] [1, 5].

A number of factors other than temperature can be involved in the response of methane emission to and elevated [CO_2]: They include cultivars, soil types, water, nitrogen and residue management. To identify possible involvement of these factors efficiently, we need three elements; (1) Well-focused experiments to test temperature and/or [CO_2], (2) quantitative reviews on the effect, (3) a good mechanistic model that can allow us to test agronomic management, soil properties. Quantitative understandings of the mechanisms for this interaction are highly important so as to reduce uncertainties in the future methane emission prediction and to develop mitigation measures.

2. Research Objectives and Methods

The objective of this study is to improve our quantitative understandings of the effects of global warming and elevated [CO_2] on the methane emission from the paddy soils and to determine the magnitude of the effect under various soil, management and climatic conditions. For this purpose, we have three strategies: (1) To determine general responses of methane emission to the environments, we use a quantitative literature review method called "meta-analysis" based on the response ratio of elevated CO_2. (2) To better understand the mechanism of temperature and CO_2 effects on methane emission and to test interaction between CO_2 and temperature or genotypes in terms of methane emission, we conducted our chamber and open-air experiments under elevated [CO_2] and warming conditions and compare the results with those under ambient (or control) conditions for two years. (3) We also conducted a free-air CO_2 enrichment (FACE) and soil/water warming experiment in the open field in Shizukuikshi, Japan in 2007 and 2008. This rice FACE system uses a pure CO_2 injection system without a blower[4)] and controls [CO_2] in the octagonal shaped area 12m across by 200 ppm above the ambient concentration. Within each [CO_2] treatment (both FACE and ambient plots), we installed silicone heater cables in a 5.5 x 2.7 m-area enclosed with a PVC boarding to raise water/soil surface temperature by 2^{o}C. We measured methane flux by the chamber method every week. measured methane flux by the chamber method. (3) We tested if the mechanistic biogeochemistry model, DNDC (DeNitrification and DeCompostion model)[2,3)] can reproduce the course methane flux under different [CO_2] and water/soil temperatures in the FACE/water warming experiments.

3. Results

(1) Meta-analysis on the effect of the elevated [CO_2] on methane emission

We collected 21 datasets of methane emissions collected under both ambient and elevated [CO_2] conditions (200-300 ppm above the ambient). The overall average response of methane emission to elevated [CO_2] was 51 % (the 95 % confidence interval

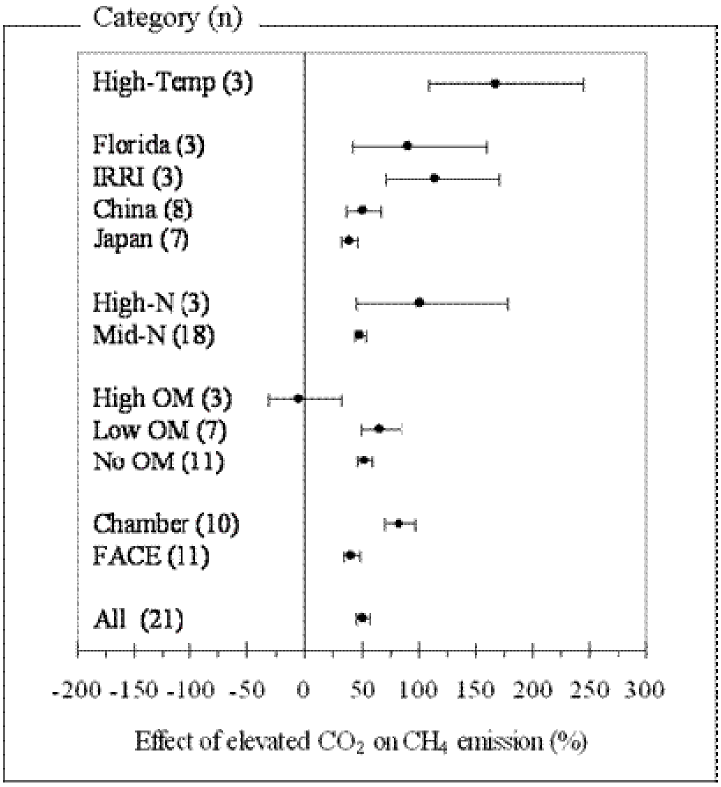

Figure 1. Effects of elevated [CO_2] on methane emission estimated from various experiments conducted under either growth chamber or free-air CO_2 enrichment (FACE). N stands for the level of nitrogen application, and OM for organic matter or residue input levels. We used the response ratio to determine the effect size, using Meta-Win ver 2.0.

