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Effects of Temperature and Moisture on Soil Organic Carbon Mineralization

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Abstract. As an important index of soil fertility and ecological balance, soil organic carbon had been universal concern. This paper summarized research conditions of temperature and moisture on soil organic carbon in recent years, introduces the effects of temperature, freezing-thawing cycles, water and dry-wet cycles on soil organic carbon mineralization, and discusses the dynamics research of soil organic carbon mineralization, proposed to be further resolved problems.

1. Introduction

Recently, research of soil organic carbon(SOC) has become a hot topic of three global change research [1]. As an important part of soil, SOC plays an important role in the fertility of soil and the balance of ecosystems, agriculture and other aspects of sustainable development, even though only a small fraction of the total mass of the soil. SOC(1500Pg) is about 2.4 times that of the terrestrial biomass carbon (620Pg), which sequestration and mineralization is directly related to soil nutrient release and supply, greenhouse gas formation and maintaining soil quality, etc [2], and also plays an important role in regulating the CO₂ concentration of global atmospheric[3].

As the main environmental factors, temperature and moisture plays important role in the SOC mineralization by affecting the activity of microbial, so the influence of temperature and moisture on the internal mechanism of transformation of organic carbon is very important. This article is main to further more understand the internal mechanisms of the effects of temperature and moisture on SOC mineralization, and proposed emphasis of SOC mineralization in the future research.

2. Effects of Temperature on SOC Mineralization

2.1. Temperature

Temperature has significant effects on SOC mineralization and the mineralization rate increases exponentially with temperature[4]. The effect of temperature on the process of soil respiration by influencing the number of soil microbial activity and community composition[5], at higher temperatures, extracellular enzymes move faster, which enhanced microbial assimilation and SOC mineralization, so release more CO₂.

Under low temperature (20°C), SOC mineralization rate is low and relatively stable, rising temperature will greatly promote the SOC mineralization; Under high temperature (25°C), pre-SOC mineralization rate is higher, with the incubation time decreased and stabilized, SOC mineralization



promoting effect weakened when elevate temperature[6]. The proportion of organic matter component can also affect the decomposition rate and mineralization temperature sensitivity. Ren et al[7] have studied three different clay content of paddy soil (sandy loam, clay loam, pink clay) in the sub-tropical regions and found that SOC mineralization amount of three kinds at 30°C is 3.5, 5.2, and 4.7 times higher than 10 °C, respectively. Yang et al[8] reported that total amount of mineralization under the flooded condition would increase by 30-200% when temperature rise 10°C.

Soil temperature fluctuated frequently under natural conditions, in order to simulate the effect of temperature on SOC mineralization under natural conditions, Zhu[9] was conducted a experiment with constant and diurnally-varying temperature, and found that Q10 values under constant temperature regime were consistently and significantly ($P < 0.05$) higher by 9-30% than those under diurnally-varying temperature regime, particularly in the later stages of decomposition. But the mechanisms leading to the difference was not clear at this point, may be associated with possible differences in microbial community composition between the two temperature regimes. Soil microbes are a diverse mixture of different species with different optimum temperatures (T_{opt}) for growth and respiration [10]. Therefore, Zhu suggest that under constant temperature regimes, species whose T_{opt} is close to the constant soil temperature may have a competitive advantage than other species. Over time, the constant temperature regime may selectively favor microbes already genetically better adapted to the temperature level. By contrast, under diurnally-varying temperature regimes, a more diverse community of microbes may coexist because more species are likely to experience their T_{opt} during this diurnal temperature range. Therefore, compared to the more diverse community including a wide range of microbes under diurnally-varying temperature regime, the community dominated by few genetically more adapted microbes under constant temperature regimemay produce more CO_2 . This hypothesis has been indirectly supported by an empirical study which showed that different soil temperatures progressively selected microbial communities growing better at the specific temperatures but direct evidence of this suggest are not yet available. More studies are needed to further test the generality of our findings and to explore the mechanistic explanations.

