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Study on Mitigation Strategies of Methane Emission from Rice Paddies in the Implementation of Ecological Agriculture

ZHAO Xiaohong, He Jia, CAO Junxin*

School of Economy and Management, Neijiang Normal University, Sichuan,641002, P.R.China

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Abstract

Mitigation of methane emission plays a very important role in carbon mitigation. A model which simulates the whole process of methane emissions can be developed based on research on the methane emission mechanism. According to this model, the methane emission is affected by all the factors, which affected the disoxidation of methanogenus and oxidation in the emission process. Therefore, the mitigation of methane emission can be achieved by selection of rice cultivar, water regime and fertilization.

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Keywords: Mitigation of Methane Emission; Emission Mechanism; Emission Model; Mitigation Strategies

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1. Introduction

Methane (CH_4) is an important greenhouse gas in atmosphere. The GWP of methane are 72, 25 and 7.6 times of CO_2 during 20a, 50a and 100a [1]. It is the second contribution to global warming, only after carbon dioxide. Therefore, Mitigation of methane emission plays a very important role in carbon mitigation.

Rice fields have been identified as major source of methane emission, which mainly comes from the paddy fields, natural swamp, termite, gas leakage, ruminant animals, urban garbage disposal, etc. Methane emission of rice paddies in China is about 500 million tons per year, which accounts for about 10% of the world [2]. Without doubt, mitigation of methane emission in China plays a very important role in the world. With the rise of ecological agriculture in China, a variety of efficient and sustainable

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* Corresponding author. Tel.: +86-18728109198; fax:+86-832-2342588.
E-mail address: caojx0108@163.com.
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ecological technologies have been adopted, which has brought new opportunities to mitigation emission in agro-ecosystem. On the other hand, with the rapid growth of intensive rice cultivation fields scale, more fossil energy were directly or indirectly put into rice fields, energy saving problem about rice cultivation has attracted extensive attention of the whole society. Under this background, studying on mitigation of methane emission during the implementation of ecological agriculture is undoubtedly tremendously significant.

2. **Methane emission mechanisms**

From a biological standpoint, methane emission produces from a difference value between methane bacteria use organic matter of field plant root system to produce methane and the quantity which methane oxidation bacteria oxidizes methane. Methane emission from paddy fields firstly is oxidized, and then the not- oxidized eventually is released into the atmosphere [3].

2.1. Production

Because the rice grows in the anoxic environment, the methane can be constantly produced. Under the anaerobic conditions, two kinds of substratum (CO_2H_2 and CH_3COOH) are deoxidized into the methane by the methane bacteria [4].

2.2. Oxidation

Some observations show that CH_4 emissions accounts for 3% ~ 81% of CH_4 quantity, most of the remaining is oxidized before it inputting into atmospheric. CH_4 can be oxidized both in aerobic and anaerobic environment, but CH_4 in the soil is oxidized mainly by aerobic environment. Because the molecular oxygen of soil in the flooded soon is consumed, the oxygen in air using respiration reaches plant roots by ventilation organizations. So in flooded rice paddies, the oxygen only exists at interface between thin soil oxide surface and water as well as plant roots oxidation film. Therefore, in flooded rice paddies, CH_4 oxidation can only occur in soil surface aerobic layer and around the root of oxide film [5] .

2.3. Emission

When CH_4 in the soil accumulates to a certain amount and CH_4 is less oxidation in transmission way, at the same time unobstructed transmission path exists, a lot of CH_4 can be released. Normally, there are three main ways for CH_4 emission: aerenchyma, bubble and liquid diffusion [6].

3. **Emission Model**

In recent years, research on methane emission model from rice fields has made great progress. And based on the understanding of key processes of methane production, oxidation and emission, a model were developed to simulate this processes by Huang (1998) [7]. This model has an explanatory power of methane emission through rice plant aerenchymac in continuous flooding paddy soil. Numerous studies show that water regime significantly affect the methane emission from rice field, and the transmission of methane bubbles was also an important way at early growth phase [8]. Hence, this paper combines Huang and Zhang'model (2005) to simulate the processes ofmethane emission.

