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Effects of extreme drought on agriculture soil and sustainability of different drought soil

S. M. Geng[1,2], D. H. Yan[2], T. X. Zhang[3], B. S. Weng[2], Z. B. Zhang[2], and W. Gang[2]

[1]College of Civil and Hydraulic Engineering, Tsinghua University, Beijing, 100084, China
[2]State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resource and Hydropower Research (IWHR), Beijing, 100038, China
[3]College of Soil and Water Conservation, Beijing Forestry University, Beijing, 100083, China

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Correspondence to: D. H. Yan (yandh@iwhr.com)

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Abstract

Content of microbial biomass carbon was selected as indicator for identifying effects of extreme drought on agriculture soil ecosystem. Through a series of prototype observation experiments, changing tendencies of microbial biomass carbon content and the proportion of microbial biomass carbon in soil organic carbon were identified. The optimum mass water content of soil for microbial biomass carbon was 19.5 % and the demarcation point of microbial biomass carbon to drought was 14.3 %, which could be used to demonstrate alters and degradation of soil ecosystem as well as the irrigation requirement of crops. We evaluated sustainability of different drought soil ecosystems after experiencing rainstorm with rehabilitation. The results suggested that soil ecosystem which was interfered by moderate drought could recover and its tolerance to drought was improved, as well as its function and activity. Soil ecosystem could barely recover from severe drought and could not adapt to severe drought stress. Soil ecosystem could not restore from extreme drought within a few days, the function and structure were damaged. We came to the conclusion that mass water content of soil should kept above 10 % to avoid destroying function and structure while soil ecosystem would better be watered when mass water content was lower than 14.3 % in order to maintain high productivity.

1 Introduction

Drought is a fundamental part and an extreme condition of hydrological cycle process with significant impacts on society and economy, as well as ecological environment. Extreme drought can greatly affect the function (Liu et al., 2010; Balser and Firestone, 2005), structure (Zak et al., 2003) and productivity (Lal et al., 2013) of soil ecosystem. Agriculture ecosystem is so sensitive to drought stress that extreme drought threaten regional food security all over the world. Losses caused by drought are generally measured by social and economic indicators, such as economic loss and yield loss on crop, nevertheless studies on the effects of drought on sustainability of soil ecosystem remains rare. Selecting indicators to identify the effects of extreme drought on agriculture soil and study the sustainability of soil ecosystem under different drought stress could fill this knowledge gap.

On one hand, microbial biomass carbon, as an important component of soil ecosystem, responds dramatically to soil environment and climate condition, e.g., growth and reproduction of soil microbial are influenced by global warming, precipitation and rainfall pattern changing. Furthermore, different types of microorganism response differently to these stress (Zelles, 1999; Houghton et al., 2001; Panikwv, 1999; M. J. Johnson, 2003). Therefore content of microbial biomass carbon is sensitivity indicator and early warning indicator for soil ecosystem degradation (Nielsen et al., 2002; Kennedy and Smith, 1995; Somova and Pechurkin, 2001). Though microbial biomass carbon generally comprises only 1 ~ 4 % of soil organic carbon, it is a big recharge source and reserve of soil available nutrient (Jenkinson and Powlson, 1981) and has played an important role in maintaining and improving soil structure. The proportion of microbial biomass carbon in soil organic carbon has been an important indicator for soil carbon availability (Insam et al., 1989) and soil ecosystem productivity (Biederbeck et al., 1994), which is a more sensitive indicator than soil organic carbon alone. As a result, content of microbial biomass carbon was selected as indicator to study the effects of drought on agriculture soil. On the other hand, a rainstorm usually followed a drought event, suggesting the relief of drought. Here, we evaluate the sustainability of different drought soil ecosystem after experiencing rainstorm with rehabilitation – if the content of microbial biomass carbon could recovery or not before water content reduced to the thresholds that could be used to demonstrate destruction of the function and structure in soil ecosystem.

Researchers have developed their studies on effects of water stress on soil microbial abundance, composition of community and metabolized production. Many studies have verified that within a certain range, soil microbial activity weakened as soil drought stress intensified (Wilkinson et al., 2002; Drenovsky et al., 2004; Liu et al., 2006) and content of microbial biomass carbon decreased by 39 % (Karen et al., 2003). Since the 21 century, issues on microbial metabolism and microbial adaptability to drought have been studied under the background of frequent, multiple, successively and concurrent occurrence of droughts. Additionally, soil organic carbon/nitrogen declined dramatically with the intensification of drought (Li and Sarah, 2003a, b). However, little research has contented these changes with alters and degradation of soil ecosystem.