between 45 and 57 %). The high temperature and high N treatments resulted in a larger response whereas the high organic matter input showed virtually no response to elevated [CO_2]. This is largely due to the fact that the large amount of carbon was supplied from the organic matter application for as a methane substrate. Another interesting feature of this meta-analysis is to compare two different CO_2 enrichment methods; FACE vs chamber. The average response of the chamber in this study was substantially larger than in the FACE, but if the high temperature data are excluded from the chamber group, average response of chamber drops to 48 %, which was comparable with that of FACE.

(2)Experimental determination of the interaction between CO_2 and other factors
A. Genotypic response
We conducted our chamber experiments to determine varietal difference in the response of methane emission to elevated [CO_2] using varieties of various origins. A two-fold difference was observed for the total methane emission amongst the varieties tested: Two indica varieties showed substantially higher methane emission than did Koshihikari. Root weights and root number seem to be responsible for the genotypic difference.
Elevated [CO_2] had a positive effect on the methane emission but to a different degree depending on the variety. The difference largely stemmed from the growth response to elevated [CO_2]. These findings will be useful to incorporate varietal traits for the methane emission models.

B. Nocturnal warming
A few previous experiments have tested if CO_2 and temperature effects on methane emission from the rice paddy (Ziska et al 1998; Allen et al 2003), where they raised both day-time and night-time temperatures. Uncertainties exist if maximum and minimum temperatures increase at different rates or not, but for the past 100 year, nocturnal temperature rose faster than the day-time. It is worth testing if the nocturnal warming effect on methane emission can be simply estimated from the standard temperature function. We therefore conducted our chamber experiments with the constant day-night temperature at 32oC in comparison with 32/22 ^{o}C temperature affects the methane emission in combination with two levels of [CO_2]. The constant day –night temperature treatment at 32 ^{o}C resulted in a smaller enhancement of methane emission due t o elevated [CO_2]. Interestingly, the high night temperature treatment had a constant temperature for all day (at 32^{o}C) but showed diurnal variation in methane emission. The reason for this is not clear but this suggests that a simple temperature function for methane emission does not work for a constant temperature regime, which needs further attention.

C. Free-air CO_2 enrichment (FACE) and soil/water warming effects

The effect of the treatments on the cumulative CH_4 emission for the entire cropping season was 40-48% for warming and 22-29% for FACE (Table 1), based on the two-year FACE and warming experiments at Shizukuishi. We did not observe a significant interaction between temperature and [CO_2] treatments. The substantial increase in methane emission under elevated soil/water temperature was due to increased biomass production, increased carbon supply to the soil and accelerated soil chemical metabolism. The temperature dependence an increase in methane flux amounts to about 50 % with a 2 ^{o}C increase in water temperature converts to a Q_{10} (the response ratio of the rates when the temperature increased by 10 ^{o}C) of 7, which is substantially higher than what is commonly observed for the kinetics of biological processes.

As in the chamber studies, a total methane emission was correlated with rice biomass production, but the regression lines differed between ET, suggesting that both plant responses and soil responses to temperatures have significant contribution to methane emission from the paddy soils.

Table 1. The effects of FACE and soil/water warming on CH_4 emission from the paddy soil for the whole growing season (gC m^{-2}) . The average of two growing seasons.

Treatment	Ambient CO_2 (	Elevated CO_2 (FACE)	FACE/Amb (P = 0.19)
Normal temperature (NT)	11.3	13.8	22%
Elevated temperature (ET)	15.8	20.4	29%
ET/NT P < 0.001	40%	48%	

(3) Testing with the DNDC-Rice model

The DNDC model revised for submerged paddy soil conditions (DNDC-Rice) was tested against carbon decomposition of various soil types in the incubation studies. We also applied this model to the field level studies under two different FACE sites in Japan and China to better understand the methane emission under diverse conditions. The model accounted for well the soil carbon decomposition for different soil types obtained from the soil incubation experiments. The model also reproduced well the difference in methane emission due to organic matter (wheat straw) application, fertilizer application in Wuxi, Jiangsu Province, China. This suggests that DNDC-Rice model can serve as a useful to evaluate mitigation options for rice cultivation.

