

Dynamic Emission of CH₄ from a Rice-Duck Farming Ecosystem

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ABSTRACT

Global climatic change induced by emissions of greenhouse gases from human activities is an issue of increasing international environmental concerns, and agricultural practices and managements are the important contributors for such emissions. This study investigated dynamic emission of methane (CH₄) from a paddy field in a rice-duck farming ecosystem. Three different cultivation treatments, namely the organic fertilizer + duck (OF+D), chemical fertilizer + duck (CF + D), and chemical fertilizer (Control) treatments, were employed in this study. Experimental data showed that hourly variations of CH₄ emission from the paddy field during the day were somewhat positively correlated ($R^2 = 0.7$ for the OF + D treatment and $R^2 = 0.6$ for the CF+D treatment) to the hourly changes in air temperatures in addition to the influences of the duck activities. The rate of CH₄ emission for the CF+D treatment was higher than that of the Control treatment at the tillering stage, whereas the opposite was true at the heading stage. In contrary, the rate of CH₄ emission for the OF + D treatment was always higher than that of the Control treatment regardless the tillering or heading stage. Our study revealed that the rate of CH₄ emission depended not only on air temperature but also on the rice growth stage. A 6.7% decrease in CH₄ emission and in global warming potential (GWP) was observed for the CF + D treatment as compared to the Control treatment. This study suggested that although the impacts of duckling on the emission of CH₄ depended on the rice growth stage and air temperature regime, the introduction of ducks into the rice farming system in general mitigated the overall CH₄ emission and thereby the GWP.

Keywords: Methane Emission, Global Warming Potential, Rice-Duck Farming

1. Introduction

Global warming, resulted from the elevated concentrations of greenhouse gases in the atmosphere, has emerged as the most prominent global environment issue. While many gases have been examined, only three of them, namely carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), were identified to have significant global warming potential (GWP) [1]. These gases have strong infrared absorption capacity and trap part of the thermal radiation from earth's surface. Methane is an important greenhouse gas and has approximately 25 times more infrared absorption capacity or GWP than that of CO₂ on a molecule basis [2,3]. It has been reported that the atmospheric concentration of CH₄ increased from 1.50 to 1.72 ppm during the last decades [4,5] and contributed 5% toward the enhanced global warming [6].

Methane is produced naturally in soils through the microbial processes. Under the anaerobic conditions, a type

of soil organisms or methanogens can transform some of the soil organic matter into CH₄ through the following two pathways: 1) CH₃COOH → CH₄ + CO₂, and 2) CO₂ + 4H₂ → CH₄ + 2H₂O [7,8]. Meanwhile, methane can also be oxidized by another type of soil organisms or methanotrophs into CO₂. Therefore, soil CH₄ emission into the atmosphere is a net result of CH₄ production and CH₄ oxidation [9,10]. In addition, soil temperature regime and organic carbon content are the major environmental factors affecting the emission of CH₄ into the atmosphere.

Although the dominant source of anthropogenic CO₂ is from fossil fuel burning, various agricultural activities in general and wetland rice agricultural practices in particular are the major sources of CH₄ emissions [11-14]. This source has increased in recent years due to the expansion of rice cultivation in Southeast Asia [15,16]. The amount of CH₄ emission from paddy fields is estimated to be 10% - 20% of the total CH₄ emission [17,18].

Therefore, a need exists to understand which agricultural farming systems have the greatest potential to mitigate CH₄ emission contributing to global warming. To develop an improved conservation technology for mitigation of CH₄ emission with multiple benefits in economy, environmental protection, food security, and agricultural sustainability, an old farming system, *i.e.*, the rice-duck farming system, has been re-examined for this purpose in recent years, especially in South China [19-21].

The system of rice cultivation associated with duck raises is known as an integrated rice-duck farming system. This system is a form of organic farming that yields two crops simultaneously, one for rice as the main crop and the other for ducks as the subsidiary crop, using the same natural resources. Integrated the rice-duck farming is known to have numerous economical, environmental, and ecological benefits. Ducks control weeds and insects effectively in the paddy field. Ducks eat weed seeds, tender weeds, insects and crabs, and thus keep the paddy field pest free. They also improve microclimate environment in rice canopy and thereby indirectly mitigating the outbreak of some rice diseases. Due to the frequent movement, ducks improve the physical structure of the paddy soil that enhances the root growth and ultimately produce more yields. The rice-duck system can also reduce the costs of the weeding, insecticides, and chemical fertilizers, and therefore the higher net returns could be achieved. The rice-duck farming has a long history and is also a major complex planting and breeding model of paddy fields in South China [21].

