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# RESPONSE OF METHANE EMISSIONS TO WATER LEVELS IN SIMULATED CONSTRUCTED WETLANDS

Wetland is an important natural source of methane ($CH_4$) generated under the actions of methanogens in the anaerobic environment. A greenhouse experiment was conducted to quantify the response of methane emissions to water levels by simulating three water levels (10, 20, and 40 cm) in constructed wetlands and the methane was determined by the static chamber-gas chromatograph technique. Pearson correlation analysis showed that the emissions of $CH_4$ were positively correlated with water temperature and air temperature while they were negatively correlated with air humidity. The water levels simulation experiment showed that the emission of $CH_4$ was the highest when the water level was 20 cm and the $CH_4$ concentrations of the water-air interface had different patterns at various water levels in the daytime. In conclusion, water level and temperature should be considered when accounting for greenhouse gas emissions in constructed wetlands as they both have important influences on $CH_4$ emission.

## 1. INTRODUCTION

Global warming attracts more and more attention in the world and the effects of greenhouse gases are major causes of global warming. Methane ($CH_4$) is listed as an important greenhouse gas after carbon dioxide ($CO_2$) and its global warming potential is 25 times greater than that of $CO_2$ per unit of weight [1, 2]. Wetlands are the major sources of $CH_4$ emission, which contribute from 15 to 45% of global methane emission [3]. Further, $CH_4$ emission in wetlands increases the atmospheric methane concentration partially [4]. Since 2007, methane concentration increased again with a global average growth that was approximately 6 ppb/year [5]. The production, conversion,

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consumption, and emission of $CH_4$ had been hotspots for global change ecology and environmental science.

Methane production and consumption are both microbiological processes. The production is mainly determined by the amount of degradable action and the absence of oxygen, while the consumption is controlled by soil oxygen and methane concentrations [6]. In the anaerobic environment of the wetlands, organic matter produces $CH_4$ under the actions of methanogens [7]. Uncertain factors exist, which affect the accounting of $CH_4$ emissions from wetlands, specially constructed wetlands. The process is influenced by heat transport, organic matter mineralization, and soil aeration [3]. It has also been suggested that water levels were an essential driver for $CH_4$ emission but direct evidence in constructed wetlands for this is very limited [8, 9]. Also, rainfall and water table affected $CH_4$ emission [10]. In the constructed wetlands, the important influence factor of water level is the hydrologic condition including rainfall, underground water, surface runoff, etc. Water level affected $CH_4$ production and oxidation by determining air humidity and oxygen profile [11]. Moreover, soil properties like redox potential and soil temperature were influenced by water level [12], which influenced $CH_4$ emission by affecting methanogen activity, $CH_4$ oxidation [13], and $CH_4$ transfer through plants [14].

Therefore, to understand the effects of water levels on methane emission from wetlands, a greenhouse experiment was conducted by simulating three water levels (10, 20, and 40 cm) of constructed wetlands. We aim to test the hypotheses: (1) temperature and air humidity positively affect the methane emission from wetlands; (2) the methane emission from wetlands increases with water level increase.

## 2. MATERIALS AND METHODS

The experiment was conducted in the Fanggan Ecological Research Station in Shandong Province, China. The station locates in the south of Jinan and the north of Tai'an, with a temperate continental monsoon climate. Its elevation is nearly a thousand meters and it belongs to Mountain Tai.

To examine the influence of water level on $CH_4$ emission in the constructed wetlands, simulated constructed wetlands were designed. A small-scale control system was set in Fanggan Ecological Research Station to analyze the difference in $CH_4$ emission under different water level conditions. Nine units were established of which length, width, and height were 100 cm, 100 cm, and 70 cm, respectively. Three kinds of water depths, 10 cm, 20 cm, and 40 cm were set respectively and three groups of parallel experiments were designed at each depth. The bottom of every unit was filled with a 25 cm thick soil layer as the substrate. The substrate was obtained from Fanggan Village and mixed well. The small-scale control system began to fill with water in October 2014, and then the system worked properly after inlet 4 weeks.

