Pol. J. Environ. Stud. Vol. 23, No. 4 (2014), 1255-1262

Original Research

Main Affecting Factors of Soil Carbon Mineralization in Lake Wetland

Yan Lu, Hong-wen Xu*

Jiangsu Key Laboratory for Eco-agricultural Biotechnology around Hongze Lake,
School of Urban and Environmental Science, Huaiyin Normal University, Huai'an, China

Received: 13 November 2013
Accepted: 14 January 2014

Abstract

The aim of our study was to investigate the effects of some main factors, temperature, moisture condition, and organic matter input on soil organic carbon mineralization based on the method of an incubation experiment carried out at Hongze Lake wetland in Jiangsu province of China. The result showed that mineralization rate dynamics of soil organic carbon conformed to the logarithmic equation. Temperature increase could accelerate mineralization rate and cumulative mineralization amount of soil organic carbon in the wetland soils, and improving flooded soils most sharply. Flooding could boost mineralization rate and the cumulative mineralization amount of soil organic carbon, but inhibit decomposition of organic matter. Organic matter input increased the mineralization rate and cumulative mineralization amount of soil organic carbon in the treated soils, which was mainly due to enhanced activity of soil microorganisms caused by organic matter input. Our results indicated that soil carbon mineralization was a relatively complicated process influenced by various environmental factors. Thus, it is necessary to conduct further studies on the mathod through which other environmental factors affect soil carbon mineralization in order to understand their role in soil carbon emissions of wetland ecosystems.

Keywords: wetland soil, temperature, moisture, organic matter input, Hongze Lake Wetland

Introduction

Hongze Lake is China's fourth largest freshwater lake (33º06' N~33º40' N, 118º10' E~118º55' E), located in the northwest of Jiangsu province with a water area of 1,597 km^2. The lake and the surrounding area have formed a relatively complete inland wetland, which is one of the most important wetlands in China. At present, organic carbon dynamics in wetland soil research focuses on the study of climate change. The soil organic carbon dynamic process involves two aspects. First, the soil organic carbon is changed into carbon dioxide through mineralization. Second, the soil organic carbon becomes more stable through the process of humification. Carbon dioxide released through soil mineralization is the product of soil active carbon pool and its microbial decomposition. It is also the product of the used organic carbon, which acts as an energy substrate in the process of microbial metabolism [1].

Mineralization of soil organic carbon is an important biochemical process directly related to the release and supply of nutrient elements, formation of greenhouse gases, and maintenance of soil quality. Thus, revealing the law in soil organic carbon mineralization will have important practical significance for scientific management of nutrients and effective control of global climate warming. The soil organic carbon mineralization process is conducted with microorganism involvements, and is influenced by many factors, including temperature, moisture condition, soil properties, and so on. One of the most important factors

*e-mail: hongwen_xu@163.com

Table 1. Basic physical and chemical properties of studied soils.

Soil type	Total carbon ($g \cdot kg^{-1}$)	Total nitrogen ($g \cdot kg^{-1}$)	Ammonia nitrogen ($mg \cdot kg^{-1}$)	Nitrate nitrogen ($mg \cdot kg^{-1}$)	Available nitrogen ($mg \cdot kg^{-1}$)	Bulk density ($g \cdot cm^{-3}$)
Swamp soil	62.11±5.97	3.96±0.19	26.68±2.11	6.55±0.72	382.81±29.33	0.87±0.07

affecting soil carbon mineralization is soil moisture, which can improve mineralization rates by enhancing microbe activity and by increasing microorganism quantity [2]. Soil organic carbon mineralization generally increases with an increase in soil moisture under the same temperature conditions [3]. Temperature is another important factor influencing soil carbon mineralization [4]. Significant variance was found under different temperatures by Bai et al's report [5]. Organic matter input will affect the balance between carbon mineralization and stabilization, carbon mineralization is affected by significant differences in chemical composition of crop residues [6], and mixed residues could promote the cumulated carbon mineralization at the end of incubation [7].

Although research about affecting factors on carbon mineralization in soil have been well documented, most are about cropland-soil systems and there are limited systematic investigations on wetland ecosystems. In order to reveal the influence mechanism of main affecting factors on wetland soil organic carbon mineralization, incubation experiments were conducted using wetland soil in Hongze Lake of China under different conditions of temperature, moisture, and organic matter input.