In this paper, in order to study effects of extreme drought on soil ecosystem and the rehabilitation of different drought soil ecosystem after rainstorm, we designed a series of prototype observation experiments. Considering effects of drought on microbial might be influenced by vegetation composition (Muhammad et al., 2011), we take soil planted with summer maize for this study. The objectives of the study are: (1) identifying the effects of extreme drought on content of soil microbial biomass carbon and the proportion of microbial biomass carbon in soil organic carbon; (2) finding the thresholds of water content that could be used to demonstrate destruction of the function and structure in soil ecosystem; (3) studying the rehabilitation of soil ecosystem after rainstorm under different drought scenarios. The remainder of this paper is organized as follows. Section 2 presents materials and methods for prototype observation experiments. In Sects. 3 and 4, the results of the prototype observation experiments are presented and discussed. Finally, conclusions are provided in Sect. 5.

2 Materials and methods

2.1 Site characteristics

Soil samples were collected from Daxing Test Base (116°25′ E and 39°37′ N) located in northern Beijing, in China, which was established by China Institute of Water Resources and Hydropower Research. The base lies at 31.3 m a.s.l. and the climate is temperate. The mean annual temperature is 12.1 °C with a mean temperature of approximately 25 °C from July to September. Frostless period lasts for about 185 days and the time of sunshine is about 2600 h. The mean annual precipitation is 540 mm, but more than 80 % distributes in the rain season from June to September while rainfall in spring only accounts for 10 %. Potential evaporation, about 1/3 concentrated from May to June, is 1900 mm, which is much higher than annual precipitation. Relative humidity ranges from 50 to 70 % (Liu et al., 2012).

2.2 Soil characteristics

The soil in Test Base was sandy loam. A more detailed description of soils (the physical, chemical and biological properties) of this research site can be found in Table 1.

2.3 Experiment design and layout

Prototype observation experiments were conducted from late June to late September (summer maize growth season) in winter wheat and summer maize rotation system in the year 2011. In order to stimulate extreme drought scenario, rain shelter was established, which was constructed with stainless steel frame covered on top, and with plastic membrane affixed to all around wall. The rain shelter was opened on fine days for ventilation, and closed on rainy days to prevent rain water entering into rain shelter. Separation waterproof panels were laid 600 mm deep in soil to divide experimental field into three test sections (section A, section B and section C), which was also fixed up between experimental farm and open field to avoid side leakage. To investigate the rehabilitation of different drought soil ecosystem after rainstorm, we considered three test sections responding to three drought scenarios – moderate drought, serious drought and extreme drought, which were classified with relative soil water content (Tables 2 and 3).

At the beginning of our experiment, mass water content of soil was around 25 % in the three test sections. One pooled sample was collected every one or two days in each test section. When the relative soil water content was 47.3 % and drought severity was moderate drought, drought scenario stimulation in test section A was over. At that time, drought in test section A had lasted for 32 days and the mass water content of soil was 12.7 %.Then rainstorm was simulated in test section A, while drought persisted in test section B and test section C.

Pooled samples were collected every one or two days from test section B and C. When the relative soil water content was 36.3 % and drought severity was severe drought, drought scenario stimulation in test section B was over. At that time, drought in test section B had lasted for 43 days and the mass water content of soil was 9.8 %. Then rainstorm was simulated in test section B, while drought persisted in test section C.

Soil samples were collected every one or two days from test section C. When the relative soil water content was 23.3 % and drought severity was extreme drought, drought scenario stimulation in test section C was over. At that time, drought in test section C had lasted for 55 days and the mass water content of soil was 6.3 %.Then rainstorm was stimulated in test section C.

After the end of each drought scenario, the test sections were watered with sprinkling can and the quantity and strength was equal to a rainstorm process. Then the field was naturally dried. When mass water content of soil was adjusted to 21 % (80 % of relative soil water content) around, samples were collected from each test section every four days. Contents of microbial biomass carbon in soils that were watered were compared with contents in soils that were not watered, to know the rehabilitation of different drought soil ecosystem after rainstorm.