Several studies have been devoted to investigating the emissions of greenhouse gases in the rice-duck farming system in recent years. Kumaraswamy *et al.* [22] demonstrated that the amount of CH₄ emission declined from the rice-duck farming system due to the increase in dissolved oxygen (DO) concentration, resulting from the frequent movement of ducks. Huang *et al.* [16] characterized the emission of CH₄ from a wetland rice-duck ecosystem in the subtropical region of China. These authors found that the diurnal variations of CH₄ emission were highly correlated to diurnal variations of paddy field temperature, whereas the seasonal variations of CH₄ emission were primarily dependent on the rice growth stages and planting periods (*i.e.*, early and late rice). These studies have provided good insights into the impacts of the rice-duck farming system upon the emission of CH₄ into the atmosphere. However, the role of ducks in regulation of CH₄ emissions from the paddy fields into the atmosphere under varying soil conditions, planting and breeding models, and fertilizer cultivation treatments is still poorly understood.

The purpose of this study was to investigate the dynamic emission of CH₄ from a rice-duck farming eco-

system and its impacts upon the GWP. Our specific motivations were to: 1) estimate the hourly variations of CH₄ emission from the paddy field in a rice-duck farming ecosystem under conditions with varying rice growth stages and fertilizer application treatments; 2) evaluate the monthly variations of CH₄ emission from the paddy field under the same conditions as stated in 1); and 3) assess the cumulative emission of CH₄ into the atmosphere and its impacts upon the GWP for conditions with and without the rice-duck farming systems. Additionally, the introduction of ducks into rice field upon CH₄ emission also was evaluated.

2. Materials and Methods

Study Site and Experimental Design

The experiment was conducted at the Ning-Xi Research and Educational Station located about 40 km east campus of South China Agricultural University, Guangzhou City, China. This station has a subtropical climate with an average annual rainfall of 1.8 m and a mean annual temperature of 22°C. The paddy field soil in the station is developed from the Latosol and has pH 6.0 with an organic matter content of 29.35 g·kg⁻¹, a total nitrogen (N) of 0.07 g·kg⁻¹, a total phosphorus (P) of 0.21 g·kg⁻¹, an available P of 0.03 g·kg⁻¹, a total potassium (K) of 13.54 g·kg⁻¹, and an available K of 0.07 g·kg⁻¹.

The rice species used in this study was *Sheng Ba Xi Miao*, which was provided by South China Agricultural University, Guangzhou City, China. The following three cultivation treatments each with duplicated experimental plots were chosen for the experiment: 1) organic fertilizer + duck (OF + D); 2) chemical fertilizer + duck (CF + D); and chemical fertilizer (Control), which resulted in the total of six experimental plots. Each experimental plot had an area of 666 m² and was separated from each other by inserting the plastic barriers into a soil depth of 0.3 m around the plot boundaries to prevent water and air exchanges between the plots. These plots were randomly distributed in the study site. The organic fertilizer used was the dried chicken manure at the application amount of 3750 kg·ha⁻¹ which contains about 51% of organic matter, 3.26% of N, 3.08% of P₂O₅, and 1.7% of K₂O, whereas the chemical fertilizer used was the compound fertilizer (Compound Fertilizer Inc., Academy of Agriculture of Guangdong, China) with the application amounts of 100, 90, and 90 kg·ha⁻¹, respectively, for N, P, and K. The pesticide used was Masha with "Antai" brand that was purchased from the Antai Limited Inc., Guangxi Zhuang Autonomous Region, China.

The experimental plots in the paddy field was tilled, fertilized, and planted, respectively, on April 1, 5, and 6, 2004. To prevent the ducks from escaping, the plots were contained by the nylon-net with a height of 0.5 m. After

10 days of rice transplanting, an average of 25 ducklings with the ages ranged from 10 to 15 days were introduced into each experimental plot. The flooding depth in the plots during the rice-duck experimental period was kept at 0.06 to 0.08 m through periodically irrigation. The ducks were retrieved and transferred to other places after the heading stage of the rice growth.