3.1. Rice plant methane emission model

3.1.1. Substratum for methane production

Substratum for methane production are derived from the decomposition of exogenous organics and root exudates.The equations describing the exogenous organic decomposition is:

$$C_{OM} = 0.65 \times SI \times TI \times (k_1 \times OM_N + k_2 \times OM_S) \tag{1}$$

Where C_{OM} represents the substratum for methane production (g/(m^2·d)) resolved by exogenous organics per day; OM_N and OM_S (g/m^2) respectively represents the component content of the easily-decomposed and the hardly-decomposed; k_1 and k_2 respectively represents the first order dynamics coefficient of decomposition rate corresponding to the two contents; S_I and T_I respectively represents the influence of soil texture and soil temperature.

The simulation equation of root exudates decomposition is:

$$C_R = 1.8 \times 10^{-3} \times VI \times SI \times W^{1.25} \tag{2}$$

Where C_R represents the substratum for methane production (g/(m^2·d)) metabolized by rice plant each day; V_I represents rice varieties coefficient; W (g/m^2) represents aboveground biomass of rice plant. W can be calculated by this equation:

$$W = \frac{9.46 \times GY^{0.76}}{1 + \left(\dfrac{9.46 \times GY^{0.76}}{W_0} - 1 \right) \times \exp(-r \times t)} \tag{3}$$

Where GY (g/m^2)represents yield; W_0 and W_{max} ($W_{max} = 9.46 \times GY^{0.76}$) respectively represents above ground biomass of rice plant in transplanted stage and mature stage; t represents transplanting days; r represents intrinsic growth rate of above ground biomass.

3.1.2. Soil environment

The soil environmental factors such as soil sandy particle (*SAND*), soil temperature (T_{soil}) and oxidation reduction potential (*Eh*), etc. were drawn into a function to quantify their influence for methane emission.The soil texture influence function:

$$SI = 0.325 + 0.0225 \times SAND \tag{4}$$

Soil temperature influence function:

$$TI = \frac{T_{soil}{}^{-3}}{Q_{10}{}^{10}} \tag{5}$$

(T_{soil}=30℃ only if 30℃ <T_{soil}≤40℃)

Soil REDOX potentials influence function:

$$F_{Eh} = \exp\left[-1.7 \times \frac{150 + Eh}{150} \right] \tag{6}$$

Where F_{Eh} represents soil redox potential. *Eh* could be estimated by a function of days after first flooded. $Eh < -150$only if $Eh = -150$.

3.1.3. Methane emission rates of rice plant

Based on the above mentioned simulation of influence function, methane production of rice plant(p) can be estimated as:

$$P = 0.27 \times F_{Eh} \times (C_{OM} + TI \times C_R) \tag{7}$$

In the function, 0.27 is the ratio between CH_4 and $C_6H_{12}O6$. The methane of soil is released by the ventilatory organization. With the growth of rice, methane emission accounted for a decreasing proportion of the methane production. An equation (8) is presented to describe this process:

$$F_P = 0.55 \times \left[1 - \frac{W}{W_{MAX}} \right]^{0.25} \tag{8}$$

Then, based on equation (7) and (8), the total methane emission rates (Ep, g/(m^2·d)) should be estimated as:

$$E_P = F_P \times P \tag{9}$$

3.2. *Methane emission through methane bubbles*

Huang's model for continuous flooded paddy fields methane emissions was good, but any other ways of methane emissions for paddy fields did not been considered [8]. Therefore, in this paper the model of Zhangwen was adopted to supplement insufficient.