2.4 Sampling

All the soil samples were collected at the middle of two maize and about 10 cm far away from the rhizosphere of the maize at Beijing time (The East District Eight) 9 a.m. From the beginning of the experiment to the 32th day, soil samples were collected every one or two days at 10 ~ 20 cm soil depth in all the three test sections. Soil samples from different test sections were mixed to form a pooled sample. From the 33th day to the 43th day, soil samples were collected every one or two days at 10 ~ 20 cm soil depths in test section B and C and then they were mixed to form pooled samples. From the 44th day to the 55th day, soil samples were collected every one or two days at 10 ~ 20 cm soil depth in test section C. During drought stress stage 35 pooled soil samples were collected in all.

After rainstorm stimulation and mass water content was dried to 21 % around in each test, samples were collected at Beijing time (The East District Eight) 9 a.m. at 10 ~ 20 cm soil depth every four days. 20 samples were collected in all.

The surface organic materials and fine roots in pooled samples were removed. The pooled sample was tested for water content and then divided into two parts: one part was stored at room temperature and air dried and used for physical, physicochemical and chemical analysis (soil field capacity, contents of organic materials); the other part was kept field-moist at 4 °C and used for biological properties analysis (microbial biomass carbon content).

2.5 Soil sample analyses

Soil water content was measured gravimetrically by weighing, after drying in an oven at 105 °C for about 48 h. Prior to microbial analyses, samples were adjusted to 50 % of maximum water holding capacity and pre-incubated at 22 °C for six days. We applied chloroform fumigation-extraction method (Vance et al., 1987) to estimate soil microbial biomass carbon. Briefly, two soil portions were taken. One portion was fumigated at 25 °C for 24 h with ethanol free $CHCl_3$. After fumigant removal, soil sample was extracted with 40ma 0.01M $CaCl_2$ by 45 min horizontal shaking at 200 rev/min and then filtered through a paper filter. The other portion (non-fumigated one) was extracted at the time fumigation commenced. Organic carbon (in the extracts) was measured as CO_2 at 800 °C by infrared absorption after combustion using a Maihak Tocor 2 automatic analyser. 10 mL of $CaCl_2$ extracts was adjusted to a pH of 3.5 with HCl and fed into the carbon analyser. Microbial biomass carbon was calculated as Eq. (1). In Eq. (1), E_C was calculated as Eq. (2) and K_C was 0.45 (Joergensen, 1995). Soil organic carbon was determined using the modified Walkley–Black procedure (Nelson and Sommers, 1982).

$$\text{Microbial biomass carbon} = E_\text{C}/K_\text{C} \tag{1}$$

$$\begin{aligned} E_\text{C} = {} & \text{(organic carbon that extracted from fumigated soil)} \\ & - \text{(organic carbon that extracted from non-fumigated soil)} \end{aligned} \tag{2}$$

2.6 Data analysis

Origin 8.0 was used to investigate physical, physicochemical, chemical and biological data. Gaussian distribution test was used to see if the date has significant difference. Nonlinear exponential regression models between water content and biological properties were established to study the relationships between them. Fitting curves were drawn to analysis effects of drought on soil microbial and find the demarcation points that could be used to demonstrate alters and degradation of soil ecosystem.

3 Results

3.1 Effects of extreme drought on soil microbial biomass carbon

Dynamic of microbial biomass carbon with mass water content of soil during drought stress stage was shown in Fig. 1. Mass water content of soil dried from 25 to 6 % and drought severity developed from not drought to extreme drought. Equation (3) is nonlinear exponential regression model between soil microbial biomass carbon (B) and soil water content (W). The fitting curve and regression characteristics are given in Fig. 1 and Table 4. Significant level between microbial biomass carbon and water content was 0.01 (two-side test) and F value of the nonlinear exponential regression model was 360.5, suggesting that the matching effect was preferable.

$$B = \exp(-1.32 + 0.73W - 0.02W^2) \tag{3}$$

It could be seen from Fig. 1 that changing trend of microbial biomass carbon was divided into two sections, and the demarcation point of water content was about 19.5 %. Should water content be higher or lower than the demarcation point, microbial biomass carbon would decline. Briefly, microbial biomass carbon content increased (from 200 to 400 mg kg^{-1}) with the reduction of water content when soil moisture was higher than the demarcation point, while microbial biomass carbon content declined (from 400 to 25 mg kg^{-1}) with the reduction of water content when soil moisture was lower than the demarcation point, which indicated that 19.5 % was the optimum water content for microbial biomass carbon in our experimental soil ecosystem.