A gas chamber (**Figure 1(a)**) was installed in each experimental plot for collection of CH₄ gas, which was modified from Sass *et al.* [17] and Mishra *et al.* [9]. This chamber was made of Perspex sheets with a size of 0.5 × 0.6 m and a height of 0.9 m and the joints were sealed with silicon grease to prevent the leakage of the gases. The chamber was placed on an aluminum alloy base with an inner size of 0.5 × 0.6 m and a height of 0.2 m (**Figure 1(b)**). This base was jacketed with a water channel of 0.05 m wide and 0.01 m deep on the top and filled with water to make the gas chamber airtight. The base was inserted into the soil to a depth of 0.1 to 0.15 m, which made the air holes (for gas exchange) on the base 0.05 to 0.10 m below the soil surface.

To ensure a minimum disturbance to the soil inside the chamber during sampling, a bridge was built between the paddy field ridge and the chamber. The gas samples were collected from the chamber at the intervals of 0, 10, 20, and 30 minutes using a 120 ml airtight syringe and closed with a three-switch valve. Mixing of the gas inside the chamber was accomplished at the time of sampling by turning on the electrical fan installed on the top of the chamber. The gas samples were collected every other day before May 3, 2004 and once a week after this date. The gas samples were transferred into the laboratory and analyzed immediately by a gas chromatography (Thermo-Finigin TRACE 2000 GC) equipped with a flame ionization detector. The experimental data were further analyzed with Microsoft Excel 2000 and SPSS software (version 11.0).

The CH₄ emissions at each rice growth stage from the experimental plots were calculated based on the exper-

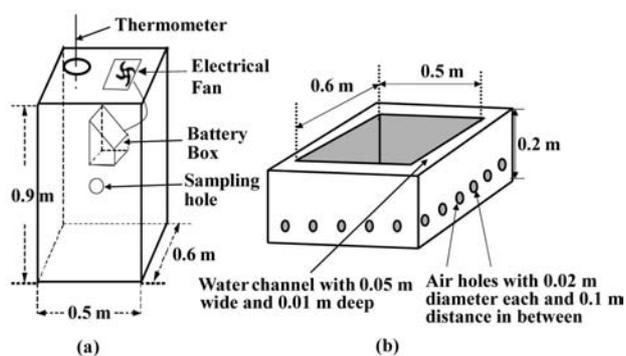


Figure 1. Experimental set up for collection of CH₄ gas. (a) the gas chamber and (b) the aluminum alloy base.

imental data using the following equation modified from Rolston [23]:

$$f = \frac{\Delta\rho V}{\Delta t A} = h \frac{\Delta\rho}{\Delta t}$$

where f is the CH₄ emission flux ($\text{mg}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$), $\Delta\rho$ the change of CH₄ density (mg cm^{-3}), Δt the interval of measuring time (h), V the volume of gas chamber (m^3), A the cross-section area of gas chamber (m^2), and h the height of gas chamber. The accumulation of CH₄ emission was obtained by the summation of CH₄ emission in all of the rice growth stages. Statistical analysis with Duncan's method at $\alpha = 0.05$ was performed to compare differences in CH₄ contents among those three different treatments using SAS 8.1. Results showed there were significant differences among the three treatments in CH₄ emission.

3. Results and Discussion

3.1. Hourly Emission of CH₄

Hourly variations of the averaged CH₄ emission from the paddy field during the day at the tillering stage of the rice growth under three different cultivation treatments are shown in **Figure 2**. This figure shows that the rates of CH₄ emission increased from 8 to 14 h and then decreased from 14 to 16 h for all of the three treatments. For example, the rate of CH₄ emission was about $38 \text{ mg}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ at 8 h, about $49 \text{ mg}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ at 14 h, and about $39 \text{ mg}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ at 16 h for the OF + D treatment. We attributed such hourly variations in CH₄ emission primarily to the hourly changes of air and soil temperatures. The typical hourly changes of air temperatures at the experimental site from April to July have the following pattern: increasing from early morning to early afternoon and decreasing from early afternoon to next morning. **Figure 3** shows a similar hourly variation pattern in air temperature as compared to that of the CH₄ emission. These air temperatures were obtained from the same experimental period and site. Air temperature has a profound impact on respiration and transpiration of the rice and thereby affecting the emission of CH₄. **Figure 4** plots the correlations between the air temperature and the CH₄ emission rate among the three treatments. Based on the correlation coefficients (R^2) and p values, the dependence of CH₄ emission rate upon air temperature was in the following order (from good to poor): OF + D > CF + D > Control. Results suggested that air temperature had discernable impacts on CH₄ emission in the rice-duck farming system.