2.2. Freezing–Thawing Cycles

Recently, freezing-thawing cycles widely attention as a special form of temperature change. Numerous studies show that the release of greenhouse gases increased in the process of the thawing permafrost. Freezing–thawing cycles enhanced soil carbon mineralization process by changing soil aggregate stability and damaging soil structure which would cause collapse of aggregate and the aggregate protect SOC exposed to the air. Freeze-thaw cycles, on the other hand, would kill microorganisms in the soil, and the death micro-organisms can be directly use by alive microbes as substrate, thereby accelerate the mineralization rate. However, there was no significant promoting effect on SOC mineralization in the short term, although freezing - thawing cycles have a stimulating effect at the beginning. Ludwig et al[11] found that CO_2 emission reaches a maximum in two days after the freeze-thaw process, and then gradually decreased, four days later reached a stable level. Hao et al[12] reported that the priming effect of SOC was abate with the increase number of freezing and thawing cycles , and for SOC mineralization showed SOC inhibition. This may be because, freezing-thawing cycles enhanced microbial respiration intensity in the early, and improved the SOC mineralization rate; then microbial gradually adapted to this change with the increase of freeze-thaw cycle times, so its ability to stimulate mineralization were gradually weakened. In addition, long-term freezing-thawing cycles would damage physical structure of soil, and reduced microbial biomass, so the priming effects on SOC mineralization turn into restrain.

3. Effects of Moisture on SOC Mineralization

3.1. Moisture

Extreme moisture conditions would limit CO_2 release: low soil moisture would limit microbial and root respiration; excessive would block the soil pore and limit O_2 and CO_2 release. Generally, SOC mineralization rate increases with the soil water content[13-15]. While, whether the effect of moisture on SOC mineralization was significantly were not sure [16]. SOC researcher reported that soil type and

the determination method of CO₂ during the period of incubation would affect the effect of moisture of SOC mineralization. There were two completely opposite conclusions about whether flooded would inhibit the SOC mineralization in farmland: (i) aerobic conditions were more conducive to the SOC mineralization than flooded conditions[17]; (ii) the flooded conditions were more conducive to the SOC mineralization than aerobic conditions[18-19].

Conventional view holds that: mineralization rate of fresh SOC is low and humification coefficient is high under flooded conditions, so result in a large number of organic carbon accumulation; Under the condition of aerobic, microorganisms can be directly converted organics into CO₂; Inhibition of soil microbial activity under the flood water treatment [20] and mainly anaerobic microbes, energy released is low in redox processes [21], so the mineralization rate of soil organic matter is low., the mineralization rate of soil organic matter was strongest When soil water content was 60%-80% of field capacity [22].

Recently, SOC test data show that, mineralization rate of SOC under flooded conditions was significantly higher than aerobic condition. Because DOC have high biological availability, and Flooding increases the amount of DOC, therefore, the mineralization rate of SOC was higher. Huang et al[23] suggest, if environmental conditions are not obstacles, anaerobic conditions would decompose more organic matter to meet the need for energy, and the decomposition rate of organic carbon may be faster under flooded condition .

The different trends of mineralization rate of SOC was related to soil microorganisms and structure[24]. Flooded increases the content of DOC, but also changed the soil aeration condition, inhibit microbial activity. So whether the mineralization rate of SOC higher or not under flooded condition, depends on the relative degree of the influence on the microbial and DOC. If flood makes a lot of DOC dissolution, while relatively small impact on microorganisms, was characterized by the mineralization rate of SOC increase; conversely, was characterized by the mineralization rate of SOC decreased. different moisture conditions, Therefore, microbial activity and its available substrate quantity were key to illustrate the change rule of SOC mineralization under different moisture conditions. At present, the research of effects of moisture on the generation of DOC was more, but SOC issues still in dispute. while the Variation of microbial under different water treatments was less. Therefore, the Variation of microbial under different water treatments would be the focus of future research on SOC mineralization.

3.2. Dry-Wet Cycles

Soil often under dry-wet cycle conditions due to the frequent rainfall or irrigation soil after slow drying under natural conditions. soil in aerobic and anaerobic alternating environment under dry-wet cycles, therefore would promote the diversity of microorganisms [25], which strongly influence soil carbon conversion, and accelerate the mineralization of SOC. The increase in mineralization of SOC can be partly attributed to microbial death upon rewetting of dry soil, and partly to the increased exposure of organic residues. Both microbial biomass and organic residue can be simultaneously involved in enhanced mineralization.