Changing rate curve of microbial biomass carbon along with mass soil water content was shown in Fig. 2. The changing rate curve was obtained by differentiating the fitting curve in Fig. 1. We can see that the changing rate curve was divided into three sections (section A, B and C) by two demarcation points, which were 19.5 and 14.3 % for water content, respectively. The demarcation point of 19.5 % was the position that increase or decrease of microbial biomass carbon, while the demarcation point of 14.3 % was the position of faster or slower of the decrease rate. In section A microbial biomass content increased with the reduction of water content, which partly attributed to the limit of soil microorganism activity when water content was higher than 19.5 %. In section B decrease rate of microbial biomass carbon became faster and faster with the development of drought. In section C decrease rate of microbial biomass carbon became slower and slower as drought stress got more and more serious. In addition, with the development of extreme drought, the change rate of microbial biomass carbon tended to zero.

3.2 Drought effects on proportion of microbial biomass carbon in soil organic carbon

Figure 3 gave dynamic of the proportion of microbial biomass carbon in soil organic carbon during the whole drought stage. It was obvious that microbial biomass carbon comprised only about 1 ~ 4 % of soil organic carbon. On the one hand, the changing tendency of proportion of microbial biomass carbon in soil organic carbon was similar with the changing trend of microbial biomass carbon along water content. When water soil moisture was higher than the demarcation point, the proportion of microbial biomass carbon increased from 1.5 to 3.9 % with reduction of water content. However, when soil moisture was lower than the demarcation point, the proportion decreased from 3.9 to 1.0 % with the reduction of water content. On the other hand, the demarcation point of increase or decrease of the proportion was about 20.5 % for water content, which was 1 % higher than the demarcation point of microbial biomass carbon changing along with water content (19.5 %).

3.3 Rehabilitation of different drought soil ecosystem after rainstorm

The rehabilitation of soil microbial biomass carbon under moderate drought scenario after rainstorm stimulation was shown in Fig. 4a.We could see that microbial biomass carbon recovered at about 16 % of mass water content, which was before water content reduced to 14.3 %. At this time relative water content was 60 % and soil ecosystem was not stressed by drought. On one hand, content of microbial biomass carbon in watered soil was even more than it was before rehydration at the same water content when water content was lower than 16 %. On the other hand, when water content was lower than 16 %, content of microbial biomass carbon increased before it decreased and water content was 15 % at the point that microbial biomass carbon was the most. What more, when soil water was dried to 12 %, the content of microbial biomass carbon was as much as it was at the 15 % of water content in the soil that was not watered.

The rehabilitation of soil microbial biomass carbon under severe drought scenario after rainstorm stimulation was shown in Fig. 4b. The results showed that content of microbial biomass carbon increased gradually and barely recovered until soil water content reduced to 14 % around. When water content was lower than that point, content of microbial biomass carbon in rehydrated soil was almost as much as it was in the soil that was not watered.

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The habilitation of soil microbial biomass carbon under extreme drought after rainstorm stimulation was shown in Fig. 4c, suggesting that soil microorganism could not recover within a short time under extreme drought stress and concentration of microbial biomass carbon kept at a low level (less than 100 $\mathrm{mg\,kg^{-1}}$).

Figure 5 showed concentrations of soil microbial biomass carbon under different drought scenarios after rainstorm stimulation. After rehydration, microbial biomass carbon was higher in moderate drought stressed soil than it was in severe drought stressed soil, which was higher than it was in extreme drought stressed soil, at the same soil water content. What more, with the development of drought stress, changing rate of microbial biomass carbon reduced after the rain. The continuing negative impacts of drought stress present additional challenges to soil ecosystem rehabilitation. The results showed that the recoverability of soil microbial biomass carbon and soil ecosystem was different with different drought scenario.