Material and Methods

Soil Sampling

Estuary wetland, located on the western shore of Hongze Lake, is a typical wetland. In November 2012, 0-20 cm of surface soil in the estuary wetland was collected by the multi-point hybrid method, and samples were taken indoors while still fresh. The samples were divided into two parts after removing visible plant roots and rocks. One part was put in the refrigerator (4ºC) for test after 2 mm sieve. And the other was dried and finely ground for chemical analysis. The basic physical and chemical properties of the tested soil are shown in Table 1.

Experimental Design

Tested soil was cultured at room temperature for three days. 40 g pre-incubated soil (dry soil) was weighed, and was put in a 1,000 mL culture bottle. In flooded water treatment, 40 mL distilled water was added (water submerging soil by 0.5 cm). In organic matter input processing, 1 g surface vegetation of Phragmites communis was added into each bottle, the culture bottle was sealed, and then culture them in the constant temperatures of 20ºC and 35ºC, respectively. At the same time, do two blank tests.On the 2nd, 3rd, 5th, 7th, 9th, 11th, 13th, 16th, 19th, 22th, 25th, 28th days (a total of 12 times), pump the gases from the culture bottle, and 30 mL gases were put in each bottle. Open the bottle for half an hour to ensure that the gas in the bottle is consistent with that in the air, and then seal the culture bottle. A was high-temperature treatment (35ºC) and B was room-temperature treatment (20ºC). A1 to A4 respectively represented the original soil, flood, the original soil with organic matter, and the flood with organic matter under high temperature. And B1 to B4 respectively showed the original soil, flood, the original soil with organic matter, and the flood with organic matter under room temperature.

Measurements

A gas chromatograph was used to measure the concentrations of carbon dioxide in the gas. And the data were analyzed by one-way analysis of variance (ANOVA) followed by Duncan's test at 0.05 significance level to compare the means using SPSS 16.0 for Windows.

Results

Effect of Temperature on Carbon Mineralization in the Wetland Soil

Comparison of mineralization rate of original soil (I), flooded soil (II), original soil with organic matter (III), and flooded soil with organic matter (IV) at high temperature (35ºC) and room temperature (20ºC) is shown in Fig. 1. It was seen that organic carbon mineralization rates at high temperature were greater than those at room temperature for any kinds of treated soil. Mineralization rate of organic carbon at room temperature was higher in the early training, and then declined until a steady level. A2, A3, and A4 first reduced, then rose, and decreased again under high temperature. This indicated that increased temperature could enhance mineralization rate of soil organic carbon in the original soil, flooded soil, and organic matter. In general, dynamic changes of carbon mineralization rate of original soil at high temperature and other soils treated at room temperature conformed to the logarithmic function:

A1: $Y=-0.38Ln(X)+1.52$, $R^2=0.77$, n=12
B1: $Y=-0.28Ln(X)+0.95$, $R^2=0.83$, n=12
B2: $Y=-0.16Ln(X)+1.12$, $R^2=0.62$, n=12
B3: $Y=-2.24Ln(X)+7.37$, $R^2=0.82$, n=12
B4: $Y=-0.84Ln(X)+5.28$, $R^2=0.64$, n=12

Y was the mineralization rate of organic carbon ($mgCO_2\text{-}C \cdot kg^{-1} \cdot h^{-1}$), X (d) was incubation time.