In the early rice growth, after new produces methane in soil water achieves maximum saturation solubility, they will then gather formation of bubbles. These bubbles gather to certain volume, and are rapid upward movement interface between hydrosphere and atmosphere. During the process, the methane is less oxidation, considering these processes, paddy methane emissions factor was expressed as follows:

$$E_{bl} = 0.7 \times (P - P_0) \times \ln(T_{soil}) / W_{root} \tag{10}$$

Where E_{bl} represents methane emission rates through bubbles(g/(m^2·d)); P_0 represents methane critical production(g/(m^2·d)); P_0 = 0.002. Wroot represents biomass of root (g/m^2). The results by Yoshida indicated W_{root} can be estimated by a recursive function through a discrete recursive algorithm (begin with $W_{root(0)}=0$ and end with $W_{root(i)} - W_{root(i-1)} < 0.1$):

$$W_{root} = 0.136 \times (W_{root} + W)^{0.936} \tag{11}$$

Consequently, the estimation model of total methane emission rates (E, g/m^2, d)) could be improved as:

$$E = E_P + E_{bl} = \min\left[F_P, 1 - \frac{E_{bl}}{P}\right] \times p + E_{bl} \tag{12}$$

3.3. *Simulation on the effect of water regime to soil Eh*

Huang' s model for simulation of soil *Eh* value change only was discussed in the first flooded paddy fields. However, the change of soil *Eh* under water regime of field drying and intermit irrigation, which significantly affected the methane emission from rice field. Therefore, a first-order differential equation was developed to simulate influence of this change [8]:

$$\begin{cases} E_h^{(t+1)} = E_h^{(t)} - D_{E_h} \times \left(A_{E_h} + \min(1, C_{OM})\right) \times \left(E_h^{(t)} - B_{E_{hl}}\right) \\ E_h^{(t+1)} = E_h^{(t)} - D_{E_h} \times \left(A_{E_h} + 0.7\right) \times \left(E_h^{(t)} - B_{E_{hu}}\right) \end{cases} \tag{13}$$

Where t represents the days after field drying or irrigation; A_{Eh} and D_{Eh} represent difference coefficient; B_{Ehl} and B_{Ehu} respectively was supposed to be lower limit and upper limit to soil *Eh*, which valued -250mv and 300mv. Due to the difference of irrigation frequency, a determinacy function was hard to describe the change of soil *Eh* under the intermit irrigation condition, the value was supposed to fluctuate stochastically at -20mv, where the fluctuating range from 10~20mv.

4. Mitigation Strategies

According to above models, the methane emission is affected by all the factors, which affects the disoxidation of methanogenus and oxidation in the emission process. Based on this principle, the mitigation of methane emission may be achieved by selection of rice cultivar, water regime and fertilization. Besides, from the perspective of ecological agriculture, economic benefit and ecological benefit should also be considered when the mitigation strategies are developed.

4.1. Selection of rice cultivar

A mass of observation data showed that methane emissions from different rice cultivars had greater difference under same conditions. Usually, total weight of plant was negatively related to the emission of rice field, in other words, breeds with heavier total weight contributed less CH_4 emission. Li Jing believed that heavier plant had fixed more carbon. The results of Li's experiment were given in Figure 1 [9].

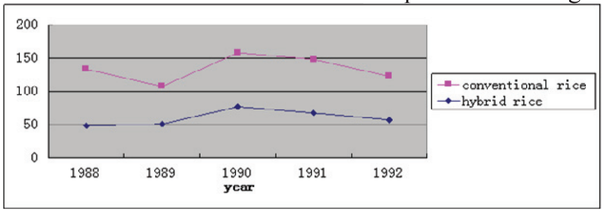

Figure 1. comparison of methane emission rates from hybrid rice and conventional rice

The result showed that methane emission rates from hybrid rice were lower than conventional rice. Further more, hybrid rice's yield was higher than conventional rice. Therefore, promotion of hybrid rice not only mitigated methane emission, but also increased yields.

4.2. Water regime

Water was considered as a key factor of methane emission from rice fields. Soil redox potential can be adjusted by changing the irrigation condition, so that methane emission should be controlled by water regime. The experiment proved that deep water irrigation, intermittent irrigation, damp treatment, and normal rice paddies can reduce methane emissions. Methane emission rates of early rice and late rice were given in Table1 [9].