The influence of soil temperature on CH₄ production and emission has been investigated by Khan *et al.* [24], Kumaraswamy *et al.* [25], Yang and Chang [26], and Huang *et al.* [16]. These authors demonstrate that the rate

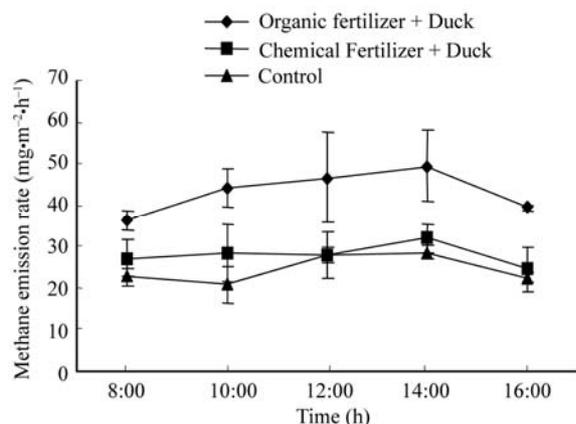


Figure 2. Hourly variations of CH₄ emission rate at the tillering stage.

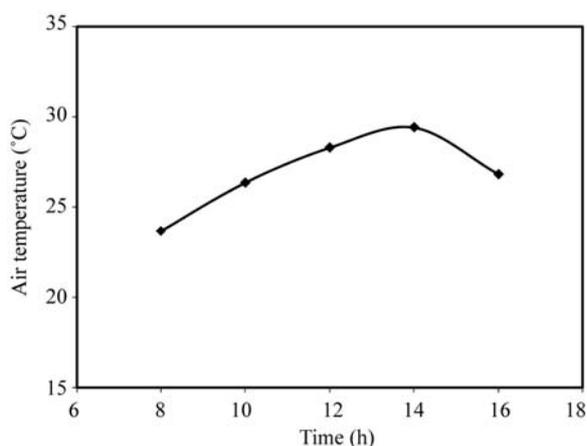


Figure 3. Hourly variations of air temperature at the tillering stage.

of CH₄ production increased with soil temperature from 15 to 40°C and a significant positively correlation exists between CH₄ emission and soil temperature, which can be characterized by Arrhenius equation. Variations in soil temperature can affect the physiological functions of rice such as oxygen diffusivity, root exudation, and root oxidation [27,28] as well as stimulate the activities of methanogenic and methanotrophic microorganisms in the rice rhizosphere [29], which could exert a substantial influence on CH₄ emission. It has been reported that rice roots can uptake the dissolved methane and transport through the aerating tissues of the rice and final emit into the atmosphere through respiration and transpiration [30]. In addition, the duck activities during the day may also affect the hourly variations of CH₄ emission from the paddy field. Ducks are the hot-susceptibility animals and they always seek for foods when the temperature is cooler in the early morning and late afternoon and rest on the ridges of the paddy field or any shed areas when the temperature is warmer at noon [20]. The frequent move-

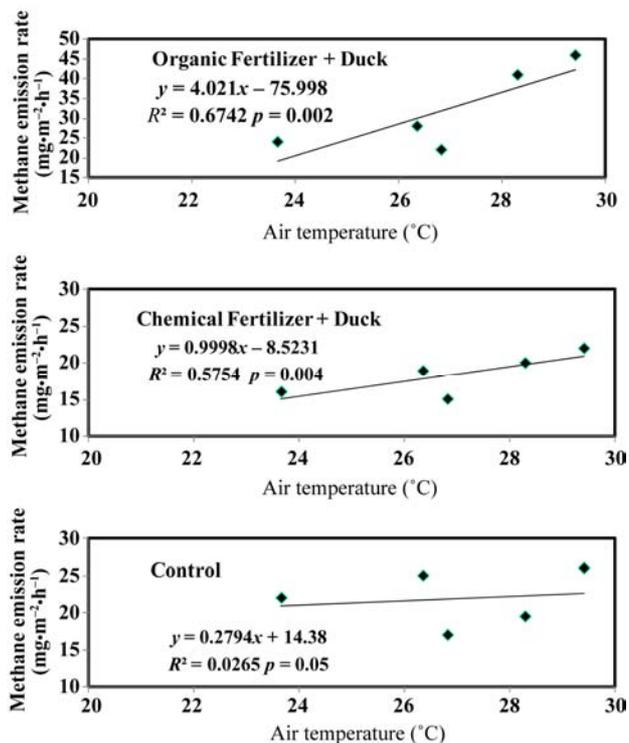


Figure 4. Relationships of air temperature and CH₄ emission among the three treatments at the tillering stage.

ment of the ducks in the early morning and late afternoon brought more DO into the surface water of the paddy field, expedited the oxidation of CH₄, and thereby reduced the rate of CH₄ emission at those time periods.