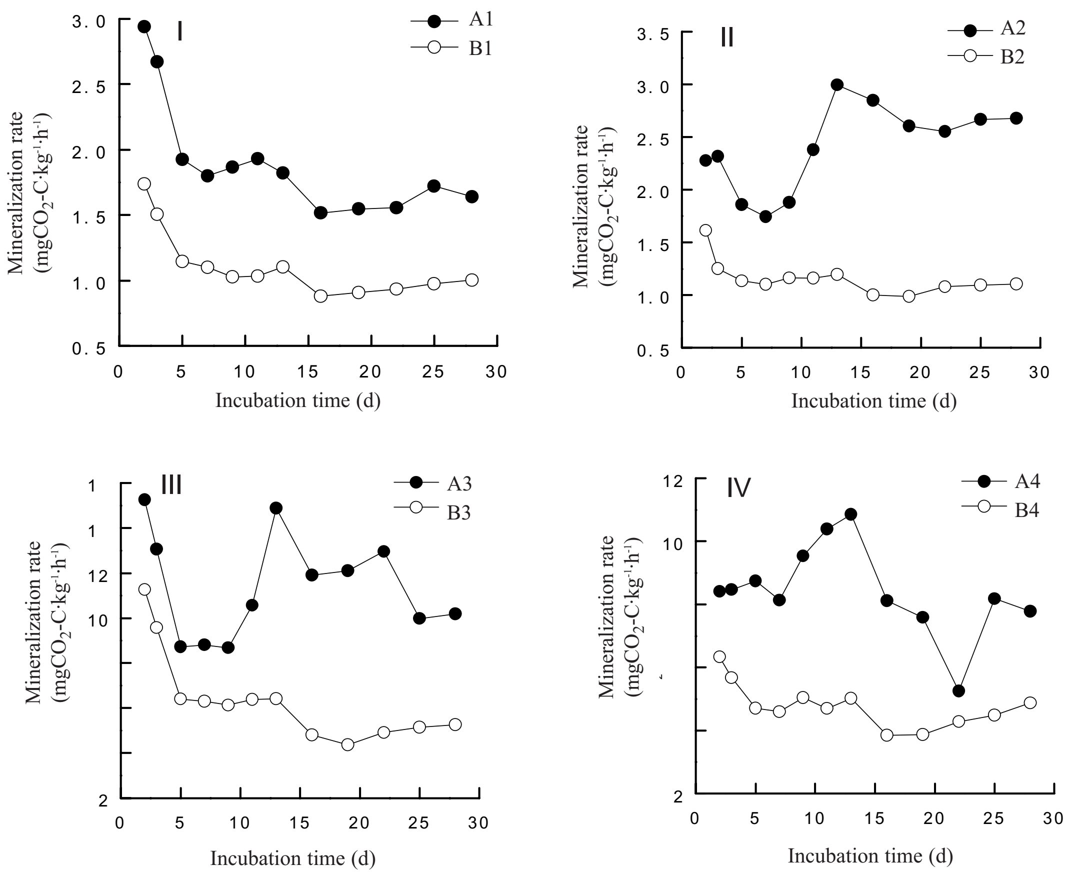

Fig. 1. Mineralization rate of soil organic carbon under different temperatures.

