Effect of elevated CO₂ on CH₄ emission

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Abstract Global CH₄ emission may increase under CO₂ enrichment condition, which is projected for the future. CO₂ enrichment could affect CH₄ emission in two ways: (i) Photosynthesis of plants that also include plants in rice paddies and natural wetlands will be stimulated under CO₂ enrichment condition. CH₄ emission rate may be increased due to the accumulation of more plant biomass, root exudes and soil organic matters. (ii) Combined with other global warming forces, CO₂ enrichment may bring a change of atmospheric temperature and precipitation around the world. CH₄ emission will also be changed with the variation of the area and distribution of rice paddies and natural wetlands.

Keywords: global change, CO₂ enrichment, CH₄ emission.

THE concentrations of major greenhouse gases in atmosphere, such as CO₂ and CH₄, have been increasing quickly because of the industrial revolution mainly due to human activities. The atmospheric CO₂ and CH₄ concentrations have reached 355 and 1.72 $\mu\text{mol} \cdot \text{mol}^{-1}$ at present, starting out at levels about 280 and 0.6—0.8 $\mu\text{mol} \cdot \text{mol}^{-1}$ respectively in the pre-industrialization period. Researches predict that the atmospheric concentrations of CO₂ and CH₄ will be about 650—700 and 3.54 $\mu\text{mol} \cdot \text{mol}^{-1}$ respectively by the end of the 21st century^[1, 2].

CH₄ is an important greenhouse gas. Although CH₄ concentration is only 1.72 $\mu\text{mol} \cdot \text{mol}^{-1}$ at present, its greenhouse effect is about 20 times higher than that of CO₂^[3]. It contributes 20% to global warming, while CO₂ 50%^[4]. CH₄ sources include natural and anthropogenic sources. Rice paddies and natural wetlands are two major natural sources for CH₄ emission. Wang *et al.*^[5] pointed out that the amount of CH₄ emission from rice paddy accounts for 50% and natural wetland for 6.3% of the total CH₄ budget in China. Within the total world CH₄ budget, about 40% of CH₄ is released from rice paddies and natural wetlands^[6, 7]. Therefore, it is important to study the CH₄ emission pattern and flux from rice paddies and wetlands under global change scenarios, especially for prediction of future CH₄ concentration in the atmosphere.

CH₄ source-sink dynamic, seasonal and diurnal CH₄ emission pattern, effects of CO₂ enrichment on the development and growth of terrestrial plant species, contribution of greenhouse gases to global change, and greenhouse gas emission mitigation are relatively well studied so far. However, the relationship of CO₂ and CH₄ has only been touched upon in previous studies. Questions likes "How does CO₂ enrichment affect CH₄ emission?" and "Should we consider CO₂ as an important factor in predicting CH₄ concentration?" need to be addressed and will be so in this paper.

1 Effects of CO₂ enrichment on CH₄ emission

CO₂ enrichment may influence the global CH₄ emission by changing CH₄ emission rate and CH₄ source size (figure 1).

(i) Effect of CO₂ enrichment on CH₄ emission rate. Rice paddies and natural wetlands are important sources for global CH₄ emission. The variation of emission rates from these sources will remarkably influence the world annual CH₄ budget and so as the prediction of CH₄ concentration in the atmosphere.

CO₂ enrichment may change the total amount of CH₄ emission through affecting emission rate from these sources. CH₄ emission rate is controlled by many environmental factors such as soil organic carbon (SOC), temperature and CH₄ bacteria activity^[6, 8—11]. Data show that CO₂ enrichment stimulates CH₄ emission from rice paddies as well as natural wetlands (table 1). The general increase is ranging between

Fig. 1. The relationship of CO₂ and CH₄ in the global change.

80 % and 288 % . What still remains to be understood, however, is the mechanisms of stimulation. This can only be discussed from a theoretical point of view as data are not available at this point in time.

Table 1 Effects of CO₂ enrichment on CH₄ emission

Research groups	Research objects	CO ₂ concentration/ $\mu\text{mol} \cdot \text{mol}^{-1}$	Effect
Wang ^[1]	rice in plots	660—700	stimulate, 153 %—288 %
Megonigal ^[12]	<i>Orontium aquaticum</i>	720	stimulate, 136 %
Hutchin ^[13]	ombrotrophic mire	700	stimulate, 145 %
Allen ^[14]	rice paddies	660	stimulate, 75 %—207 %
Dacey ^[15]	brackish tidal marsh	690	stimulate, 80 %

SOC is a key factor for CH₄ emission and the carbon source for CH₄ bacteria. High SOC will stimulate CH₄ production by reducing the soil redox potential (Eh), and celebrate CH₄ emission in bubble form^[8]. Neue and Sass^[6] found CH₄ emission was increased when more organic matter, such as organic amendments and incorporated rice straw, was put in the soil. The first CH₄ emission maximum from rice field during the growth season was researched shortly after flooding. It is thought to be caused by fermentation of easily degraded SOC accumulated from incorporated crop residues and organic amendments during the fallow period^[6, 8]. Vermoesen *et al.*^[16] also pointed out that there is a strong correlation between water-soluble organic carbon and CH₄ production.