$CH_4$ collection was conducted using the static chamber-gas chromatograph technique. The static chamber made of stainless steel had a diameter of 0.41 m, an area of

0.13 $m^2$, and a height of 0.35 m. Gas samples were collected by an emission isolation flux hood in early November. Samples were taken from 9:00 to 12:00 every hour at 0, 15, 30, and 45 min. They were taken back to the laboratory in aluminum foil bags for measurement. Meanwhile, environmental factors such as air temperature, water temperature, air humidity, latitude, longitude, and water level were recorded to enable convenient analysis. $CH_4$ emission was detected using SP-6890 gas chromatography (the pressures of carrier gas – 0.5 MPa, air – 0.4 MPa, hydrogen – 0.9 MPa, the temperatures of ovens – 70 °C, the detector – 200 °C, and emission of standard gas 5.13 ppm.

## 3. RESULTS

### 3.1. THE RELATIONSHIP BETWEEN $CH_4$ CONCENTRATION AND WATER TEMPERATURE, AIR TEMPERATURE, pH, AND AIR HUMIDITY

The relationships between $CH_4$ concentration and water temperature, air temperature, pH, and air humidity are shown in Fig. 1.

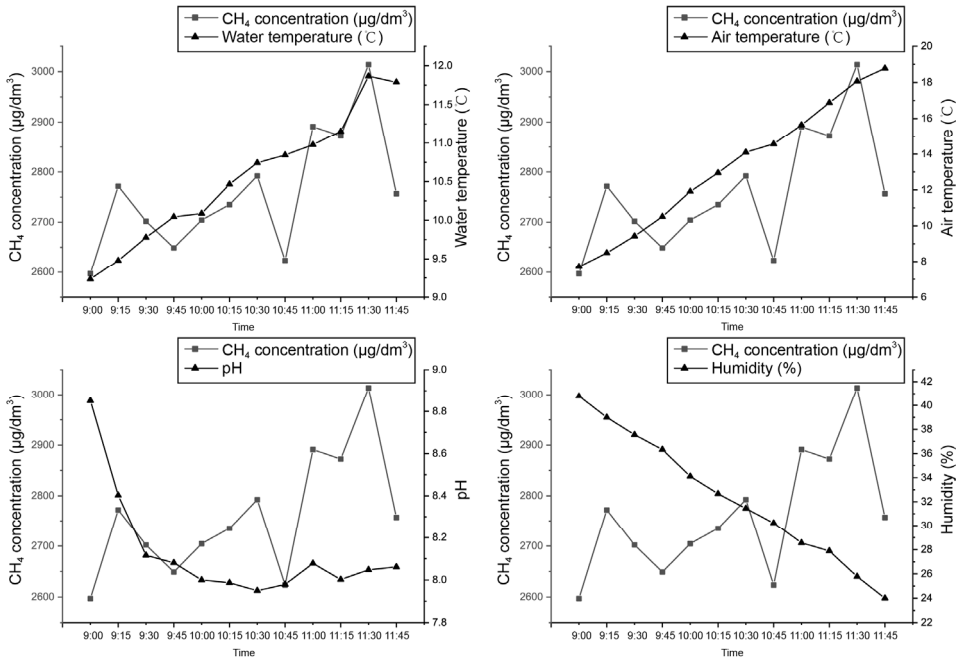


Fig. 1. The variation trend of $CH_4$ concentration and water temperature, air temperature, pH, and humidity in the pilot system

Water temperature and air temperature had the same trend with $CH_4$ concentration during the monitoring time while pH and air humidity had the opposite trend. The Pearson

correlation analysis revealed a positive correlation between $CH_4$ concentration and temperature (Table 1). $CH_4$ concentration was stronger connected with water temperature than with air temperature. The results revealed also a negative correlation between $CH_4$ concentration and air humidity. There was no significant relationship between $CH_4$ concentration and pH.

Table 1

Pearson correlation analysis of $CH_4$ concentration and water temperature, air temperature, pH, and humidity in the pilot system

| Factor | Air temperature | Water temperature | Humidity | pH |
|---|---|---|---|---|
| $r$ | 0.654* | 0.668* | –0.0638* | –0.366 |
| $p$ | 0.021 | 0.018 | 0.026 | 0.242 |

*Correlation is significant at the 0.05 level (2-tailed); $r$ is the Pearson correlation coefficient, $p$ is the significance, $N = 12$ is the sample size.