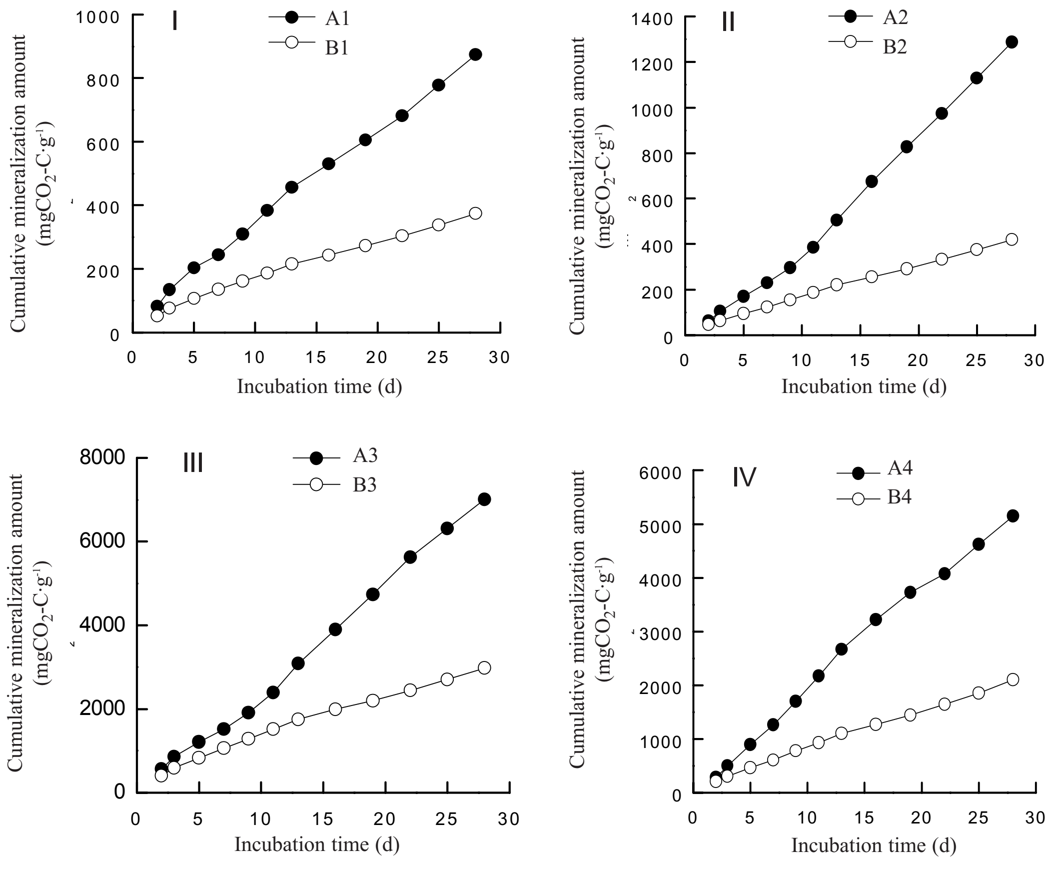

Fig. 2. Cumulative mineralization amount of soil organic carbon under different temperatures.

Throughout the whole training period, high temperature significantly increased cumulative mineralization for all kinds treated soil (Fig. 2). Significance of difference analysis showed that great differences existed between A1 and B1, A2 and B2, A3 and B3, and A4 and B4 ($n = 3$, $p < 0.05$). It was found that increased temperature could significantly improve organic carbon decomposition of wetland soil and organic matter, and the largest percent changes occurred in flooded soil.

Effect of Moisture Conditions on Wetland Soil Carbon Mineralization

Fig. 3 showed respectively comparison of mineralization rates of organic carbon in original soil (I), original soil with organic matter (II) at high temperatures, original soil (III), and original soil with organic matter (IV) at room temperature under different moisture conditions. It was suggested that soil organic carbon mineralization rate of the original soils was greater than that of flooded soils in the early period. Since day 7, the soil organic carbon mineralization rate of flooded soils was higher than that of the original soils (I, III). However, mineralization rate of flooded soils was less than that of the original soils (II, IV) after organic matter input. Thus, it could be concluded that flooding enhanced the mineralization rate of soil organic carbon, but inhibited decomposition of organic matter.

Cumulative mineralization amount of soil organic carbon in early period, A1 was higher than A2, while from the 11th day, A2 was always larger than A1, that is, the cumulative mineralization amount of organic carbon in the flooded process was greater than original soil (Fig. 4). B1 and B2 followed the same changing trend. Significance analysis showed that the cumulative mineralization amount of organic carbon between A1 and A2, A3 and A4, and B3 and B4 had significant differences ($n = 3$, $p < 0.05$). However, no significant differences were found between B1 and B2, that is the cumulative mineralization amount of organic carbon had no differences between original soil and flooded soil at room temperature.

Effect of Organic Matter Input on Wetland Soil Carbon Mineralization

Fig. 5 showed comparison of mineralization rates of organic carbon in original soil (I), flooded soil (II) under high temperature, and original soil (III) and flooded soil (IV) under room temperature, whether to input organic matter. It could be seen that no matter what kind of treatment, mineralization rates of organic carbon in the soil with organic matter was obviously higher than that in original soil. Besides, it was higher in the early period of culture, and decreased until stability. But mineralization rates of soil organic carbon in the soil added with organic matter under high temperature decreased first, then rose, and fell again until a stable level.