Elevated CO₂ can also affect soil organic carbon indirectly. As we know, the photosynthetic rate of most C₃ plants will be increased when exposed in CO₂ enrichment environment^[17—20]. This increase in photosynthesis will bring a higher biomass accumulation under most circumstances. Some metabolites such as root exudes may be enhanced while shoot and root growth increased as a result of higher photosynthesis under CO₂ enriched condition^[21, 22]. The SOC, as the substrate for CH₄ bacteria, could be increased

1) Wang, D. L., Zhu, L., Effects of CO₂ enrichment on CH₄ emission from rice, *Acta Phytocologia Sinica*, 1999, in press.

because of the higher root biomass, root exudate and plant residues input to the root rhizosphere under CO₂ enriched condition. CH₄ emission from rice paddies and natural wetlands is supposed to increase^[12-15]. Allelochemicals, an important component of root exudates and residue degradation, may affect the CH₄ bacteria activities, and furthermore influence CH₄ production. Wang and Zhu found that CO₂ enrichment stimulated CH₄ emission from rice by 153%—288% compared with ambient CO₂ treatment, while rice root biomass was only 52%—92% higher than control. This difference suggested that the stimulation of CO₂ enrichment on CH₄ emission is not a simple accumulative effect. It is possible that chemicals released from plants into environment can stimulate the CH₄ bacteria activities, which could explain the increased CH₄ production under CO₂ enrichment condition¹⁾. Effect of CO₂ enrichment on plant allelopathy is a new research area. Two kinds of responses are possible in allelopathy: stimulatory and inhibitory^[23]. It may be feasible to use bacteria inhibiting-allelochemical to reduce the CH₄ bacteria activity and CH₄ emission in rice field.

Schutz *et al.* reported that about 96% CH₄ from rice paddies was transported to the atmosphere through rice gas-conduit system^[24]. The finding that the major proportion of CH₄ was emitted through rice transport system was also found by Shangguan's research which quantified the rice transport to 55%—73%^[25]. Thus it will give us lots of help for explaining the stimulating mechanism of CO₂ enrichment to understand the variation of plant gas-conduit system under CO₂ enriched condition. However, there is no available data regarding the effects of CO₂ enrichment on quantity and transport efficiency of gas-conduit system in plant so far.

(ii) Effects of CO₂ enrichment on the area and distribution of CH₄ sources. Another way for CO₂ enrichment affecting CH₄ emission is through changing the size of CH₄ sources, especially the natural sources (figure 1).

Combined with other global warming forces, CO₂ enrichment does play a significant role in global climate change even if it is thought that there is not enough evidence to confirm the direct effect of CO₂ elevation on global warming. According to the models, the increase in atmosphere temperature is unbalanced viewed with a worldwide scale. In the coupled atmosphere and ocean general circulation model, after 26—30 years with CO₂ concentration increasing by 1% annually, it will cause the temperature increasing within the zone of 60°N to 60°S in summer, and the zone of 30°N to 60°S in winter^[1]. Because of the increasing variation in temperature, the change of worldwide precipitation will show the same imbalance. The area and distribution pattern of natural wetlands, source of CH₄ production, will change because of the unbalanced changing of precipitation and sea level increasing, especially in a regional scale. Prediction of the consequences for the natural wetlands is not yet available and needs to be done to give a precise prediction for the future.

Under the pressure of growing population, food production has to be increased during the 21st century. The ways to increase rice production are intensive rice planting technique utilizing, high yield rice varieties developing and probably, rice plantation area increasing. It is predicted that the suitable zone for rice plantation will go further to the north because of global warming. In such case, CH₄ emission may be enhanced either in these areas.

So the distribution and area of rice paddies and natural wetlands may be quite different in the 21st century. Consequently, global CH₄ emission will show a different scenario in the world.

2 Effects of CO₂ enrichment on the prediction of CH₄ concentration in atmosphere

There are two methods for predicting the CH₄ concentration in the atmosphere. One is using the current increasing rate, and the other is using the changes of CH₄ emission from rice paddies, livestock and leakage from natural gas and coal exploration^[1]. None of these two methods includes the effect of CO₂ enrichment on CH₄ emission from rice paddies and natural wetlands. CO₂ effect must be considered when we

1) See footnote 1) on page 1154.

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predict the future CH_4 concentration. Data from the above studies showed that CH_4 emission from rice field and wetlands can be 1—3 times higher under elevated CO_2 condition than that in the ambient CO_2 condition (table 1). This portion of CH_4 , released from rice paddies and natural wetlands, is more than 40% of the total CH_4 emission around the world^[6, 7], and 56% in China^[5]. Hence, CH_4 concentration will be higher than the predicted CH_4 concentration in the next century if CO_2 effect does exist. Including the effect on source size or area, CO_2 enrichment will be a remarkable factor in CH_4 emission.

In general, the effect of CO_2 enrichment on CH_4 emission is a very important research area in the future. The following research opportunities should be considered.

i) The effects of CO_2 enrichment on CH_4 emission from rice paddies and natural wetlands in different regions. The typical CH_4 sources, mainly rice paddies and natural wetlands in different regions around the world, should be selected in order to give more evidence and data for future model prediction of CH_4 concentration.

ii) The mechanism of CO_2 effect on the strength of CH_4 sources. Effects of CO_2 enrichment on CH_4 bacteria substrates, CH_4 bacteria activity and CH_4 transport efficiency are important points in this area.

iii) Modeling research on the distribution and change of CH_4 sources under future global change environment. Using modeling method to predict the distribution and change in size and strength of CH_4 sources under global changes (temperature increase and precipitation variation). In the model, the effect of CO_2 enrichment on CH_4 sources should be considered.

iv) New approach for reducing CH_4 emission in global change environment. It is a feasible way to utilize plant allelopathy to control CH_4 bacteria activity for CH_4 mitigation in agricultural production.

Acknowledgement The author wishes to thank Dr. M. Olofsdotter for reading this manuscript. This work was supported by the National Natural Science Foundation of China (Grant No. 39570133).

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(Received February 18, 1998; revised August 4, 1998)