Table 1.Methane emission rates of early rice and late rice（$mg\cdot m^{-2}\cdot h^{-1}$）

water regime	emission of early rice	emission of late rice
damp treatment	2.88	5.50
intermittent irrigation	4.54	13.62
normal irrigation（～3cm）	5.20	12.12
deep irrigation（～10cm）	2.94	15.82

It can be seen from Table 1 that deep irrigation resulted in observably low emission rates of early rice but highest emission rates of late rice. This is because that deep water blocked methane emission to atmosphere, therefore reduces CH_4 emission. However, due to the lacking of water resource for irrigation in the season of late rice and the high soil temperature, the value of *Eh* keeps a low level, which caused deep water didn't work for late rice. Furthermore, the maintenance operation of water depth is complex, therefore, deep irrigation was not a very good way to reduce emissions. Intermittent irrigation with alternate watering and field drying greatly reduces methane emissions. However, another important greenhouse gas N_2O increased in this treatment. Damp treatment, which keeps the soil damp but not flooded, was considered to have a lowest emission yet it was also not the most promising mitigation option to reduce emissions because of low yields.

Infiltration irrigation technique was considered as a feasible and successful water regime at the moment. This technique was taken across the growth of rice plant. In rice seedling stage, shallow aquifer would be kept to stimulate tillering; in tillering flourish periods and elongation, field drying would be taken to control unavailable tillerings and promote growth efficiency; in ear differentiation and booting stage, shallow aquifer would be kept again to promote the development of ear; at filling stage, intermittent irrigation with alternate flooding and drainage would be adopted to increase the activity of roots and grain plumpness. At the present time, infiltration irrigation technique has been widely used in China especially in flood drought rotation and single rice area. Some results showed that infiltration irrigation technique could reduce methane emissions of more than 40%, which had more advantages in mitigation [10].

Except above mentioned water regimes, there were other methods to mitigation such as water manure combine, ridge culture, etc. However, these mitigation technologies were in the research stage and the application was still immature.

4.3. Fertilization

The model showed that methane was produced by disoxidation, which methanogen acted on substratum under anaerobic conditions. Besides, fertilization had great influences on substratum and methanogen. Therefore, fertilization is an important factor affecting methane emission. The experiment in Hunan in 1992 compared four different types of fertilizer: normal fertilizer, organic fertilizer, mineral fertilizer andbiogas residues fertilizer. The results were given in Table2 [9].

Table 2.Methane emission rates of early rice and late rice（$mg \cdot m^{-2} \cdot h^{-1}$）

fertilizer types	emission of early rice	emission of late rice
normal fertilizer	2.88	5.50
organic fertilizer	4.54	13.62
mineral fertilizer	5.20	12.12
biogas residues fertilizer	2.94	15.82

Organic manure greatly promoted methane emission as compared to other fertilizers while mineral fertilizer discharges the least. However, mineral fertilizer would cause environmental pollution, remain toxic substances, which run counter to ecological agriculture. Normal fertilizer promoted methane emission as equal tobiogas residues fertilizer, but it didn't work to recover energy or improve economic benefit.biogas residues fertilizer had an observable effect to mitigation while the energy substitute benefit was also remarkable. Therefore,biogas residues fertilizer was the best fertilizer to mitigation.

It should be noted that the energy substitute benefit depends on the scale of methane tank. The biogas from small methane tank could only burn to substitute for straw, yet the large-scale methane tank could substitute for electric power and natural gas by centralized use. Thus,the establishment of large-scale methane tank will be the trend to mitigation and energy substitute.

In addition, application mode and time of fertilizer also affect methane emission. Some field experiment was established to show that straw returned as strip had lower emission rates than application fertilizer with mixed way and covering in drain. Application of straw fertilizer in non-growing period had lower emission rates than in plant transplanting period [11], which suggested that better selection of application mode and time was another way to mitigation.

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