4 Discussion

4.1 Response of microbial biomass carbon to extreme drought stress

In section B of Fig. 3, decrease rate of microbial biomass carbon became faster and faster with the development of drought, which was attributed to massive death of drought sensitive microorganisms, especially some bacterial. It had evidenced that soil microbial activity and community structure could be seriously damaged by drought and microorganisms that could not adapt to drought stress would disappear under the adverse condition (Van Meeteren et al., 2008; Hueso et al., 2012). It has been considered that dry fields have a highly heterogeneous distribution of nutrients and soil nutrient availability may affect biomass and activity of soil microbial (Housman et al., 2007). Therefore, the results might attribute to reduced diffusion of soluble nutrient and reduced microbial mobility and consequent access to nutrient (Van Meeteren et al., 2008; Bastida et al., 2006). Soil sodicity might be another reason behind the reduction of microbial biomass and retardation of activity. Drought influence soluble salt concentrations and there was a significant negative relationship between sodicity and microbial biomass (Rietz and Haynes, 2003; Yuan et al., 2007; Singh et al., 2013). Rietz 2003) and Tejada et al. (2006) pointed that effect of sodicity was enzyme specific, which suggested that adverse effect of sodicity was more pronounced over β-glucosidase and dehydrogenase than phosphatase. Besides, disruption of tertiary protein structure and salting out effect might take place and slow down enzyme activities (Rietz and Haynes, 2003; Tejada et al., 2006). As a consequence, microbial biomass reduced and activity retarded.

In section C decrease rate of microbial biomass carbon became slower and slower with development of drought. There were two possible reasons: (1) some drought tolerant soil microorganisms had already adapted to drought stress and its ratio in the whole microorganism had increased, which might attribute to C/N variation of microbe. It has been proved that response to drought by microbial biomass C differed from microbial biomass N: decline of microbial biomass N was more significant, resulting in rise of C/N (Karen et al., 2003). Besides, higher C/N was in favor of fungi growth (Paul and Clark, 1996) and fungi were much more tolerance to drought. With the intensification of drought stress, soil fungi/bacteria ratio rose (Fu Honglin et al., 2009) with the increase of C/N. As a result reduction rate of microbial biomass carbon was slower. (2) There was such a low base of microbial biomass carbon (about $50\,\mathrm{mg\,kg^{-1}}$) that the reproductive rate was slow and amplitude of variation was small.

4.2 Hysteresis of response of proportion of microbial biomass carbon in soil organic carbon to drought stress

Microorganism and soil organic carbon, especially water soluble organic carbon, interacted in soil ecosystem. Microbial biomass carbon was an important source of soil organic carbon. Microorganism was responsible for transforming organic carbon to mineralized carbon while organic carbon supplied substrate for microorganism (Christ and David, 1996), improving soil water holding capacity and microbial activity (Tejada et al., 2006). Figures 1 and 3 showed that changing tend of proportion of microbial biomass carbon in soil organic carbon lag behind microbial biomass carbon changes along with drought stress, suggesting that microbial biomass carbon responded faster than the proportion of microbial biomass carbon in soil organic carbon to drought stress. On one hand, labile soil organic carbon was closely associated with root productivity (Ros et al., 2009; Rui et al., 2011). In this research when water content reduced to 20.5 %, it was just the time that vegetative growth of above ground plant was vigorous. At the same time root productivity and belowground root biomass increased, resulting in an increase of soil organic carbon. However, microbial biomass carbon had not increased as much as soil organic carbon, so proportion of microbial biomass carbon in soil organic carbon decreased. On the other hand, it had been indicated that, as a response to drought, some soil bacteria are able to synthesize exopolysaccharidesas (Kohler et al., 2009), resulting in soil organic carbon increase. From the above results, it obtained that change of microbial biomass carbon proportion in soil organic carbon lag behind that of microbial biomass carbon under drought stress.