McInemey [26] had reported that, the rate of CO₂ emission reaches the maximum within 2-8h after dry-wet cycles, and then began to decline after 12-24 h. while the cumulative mineralization of SOC after frequent dry-wet cycles compared with constant humidity remains controversial. SOC researchers pointed out that the repeated dry-wet cycles reduces soil microbial activity, lead to cumulative mineralization of SOC was relatively lower than constant humidity conditions, and the response of the rate of soil respiration were weakened with the increase of dry-wet cycles times [27]. Other researchers reported that, the rate of CO₂ release was reduced with the increase of dry-wet cycles times in a certain incubation time, while the total amount of gas release was higher than constant humidity conditions [28, 29]. The difference of the results may be related to research methods (incubation temperature, duration, frequency and intensity of dry-wet cycles) and the amount and composition of SOC [30].

In general, the observed decline in the C flush with repeated dry/wet cycles cannot be explained by reductions in the size of the microbial biomass. Two possible explanations have been proposed: (i) if drying and rewetting releases physically protected organic matter, there simply may be less organic

matter available for release following a series of dry/wet cycles, reducing the C flush; (ii) after several dry/wet events, the microbial community may adjust to the water potential shock encountered during rewetting. This adjustment would lessen the mortality rate and reduce the size of the flush of labile substrate available for mineralisation by the surviving microorganisms. At present, there were two main kinds of mechanisms to explain the sources of CO₂ released of soil in the process of dry-wet cycles. The first is the “microbial stress” mechanism, to survive drought, microbes must accumulate high concentrations of solutes (osmolytes) to retain water inside the cell and prevent dehydration [31]. On rewetting, water potential rapidly increased, in order to balance the external water potential, microbes need to quickly translate the solute that accumulate before, these solutes was decomposed into carbon-containing compound and labile organic carbon. while the second is the ‘substrate supply’ mechanism. In drought conditions, soil aggregate structure would be compressed, thus would expose previously protected soil organic matter and soil surface. On rewetting, the soil would swell, soil aggregate structure was further damaged, exposed to the microbial organic surface will increase, thereby increasing the availability of soil nutrient [32].

4. Interaction of Temperature and Moisture

Temperature has significant effects on SOC mineralization and the mineralization rate increases exponentially with temperature. The significant effects of moisture on SOC mineralization remains controversial affected by soil type and other factors [33,34], while many studies have shown that the rate of SOC mineralization usually increases with the increase of soil water content, and the interaction of temperature and moisture significantly affect the cumulative mineralization of SOC and CO₂ emission.

Wang et al[13] reported that, in the minimal of soil moisture content (10% of field capacity), temperature sensitivity of SOC mineralization was the lowest; moisture sensitivity of SOC mineralization at low temperatures (10°C) was significantly lower than the optimum temperature and high temperature (20°C-30°C). Wang et al[4] point out that at the same temperature, the rate of SOC mineralization in each soil layer reached the maximum when at 60% WHC (field capacity). Joseph et al[35] examined relationships between soil moisture and the temperature sensitivity of xeric uplands and deeper, mesic lowlands in grassland, and found that Soil moisture significantly affected the temperature sensitivity of respiration. For soils collected from shallow, xeric uplands, temperature sensitivity was greatest at intermediate soil moisture. For soils collected from the deeper, mesic lowlands, temperature sensitivity increased with increasing soil moisture, lowland soils incubated at 75% WHC exhibited an apparent activation energy (E_a) that was 15 kJ mol⁻¹ greater than incubated at 30% WHC. Difference between the results of two types of soil may be related to soil physical and chemical properties. In all, it appears that alterations of soil moisture for SOC soils have the potential to alter the temperature sensitivity of decomposition in ways that could amplify or dampen direct effects of temperature on decomposition.

5. Conclusions

SOC is an important index for soil fertility evaluation and its mineralization is an important content of ecosystem carbon cycle. The effects of temperature and moisture on SOC mineralization dynamic remains controversial affected by soil type and incubation duration and the determination method of CO₂, such as the effects of temperature and flooding on dynamic characteristics of SOC mineralization; the sources of SOC mineralization under dry-wet cycles, etc. As people gradually realize the importance of SOC mineralization on soil fertility and ecosystem balance, the study of its more and more and more deeply. Estimated the future study of the dynamic of SOC mineralization mainly focuses on the following aspects: (i): the diversity of tested soil types and unity of determination method of CO₂, which were the main factor limiting test results. (ii) simulat the effects of temperature variation (temperature difference between day and night) under the natural condition on the dynamic SOC mineralization, and the response mechanism of microbial communities to constant and diurnally-varying temperature.(iii) The source of SOC mineralization and the variation of microbial community under flooding and dry-wet cycles conditions.

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