It could be seen from Fig. 6 that regardless of original soil or flooded soil, whether high temperature or room tem-

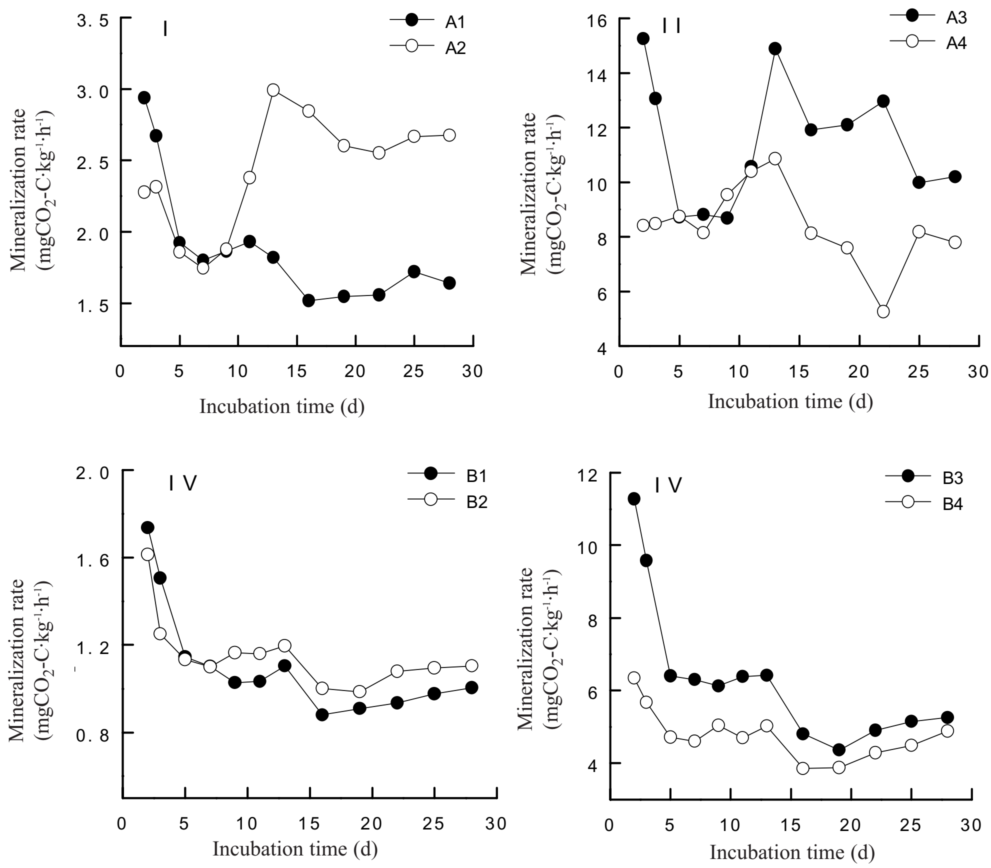

Fig. 3. Mineralization rates of soil organic carbon under different moistures.