4.3 Rehabilitation of soil ecosystem under different dry-wet scenarios

From Fig. 4 we can see that rehabilitation of soil ecosystem was positive in moderate and severe drought soil ecosystem and negative in extreme drought soil ecosystem. The results in Fig. 4a showed that soil microbial biomass carbon interfered by moderate drought and then experienced rainstorm could recover before water content reduced to 14.3 %, suggesting that soil ecosystem could recover under this drought-wet scenario. When water content was lower than 16 %, content of microbial biomass was higher than it was before rehydration at the same water content. We can come to the conclusion that some drought tolerant microorganism had already adapted to this drought stress, their tolerance to drought and ratio in all soil microorganisms were both improved. Content of microbial biomass carbon showed a small peak, suggesting that ecological amplitude of drought tolerant microorganism widened under moderate drought stress. As a result, the soil ecosystem was well tolerated to moderate drought stress, its function and activity might be improved also. Results in Fig. 4b showed that content of microbial biomass carbon could barely recovered, suggesting that soil ecosystem influenced by severe drought was at the edge of rehabilitation. The ecosystem could not adapt to the severe drought stress and its tolerance to drought stress was not improved. Results in Fig. 4c showed that content of microbial biomass carbon could not recover within the experimental time, which indicated that soil ecosystem that stressed by extreme drought could not restore within a short time. The eco-hydrological processes were interrupted and ecosystem function and structure were damaged and could not recover thought they had experienced a rainstorm. It has been proved that, when water content was less than a certain value, rewetting could lead to microbial stress because its tolerance rapid changes in microorganism osmotic potential, resulting in cell lysis (Van Gestel et al., 1992). As a consequence, microbial biomass carbon went on declining and could not give better resistance to drought. What more, microbial rehabilitation was different in different types of ecosystem and soil terms (David et al., 2013; Chaer et al., 2009; Lacombe et al., 2009; Mader et al., 2002; Van Overbeck et al., 1995).

4.4 An indicator of irrigating – dynamics and demarcation points of microbial biomass carbon along with mass water content of soil

When water content was lower than 14.3 %, microorganism reproduction and substrate utilization in soil was influenced, as well as decomposition of plant and animal residues (Johnson et al., 2003), nutrient cycling (Balser and Firestone, 2005), soil fertility maintaining and formation of soil aggregates (Gillerke, 1997), which resulted in function and structure weaken in soil ecosystem. On the contrary, high concentration of microbial biomass carbon was characteristic of a sustainable ecosystem. Therefore, the changing tendency and demarcation point of soil microbial biomass carbon along with mass water content of soil could be used to demonstrate alters and degradation of soil ecosystem as well as the irrigation requirement of crops.

It is proved that when soil moisture content was lower than 55 % of field capacity, farmland should be irrigated. Here field capacity of experimental soil was 27 % and the threshold for irrigation was about 14.9 % due to that theory. That value was in good agreement with 14.3 % – the demarcation point of faster or slower of decrease rate of microbial biomass carbon (Fig. 2) and the weakened point of function and structure in soil ecosystem. So we come to the conclusion that soil mass water content should be higher than 14.3 % in order to maintain high productivity of soil ecosystem. Besides, according to research in Sect. 3.3, the soil ecosystem must be irrigated if mass water content was lower than 10 % (drought in corn field had persisted for about 45 days), or else the soil ecosystem would not recover with a few days and the sustainability and productivity would be destroyed.

5 Conclusions

From prototype observation experiments and these results of the research, we could obtain that agriculture soil ecosystem was significantly influenced by extreme drought stress. Content of microbial biomass carbon increased with the reduction of water content when soil moisture was higher than 19.5 %, while the content declined with the reduction of water content when soil moisture was lower than 19.5 %, which indicated that 19.5 % was the optimum water content for microbial biomass carbon in sampled soil ecosystem. Decrease rate of microbial biomass carbon became faster and faster as water content decline from 19.5 to 14.3 % while it became slower and slower as water content was lower than 14.3 %, which was attributed to microbial structure changes in soil ecosystem. The changing tendency and demarcation point (in this research was 14.3 %) of soil microbial biomass carbon could be used to demonstrate alters and degradation of soil ecosystem as well as the irrigation requirement of crops. The changing tendency of proportion of microbial biomass carbon in soil organic carbon was similar but leg behind the changing trend of microbial biomass carbon along with water content. Hysteresis of response of the proportion to drought stress mainly attributed to the rapid increase of soil organic matter.

In addition, the continuing negative impacts of drought stress present additional challenges to soil ecosystem sustainability. Rehabilitation of microbial biomass carbon after rainstorm under different drought scenarios were as follow: soil ecosystem which was interfered by moderate drought could recover after rainstorm and was well tolerated to moderate drought stress, its function and activity might be improved also. Severe drought soil ecosystem could barely recover and could not adapt to severe drought stress. Extreme drought soil ecosystem could not restore within a few days, the function and structure were damaged. So mass water content of soil should kept above 10 % to avoid destroying function and structure while soil ecosystem should be watered when mass water content was lower than 14.3 % in order to maintain high productivity.

Because of high degrees of variability in water availability (Fierer and Schimel, 2003; Alwyn et al., 2005), adaption of soil ecosystem that had experienced long term water stress to drought stress should be researched in further.