In general, the rates of CH₄ emission among the three cultivation treatments during the tillering stage of the rice growth were in the following order: OF + D > CF + D > Control. The maximum rates of CH₄ emission were about 48, 32, and 27 mg·m⁻²·h⁻¹, respectively, for the OF + D, CF + D, and Control at 14 h. In other words, the maximum rates of CH₄ emission increased 78% and 19%, respectively, for the OF + D and CF + D treatment as compared to that of the Control treatment during the tillering stage of the rice growth. A 58% (*i.e.*, 78% - 19%) increase in the maximum rate of CH₄ emission for the OF + D treatment against that for the CF + D treatment occurred probably because there was more carbon sources available from organic fertilizer for methanogens to produce CH₄. It is also very interesting to learn that a 19% increase in the maximum rate of CH₄ emission for the CF + D treatment occurred as compared to that of the Control treatment at this rice growth stage. We attributed this phenomenon to frequent activities of the ducks that physically accelerated the CH₄ emission from the paddy field.

Similar hourly variations in CH₄ emission from the

paddy field during the day for the same cultivation treatments were obtained at the heading stage of the rice growth (Figure 5). That is, the rates of CH₄ emission increased from the morning to the early afternoon and decreased from the early afternoon to late afternoon. As stated above, this process was primarily driven by hourly variations of soil and air temperatures. The hourly temperature variations and CH₄ emissions are a cause-and-effect phenomenon. As the temperature varies, the rate of CH₄ emission changes accordingly.

Comparison of Figures 2 and 5 shows that the rates of the hourly CH₄ emission were higher at the tillering stage than at the heading stage for all of the three treatments. For instance, the rate of the hourly CH₄ emission for the OF + D treatment was about 42 mg·m⁻²·h⁻¹ at the tillering stage but was about 33 mg·m⁻²·h⁻¹ for the same treatment at the heading stage. The former was about 21% higher than the latter. A similar finding also was reported by Haung *et al.* [16] although no explanations have been provided by these authors. We speculated this occurred because more carbon sources were available for methanogens to produce CH₄ at the tillering stage (early time of rice growth) than at the heading stage (late time of rice growth). The more carbon sources were available, the higher rate of CH₄ emission occurred.

Comparison of the two rice growth stages further reveals that the rate of the hourly CH₄ emission for the CF + D treatment was higher than for the Control treatment at the tillering stage, whereas the opposite was true at the heading stage. In other words, the duck activities increased the rate of CH₄ emission during the tillering stage but decreased such a rate during the heading stage. Although the exact reasons for such a phenomenon remain unknown, a possible explanation is as follows. The role of the duck activities is two-fold: 1) it can accelerate the CH₄ emission into the atmosphere by physically stirring the water of the paddy field, and 2) it can expedite the CH₄ oxidation by physically increasing the DO con-

centration in the water of the paddy field, and thereby decrease the rate of CH₄ emission. At the tillering stage, the rate of CH₄ production was high presumably because there was more soil organic matter available in the paddy field. Under such a high rate of CH₄ production, the physical acceleration of CH₄ emission due to the duck activities seems to be more important than the oxidation of CH₄ through the physical increase of DO concentration due to the duck activities. Therefore, more CH₄ was emitted at the tillering stage. As time elapsed to the heading stage, the rate of CH₄ production was low because there was less soil organic matter available. Under such low rate of CH₄ production, the physical acceleration of CH₄ emission due to the duck activities seems to play a least important role than the oxidation of CH₄ through the physical increase of DO concentration due to the duck activities when the ducks grew bigger and became very strong at this stage. As a result, less CH₄ were emitted at the heading stage.