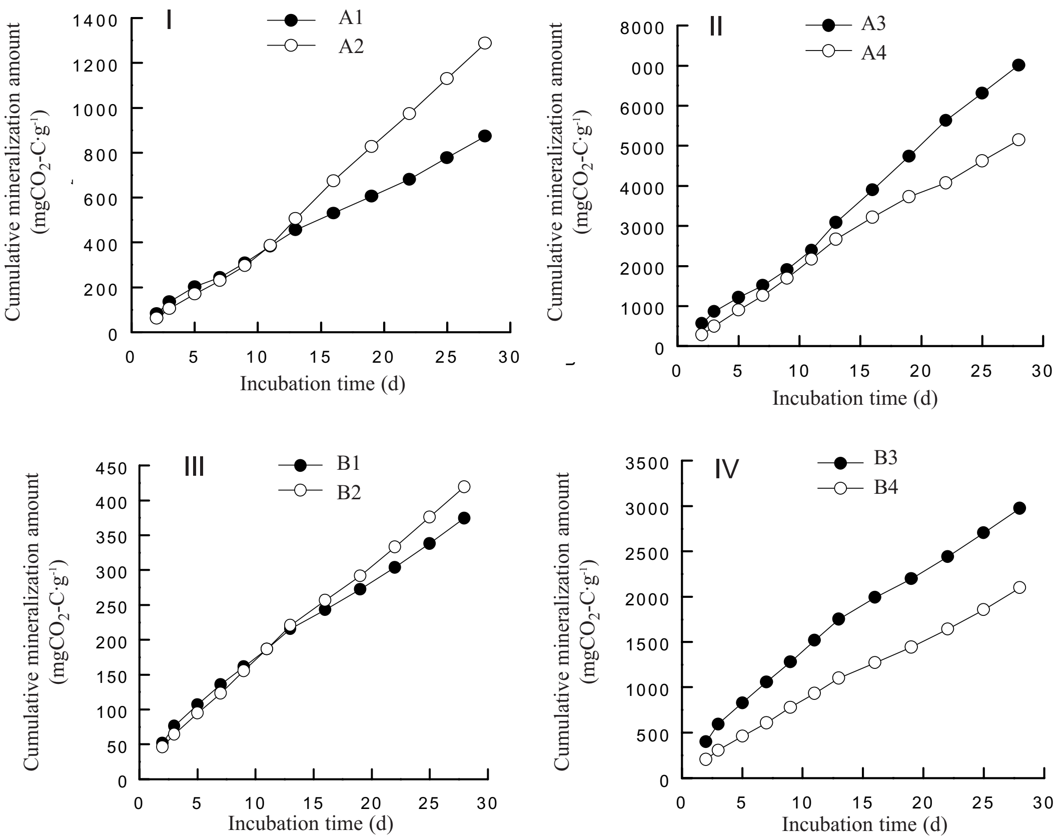

Fig. 4. Cumulative mineralization amount of soil organic carbon under different moistures.

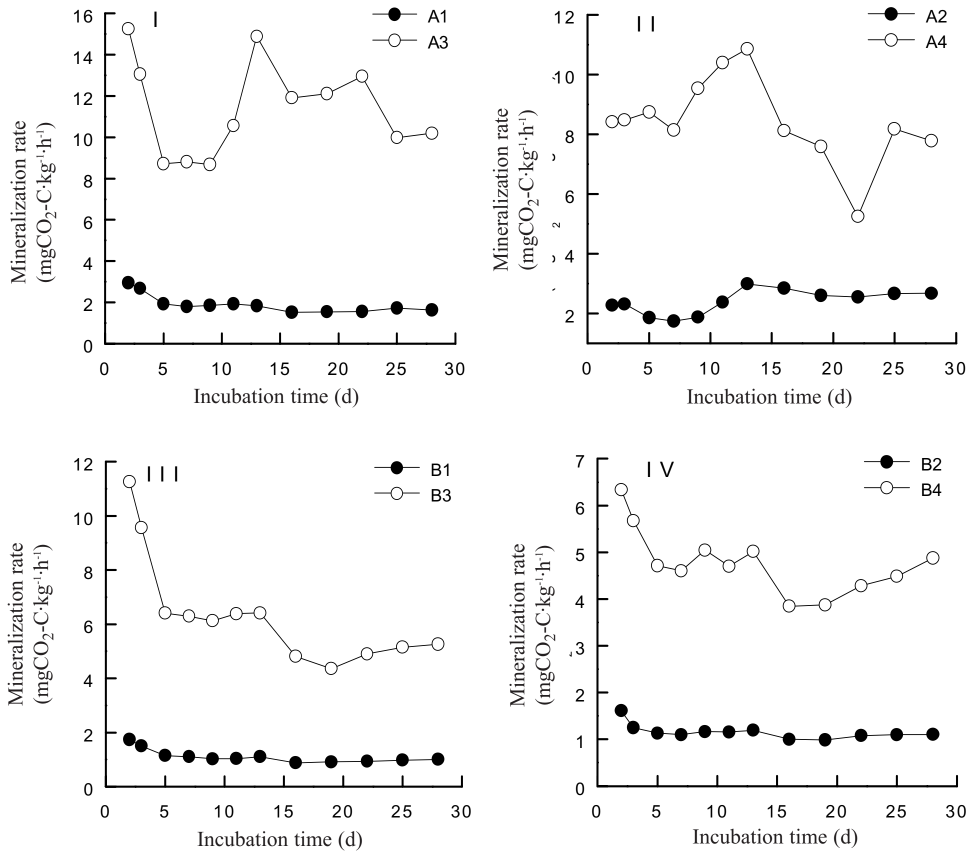

Fig. 5. Mineralization rate of soil organic carbon under organic matter input.

perature, organic matter input significantly increased cumulative mineralization amounts of soil organic carbon and differences reached a significant level ($n = 3$, $p < 0.01$).