DNDC-Rice also simulated increases in methane production under elevated CO_2 and elevated temperature conditions, but underestimated their magnitudes. The model includes basic functions for photosynthetic enhancement due to elevated CO_2, temperature functions for carbon metabolisms, but failed to account for the observed level of methane emission under high [CO_2] and temperature. The model failed to reproduce biomass enhancement due to elevated temperature, enhanced carbon supply to the roots, higher rate of root turnover that may become substrate for methane emission, which should not be overlooked for the future climate projection.

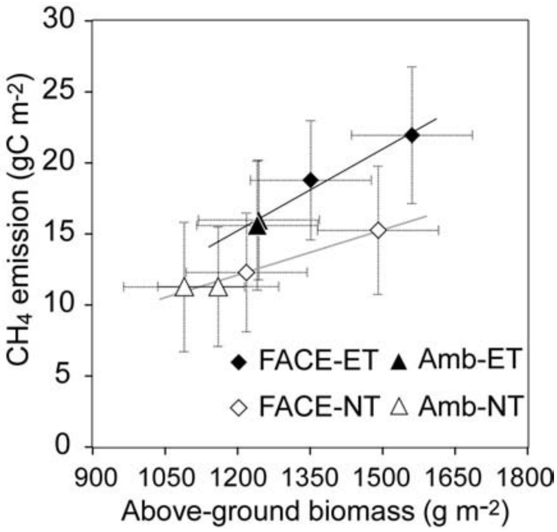

Figure 3. The relationship between methane emission and above-ground biomass at Shizukuishi FACE & wariming experimental plots in 2007 & 2008. For legends, see table 1.

4. Discussion

A large uncertainty still exits for the methane emission estimates from the paddy fields. The major reason for this

is that a series of processes from organic matter decomposition to methane transport to the atmosphere are under strong influences of multiple environmental factors; A slight change in one factor can affect overall quantity of methane emission.
Therefore a huge range in the magnitude of the elevated [CO_2] effect on the methane emission can result. The present meta-analysis is to our knowledge the first report showing the "average response" of 51 % over a range of experimental conditions. We believe this can be the simplest estimate of the climate change feedback effect.

The experiment using the FACE/soil warming system is the first attempt to determine methane emission under likely future climates in the open field. A substantial enhancement was recorded by the 2 ^{o}C increase in water temperature. This high temperature dependence, equivalent to a Q_{10} of 7, is substantially larger than what is commonly observed for kinetics of biological processes and/or enzyme-related chemical reaction. Our analysis on the electron transport in the soil indicated that soil warming increased the rate of organic matter decomposition, which provides electron donor and is a major driver for the accelerated methane emission in the first half of the growth. For accelerated methane emission in the second half, however, soil warming increased rates of root exudates and root turnover in addition to the accelerated carbon decomposition should have been involved.

We confirmed that the DNDC-rice model can be an excellent tool to evaluate mitigation options for mitigation options, but failed to simulate the magnitude of the observed effects of elevated temperature and [CO_2]. The present study revealed that the impact of carbon flow from the above ground to the below ground is somewhat overlooked to predict the future methane emission from the wet land surface. We also need further experimental evidence for the longer term response to environmental changes to extrapolate our experimental results to the future events.

Reference

Allen LH Jr, Albrecht SL, Colon-Guasp W, Covell WSA, Baker JT, Pan D, Boote KJ. 2003. Methane emissions of rice increased by elevated carbon dioxide and temperature. Journal Environmental Quality, 32: 1978–1991

Ziska LH, Moya TB, Wassmann R, Namuco OS, Lantin RS, Aduna JB, Abao Jr E, Bronson KF, Neue HU, Olzyk D. 1998. Long-term growth at elevated carbon dioxide stimulates methane emission in tropical paddy rice. Global Change Biology, 4:657-665.