3.2. Monthly Emission of CH₄

Changes in monthly emission of CH₄ from the paddy field for the three cultivation treatments were shown in Figure 6. The rates of CH₄ emission increased dramatically in approximately the first month after the rice planting, decreased consecutively, and reached their minimums after three months. The maximum rates of CH₄ emission within the first month of the rice growth period were about 55, 37, and 26 mg·m⁻²·h⁻¹, respectively, for the OF + D, CF + D, and Control treatments. It is apparent that more CH₄ were produced during the first month of the rice growth although the exact reasons remain to be investigated. Further investigation of Figure 4 disclosed that the rate of CH₄ emission was greater for the CF + D treatment than for the Control treatment before May 20 (the tillering stage), whereas the opposite was true after this date (the heading stage). This occurred due to the same reasons as in the case of hourly CH₄ variations for the tillering and heading stages.

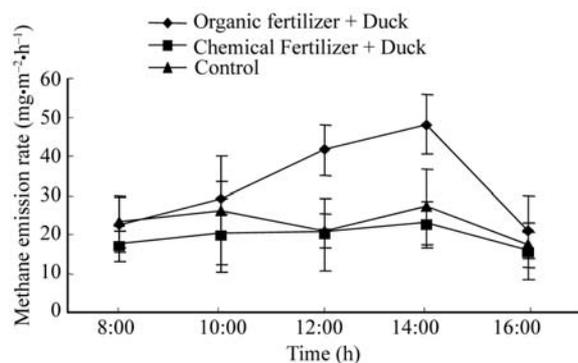


Figure 5. Hourly variations of CH₄ emission rate at the heading stage.

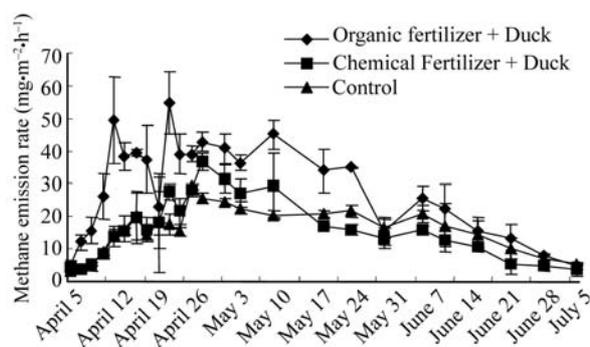


Figure 6. Monthly variations of CH₄ emission rate.

No correlation existed between the monthly changes in air temperature and the monthly variations in the rate of CH₄ emission. The average monthly air temperatures were 22°C, 25°C, and 27°C, respectively, for April, May, and June at the experimental site, whereas the average monthly rates of CH₄ emission were about 18, 25, and 11 mg·m⁻²·h⁻¹, respectively, for April, May, and June at the same site. In other words, an increase in average monthly temperature did not necessary increase in the average rate of monthly CH₄ emission. This occurred because the rate of CH₄ emission was more or less dependent on the rate of CH₄ production, which, in turn, was presumably controlled by the soil organic matter content. As time elapsed, the rate of CH₄ production decreased due to the reduction of soil organic matter content in the paddy field. As a result, the rate of CH₄ emission decreased although the air temperature increased with time.

Cumulative emission of CH₄ (the amount of total CH₄ emission at a give experimental period) for the three cultivation treatments is given in **Figure 7**. The overall emissions of CH₄ from the paddy field were 62810, 38583, and 41375 mg·m⁻², respectively, for the OF + D, CF + D, and Control treatments at the end of the experiment. It is apparent that a 6.7% of CH₄ emission reduction was obtained for CF + D treatment as compared to that of the Control treatment. Results imply that although the impacts of duckling on the emissions of CH₄ depended on the rice growth stages, the introduction of ducks into the rice farming system normally mitigated the emission of CH₄ into the atmosphere.

3.3. Impacts on Global Warming Potential

Global warming potential is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is an index defined as the cumulative radiative forcing between the present and a chosen later time horizon caused by a unit mass of gas emitted now [30]. The GWP can be used to compare the effectiveness of each greenhouse gas to trap heat in the atmosphere relative to CO₂. A GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted or else the value is meaning