Discussion

Weintraub and Schimel concluded that soil organic carbon mineralization rate was continuously declining in a year, and a similar trend was also found in Franzluebbers' report [8, 9]. Soil organic carbon mineralization changed with the incubation time mainly due to changes of active organic carbon content caused by less incubation time. The present study has suggested that soil organic carbon mineralization rate was quick then slow until falling to a steady state, which is in line with previous research results. But only the soil organic carbon mineralization rate of original soil showed this trend under high temperatures, and the other processing changes were uncertain. This indicated that increased temperature accelerated the decomposition rate of soil and organic matter, but the impact process was relatively complex.

Temperature is an important factor in wetland soil organic carbon decomposition and mineralization [10]. Numerous studies have shown that temperature had a significant effect on soil organic carbon mineralization [11-14]. Fang and Moncrieff's studies indicated that farmland and the plantation soil mineralization index change with increases in soil temperature [15]. Wu et al. also proved the trend through his investigation [16]. Huang et al. thought that increased temperature could significantly promote decomposition of organic carbon, but insignificant improvement was found under low temperature [17]. While under high temperature, the promotion effect temperature rise has on organic carbon decomposition. Research indicated that soil organic carbon mineralization and content of microbial biomass carbon is positively related [18]. Therefore, we could deduce that the increased amount of soil organic carbon mineralization was due to quickened soil microorganisms activity caused by a rise in temperature. And it could accelerate decomposition of organic carbon and release more inorganic carbon [19, 20].

Moisture conditions affected soil organic carbon mineralization rate and mineralization amount, and flood could improve dissolution of soil organic carbon and lead to dispersion of aggregates [21, 22]. Flooding could increase the soil-effective carbon pool amount, thus affecting mineralization rate of soil organic carbon. Research indicated that the cumulative mineralization amount of soil organic carbon in flooded water treatment was higher than that in non-flooded water treatment. In flooded conditions, however, the soil aeration was changed, which inhibited activity of microorganisms. If flooding made a lot of dissolved organic carbon dissolute, and effect on microorganisms was relatively weak, then soil organic carbon mineralization rate and amount increased. On the other hand, if the contribu-