### 3.2. THE $CH_4$ EMISSION AT VARIOUS WATER LEVELS

No obvious differences were found among the $CH_4$ concentrations at the depth of 10, 20, and 40 cm ($p > 0.05$), but the $CH_4$ concentrations at the water–air interface had different patterns at different water levels.

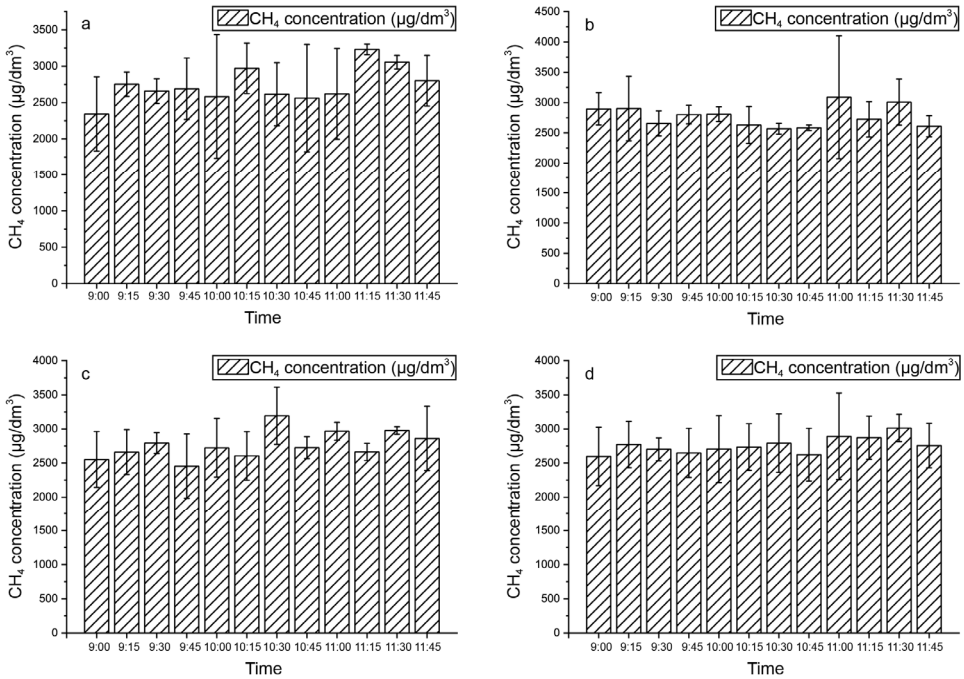


Fig. 2. $CH_4$ concentrations at the depths of 10 (a), 20 (b), 40 cm (c), and average (d)

The $CH_4$ concentration first increased and then decreased at the depths of 10 cm, while it had a different trend at the depth of 20 cm.No obvious trends were observed at the depth of 40 cm. On average, the $CH_4$ concentration first increased and then decreased every hour (Fig. 2). We calculated the $CH_4$ fluxes at 9, 10, and 11 o'clock when the depth is 10 cm, 20 cm, and 40 cm by the linear relationship between $CH_4$ concentration and time and got the wrong results because of $R^2 < 0.9$. Therefore, when we calculated the $CH_4$ flux we should be careful with whether there is a linear relationship between $CH_4$ concentration and time ($R^2 > 0.9$).

## 4. DISCUSSION

### 4.1. THE INFLUENCE OF WATER TEMPERATURE, AIR TEMPERATURE, AND HUMIDITY ON $CH_4$ CONCENTRATION

Our results demonstrated that emissions of $CH_4$ were positively correlated with water temperature and air temperature, and negatively correlated with air humidity. Tong et al. [15] also shown $CH_4$ emission increased upon increasing temperature [15]. Research conducted in Donghu in China found a significantly exponential increase in $CH_4$ emission when temperature increased [16]. In our research, Pearson correlation analysis showed emissions of $CH_4$ were more strongly correlated with water temperature than with air temperature. The increase in air temperature brings about a rise in water temperature, which makes the sludge temperature raising. An increase in temperature led to the high activity of methanogens, also benefiting $CH_4$ transfer [14]. The result demonstrated that the increase in water temperature contributed directly to the acceleration of $CH_4$ emissions, while the influence of air temperature was indirect. In theory, the number of water vapor molecules in the air increases with increased air humidity. Because the density of water vapor molecules is smaller than that of air molecules, the pressure on the water-air interface decreases as the gas molecular density of the mixture decreases. Low pressure favors $CH_4$ emission with an increase in air humidity [17]. However, the results in our study are opposite to the theory, so further studies should be conducted to explore the effects of air humidity and the mechanisms of the variation of $CH_4$ emission.