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Table 1. Soil physical, chemical and biological properties.

Soil parameters	Value	Units
pH	7.8	–
organic matte	20 ~ 153	%
total nitrogen	0.075	%
available nitrogen	0.121	mg kg^{-1}
total phosphorus	1.912	%
available phosphorus	38.04	mg kg^{-1}
total potassium	58.41	%
available potassium	134.62	mg kg^{-1}
microbial carbon	18.2 ~ 373.9	mg kg^{-1}
microbial nitrogen	49.45	mg kg^{-1}
unit weight of soil	2.78	g cm^{-3}
clay	12.83	%
silt	28.92	%
sand	58.25	%
soil field capacity	27	%

Table 2. Standard of classification for drought severity.

Drought severity	Relative soil water content
not drought	$R > 60\,\%$
mild drought	$60 \geq R > 50\,\%$
moderate drought	$50\,\% \geq R > 40\,\%$
severe drought	$40\,\% \geq R > 30\,\%$
extreme drought	$30\,\% \geq R$

Table 3. Drought scenario in each test sections.

Field number	Duration of drought	Gravimetric water content	Relative soil water content	Drought scenario
A	32 days	12.7 %	47.3 %	moderate drought
B	45 days	9.8 %	36.3 %	severe drought
C	55 days	6.3 %	23.3 %	extreme drought

Table 4. Characteristics of regression model between microbial biomass carbon and mass water content.

Regression equation	a		b		c		
	Value	Standard error	Value	Standard error	Value	Standard error	Adjust R^2
$Y = \exp(a + bX + cX2)$	−1.32	0.83	0.73	0.09	−0.02	0.002	0.87

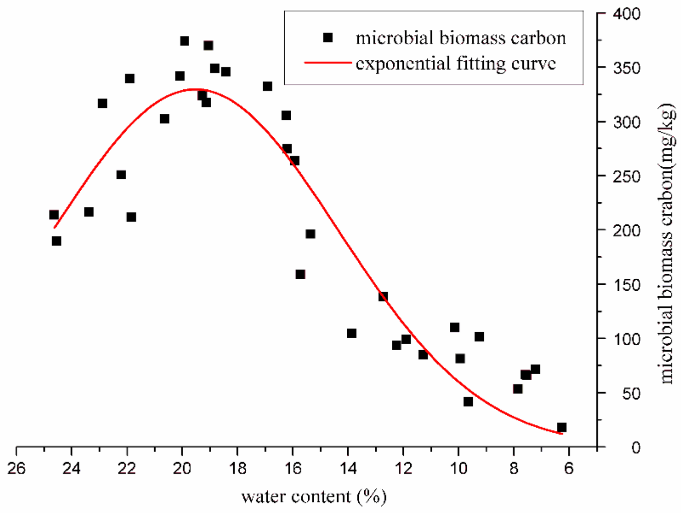

Fig. 1. Dynamics and fitting curve of microbial biomass carbon along with mass water content of soil (■ is measured data of soil microbial biomass carbon and correspond mass water content; red curve is the fitting curve).

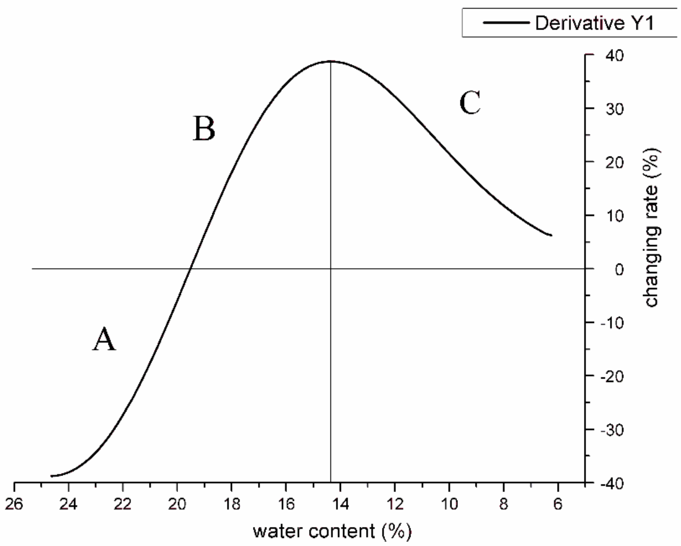

Fig. 2. Chang rate curve of microbial biomass carbon along with mass water content of soil.