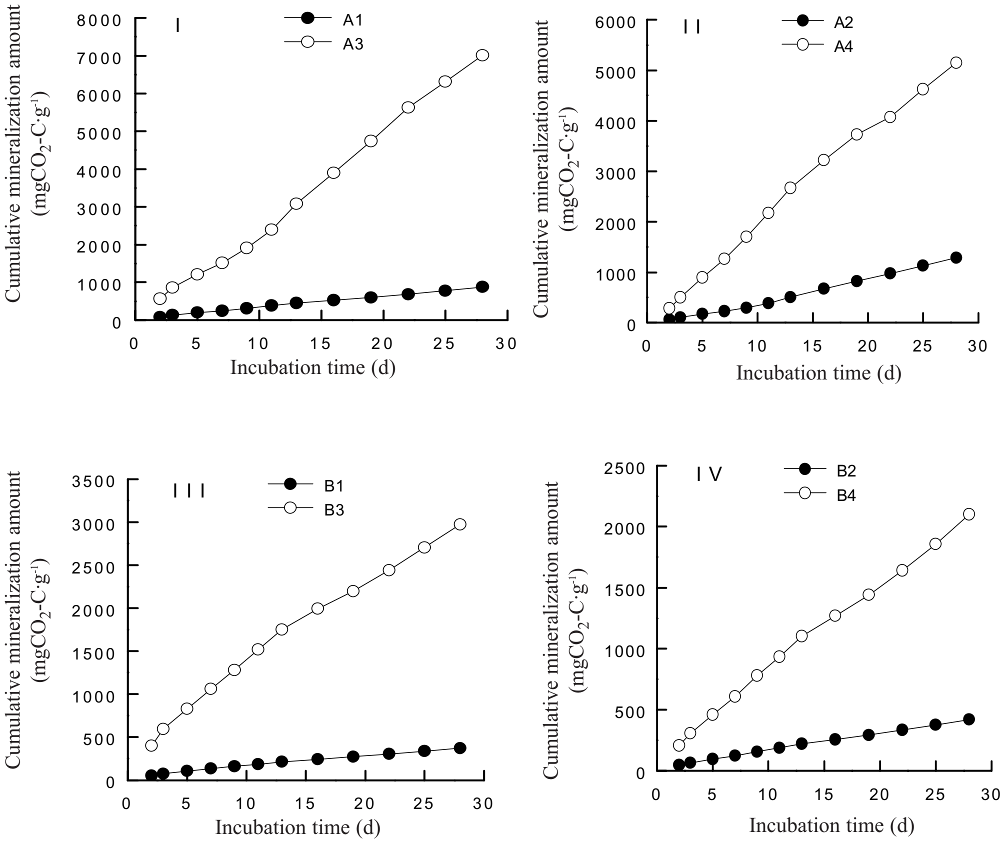

Fig. 6. Cumulative mineralization amount of soil organic carbon under organic matter input.

tion from flooding to the dissolved organic carbon dissolution was relatively less than the effect on microorganisms, then soil organic carbon mineralization rate and amount decreased.

This study found that cumulative mineralization amount of organic carbon in flooded soil was obviously higher than that of original soil under high temperature, which is due to the fact that the increased effect of soil dissolved organic carbon content was higher than the inhibition of microbial activity caused by flooding. Thus, cumulative mineralization amount of organic carbon in flooded soil increased significantly. However, insignificant differences were found between flooded soil and original soil at room temperature, which is consistent with research results of wetland soil conducted by Zhang et al. [23]. Different results between high temperature and room temperature could be explained by high temperatures increasing soil microbial activity or inhibited decreases in microbial activity. By comparison, flooding had an obvious inhibition effect on soil microbial activity at room temperature. Although flooding could improve content of soil-dissolved organic carbon and promote organic carbon mineralization, this promoting effect rivaled the inhibition effect of microbial activity, so the mineralization amount of soil organic carbon in original soil and flooded soil under room temperature had insignificant differences. While decomposition of exogenous organic matter in soil was mainly conducted under the reaction of microorganisms [24], flooding inhibited soil microbial activity. Thus, the cumulative mineralization rate and amount decreased after organic matter input to flooded soil in our experiment.

Organic matter input could significantly improve mineralization rate and cumulative mineralization amount of soil organic carbon [25-28]. This suggested that organic matter input accelerated decomposition of soil organic carbon, and occurred to positive priming effect. Zhou et al. found that species components of vegetation determined the decomposition rate of soil organic carbon. Soil organic carbon originated mainly from litter aboveground and root exudates underground. The carbon compounds have their own chemistry characteristic, so their decomposition rate is different in soil [29]. Furthermore, organic matter input provided a readily utilizable carbon source for soil microorganisms and promoting their growth and reproduction [30, 31]. Studies of Zhang et al. showed that soil dissolved organic carbon content as the main energy source increased after organic matter input [32]. This suggests that organic matter input stimulated soil microbial activities [33]. Soil microorganisms made full use of soil organic carbon for their growth and reproduction, and carbon dioxide was released through soil organic matter decomposition in the process of life. As continuous decomposition of exogenous organic matter, easily dissolved nutrients died out, and stable ingredients broke down slowly. As a result, energy and nutrients supplied for microorganisms gradually were reduced. Microbial activity was diminished and thus the number of microorganisms decreased and finally leveled off .

Conclusions

(i) Mineralization rate dynamics of wetland soil organic carbon in original soil under high temperature, original soil under room temperature, and soil submergence and soil input in organic matter, conformed to the logarithmic equation. Increased temperature enhanced mineralization rate and the cumulative mineralization amount of soil organic carbon in wetland soils, and improved flooded soils most sharply.

(ii) Flooding improved mineralization rate and cumulative mineralization amount of wetland soil organic carbon, but inhibited decomposition of organic matter. The impact flooding had on soil organic carbon mineralization was the result of a function of the equilibration between enhancement of dissolved organic carbon content and inhibition of microbial activity.

(iii) Organic matter input increased mineralization rate and cumulative mineralization amount of soil organic carbon in all kinds of treated wetland soil. And all cumulative mineralization amounts were significantly raised after organic matter input ($p<0.01$), due to increased activity of soil microorganisms caused by organic matter input.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (41201559, 41301314), the Natural Science Foundation of Universities in Jiangsu province area of China (10KJB170003), and the Natural Science Foundation of Jiangsu province (BK2011412).

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