### 4.2. THE PATTERNS OF $CH_4$ EMISSION AT VARIOUS WATER LEVELS

The variations of $CH_4$ concentrations were different when the water depth changed. When the depth was 10 cm, $CH_4$ concentration increased in the first stage and then decreased. Under this condition, more $O_2$ diffused into the soil [18] resulting in more $CH_4$ oxidized at the surface layer of soil where the $CH_4$ oxidation activities were the strongest, and the rest emitted to the water-air interface rapidly and released. Approximately 15 min later, the $CH_4$ concentration in the static chamber was close to saturated

concentration. Therefore, the rate of $CH_4$ emitting from water to the chamber decreased over time. The reduced $CH_4$ emission did not mean that $CH_4$ was absorbed by water; the rate of $CH_4$ emitting decreased. It can be approved by a higher concentration of $CH_4$ than the initial one. When the depth was 20 cm, the concentration decreased first and then increased. The approaches to $CH_4$ emission are bubbles, diffusion, and the pathway through vascular plants [19]. Especially the main pathway for $CH_4$ emission is bubbling [20]. At the depth of 20 cm, the emission paths became longer, and more $CH_4$ would be oxidized by the soil oxidation layer due to its deeper than the water level of 10 cm. This would lead to less release of $CH_4$, and a trace of $CH_4$ in the air would diffuse to water to keep balance. Therefore, the $CH_4$ concentration decreased. However, as the temperature increased with time from morning to noon, the activity of methanogens became stronger to generate more $CH_4$ [21]. $CH_4$ emission increased due to a period of accumulation. These caused the $CH_4$ concentration to increase. $CH_4$ emission had no obvious pattern at the depth of 40 cm probably because of the complex factors and their interaction [15].

### 4.3. RESPONSES OF THE $CH_4$ EMISSION TO WATER LEVELS

In our study, the average $CH_4$ loads at different water levels of 10, 20, and 40 cm were 2739.76, 2773.06, and 2764.47 mg/($m^2$·h), respectively; thus the order of average $CH_4$ loads was 20 cm > 40 cm > 10 cm. This illustrated that the depth of 20 cm is the optimum condition for $CH_4$ emission.

$CH_4$ is generated by methanogens in an anaerobic environment. At deeper water levels, only a small amount of $O_2$ diffuses into the soil resulting in more $CH_4$ production in a strictly anaerobic environment. Methanotroph activity increases with an increase in the amount of $O_2$ transferred to roots [22], then an oxidization layer formed that can oxidize $CH_4$ generated from sludge in the shallow water [23]. Besides, water levels affected the $CH_4$ emission by affecting the soil's redox potential [12]. Decreased redox potential caused by flooding led to an increase in $CH_4$ emission [12]. The above caused more $CH_4$ emission at deeper water levels. Some researchers reported similar results. For example, similar results that fluxes of $CH_4$ increased with the increase of water depth from 5 to 20 cm have been shown in Sanjiang Plain [24]. However, the $CH_4$ emission at the depth of 40 cm was less than that at 20 cm in this research, probably diffusion of bubbles from 40 cm underwater to the water-air interface was more difficult [25, 26].

## 5. CONCLUSIONS

$CH_4$ emission had different patterns at various water levels and $CH_4$ emission would be more facilitated at the water depth of 20 cm. Emissions of $CH_4$ were positively correlated with temperature and negatively correlated with air humidity. It is worth noting

that water level and temperature should be considered when accounting for greenhouse gas emissions in the constructed wetlands as they both play important roles in determining $CH_4$ emission.

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