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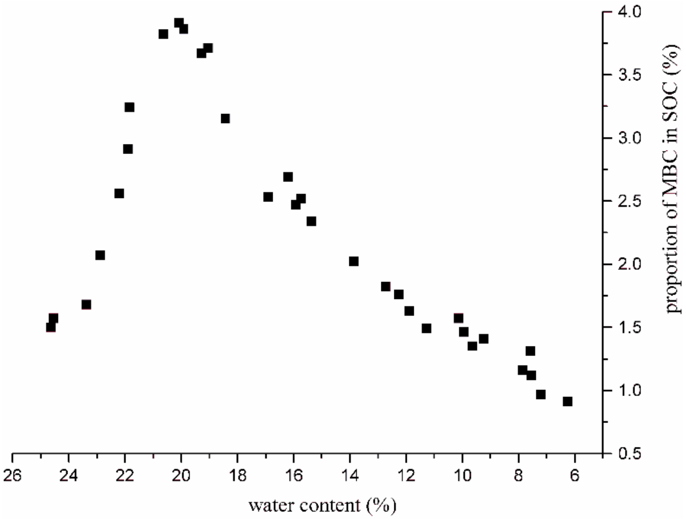

Fig. 3. Dynamics of proportion of microbial biomass carbon in soil organic carbon along with mass water content (■ is measured data of proportion of microbial biomass carbon in soil organic carbon correspond to mass water content).

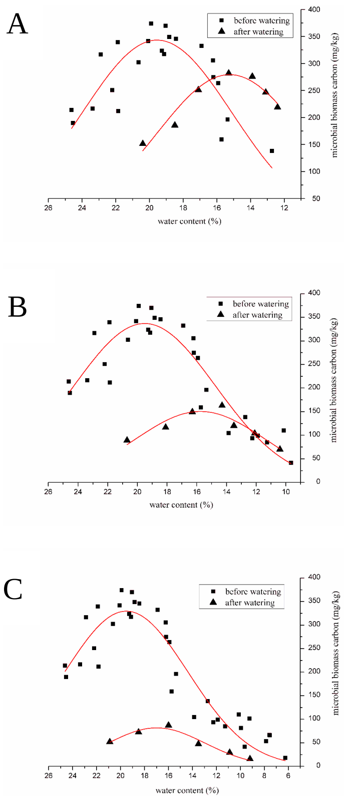

Fig. 4. Rehabilitation of microbial biomass carbon after rainstorm stimulation in moderate drought scenario **(A)**, severe drought scenario **(B)** and extreme drought scenario **(C)**; ■ is measured data of microbial biomass carbon correspond to soil mass water content before rehydration under drought scenarios; ▲ is measured data of microbial biomass carbon after re-hydration; Red curves are the fitting curves between microbial biomass carbon and mass water content of soil.

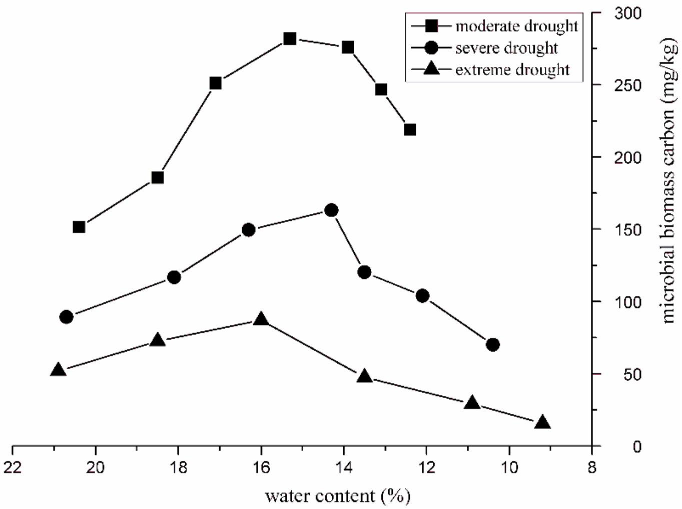

Fig. 5. Comparison of rehabilitation of microbial biomass carbon content after rainstorm stimulation under moderate drought scenario (■), severe drought scenario (•) and extreme drought scenario (▲).