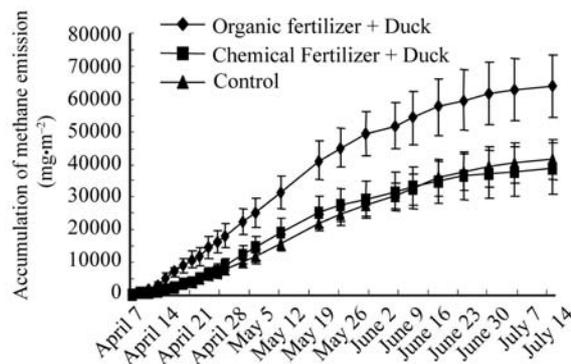


Figure 7. Accumulation of CH₄ emission during the experiment.

less. The GWP is based on a number of factors, including the radiative efficiency (heat-absorbing ability) of each gas relative to that of CO₂ as well as the decay rate of each gas (the amount removed from the atmosphere over a given number of years) relative to that of CO₂. The GWP value for CH₄ is 62 based on a 20-year time horizon and is 23 based on a 100-year time horizon when the GWP value for CO₂ is taken as 1 [30].

Impacts of CH₄ emission on the GWP from the rice-duck farming ecosystem under three different cultivation treatments used in this study are shown in **Table 1**. The GWP based on the 20- or 100-year time horizon was high for the OF + D treatment, low for the CF + D treatment, and with the Control treatment in between. A 6.7% decrease in GWP based on the 20- or 100-year time horizon was observed for the CF + D treatment as compared to that of the Control treatment. A statistical analysis with F-test demonstrates such a percentage decrease was within a 1 percent level of significance (*i.e.*, $\alpha = 0.01$). Results demonstrate that the introduction of ducks into a rice farming system reduced the emission of CH₄ into the atmosphere as compared to that of the conventional rice farming system (*i.e.*, the Control treatment) in South China. **Table 1** further reveals that the GWP with the use of organic fertilizer was 65% higher than with the use of chemical fertilizer in the rice-duck farming system. It is apparent that the use of organic fertilizer would enhance the GWP through the increase of CH₄ emission.

Table 1. Impacts of CH₄ emission from the rice-duck forming ecosystem on the global warming potential (GWP).

Treatment**	Average hourly CH ₄ emission (mg·m ⁻² ·h ⁻¹)	Cumulative CH ₄ emission (mg·m ⁻²)	*GWP based on 20 years	GWP based on 100 years
Organic fertilizer + duck (OF + D)	26.32	63810.48	3956249.76	1467641.04
Chemical fertilizer + duck (CF + D)	15.91	38583.98	2392206.76	887431.54
Chemical fertilizer (Control)	17.06	41375.88	2565304.56	951645.24

*The GWP values based on 20- and 100-year time horizons are calculated by multiplying the cumulative CH₄ emissions with 62 and 23, respectively; **The values among different treatments are statistically different at $\alpha = 0.01$ through F-test.

However, the use of chemical fertilizer can increase the rate of N₂O emission into the atmosphere in rice agriculture [14]. Therefore, further study is warranted to compare the GWP induced from the emission of CH₄ due to the use of organic fertilizers and from the emission of N₂O due to the use of chemical fertilizers in the rice-duck farming system.

4. Summary

Experiments were conducted to investigate the dynamic emission of CH₄ from a paddy field under the rice-duck farming system. Three different cultivation treatments, namely the organic fertilizer + duck (OF + D), chemical fertilizer + duck (CF + D), and chemical fertilizer (Control) treatments, were selected in this study. Our study showed that hourly variations of CH₄ emission from the paddy field during the day were positively correlated to the hourly changes in air temperatures in addition to the influences of the duck activities. The rate of CH₄ emission for the CF + D treatment was higher than for the Control treatment at the tillering stage, whereas the opposite was true at the heading stage. Our study revealed that the rate of CH₄ emission depended not only on temperature but also on the rice growth stage. A 6.7% reduction in CH₄ emission as well as in GWP was observed for the CF + D treatment as compared to the Control treatment for the entire experimental period. This study suggested that although the impacts of duckling on the emission of CH₄ depend on rice growth stage and air temperature regime, the introduction of duckling into the rice farming system in general mitigated the overall CH₄ emission and thereby the GWP.

Although the use of organic fertilizers enhanced the GWP through the increase of CH₄ emission, the use of chemical fertilizers would also enhance the GWP through the increase of N₂O emission. Therefore, further study is warranted to compare the GWP from the emission of CH₄ due to the use of organic fertilizers with the GWP from the emission of N₂O due to the use of chemical fertilizers in the rice-duck farming system. Additionally, soil organic matter should also be measured for a better characterization of CH₄ emission from the rice-duck farming system.

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