Effects of Extreme Drought on Agriculture Soil and Sustainability of Different Drought Soil[1]

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Abstract: Content of microbial biomass carbon was selected as indicator for identifying effects of extreme drought on agriculture soil ecosystem. In the study, we identified changing tendencies of microbial biomass carbon content and the proportion of microbial biomass carbon in soil organic carbon Based on a series of prototype observation experiments, we could come to the conclusions that 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 also evaluated sustainability of different drought soil ecosystems after rainstorm with rehabilitation. The results suggested that soil ecosystem could recover after interfered by moderate drought, and its tolerance to drought, as well as its function and activity were improved. 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, meanwhile, the function and structure were damaged. We could come to the conclusion that mass water content of soil should kept above 10% to avoid destroying function and structure. In order to maintain high productivity, soil ecosystem would be watered when mass water content was lower than 14.3%..

Keywords: extreme drought; rainstorm; soil ecosystem; microbial biomass carbon; sustainability; 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. Especially, extreme drought can greatly affect the function (LIU et al., 2010; Balser and Firestone, 2005), structure (Zak et al., 2003)and productivity (Lal, 2013)of soil ecosystem. Meanwhile, agriculture ecosystem is so sensitive to drought stress that extreme drought threaten regional food security all over the world. In general, losses caused by drought are measured by social and economic indicators, such as economic loss and yield loss on crop. However, studies on the effects of drought on sustainability of soil ecosystem remain rare. So it important that selecting reasonable indicators to identify the effects of extreme drought on agriculture soil and study the sustainability of soil ecosystem under different drought stresses.

On one hand, as an important component of soil ecosystem, microbial biomass carbon 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). So content of microbial biomass carbon is a 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, which is a big recharge source and reserve of soil available nutrient (Jenkinson D.S., 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 (H. Insam, et al, 1989) and soil ecosystem productivity (V.O. Biederbeck et al, 1994), and it

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is more reasonable that selecting The proportion of microbial biomass carbon as an indicator than only selecting soil organic carbon. As a result, in this study, we selected content of microbial biomass carbon as an indicator to study the effects of drought on agriculture soil. On the other hand, rainstorm usually occurred after drought. Therefore, we evaluate the sustainability of different drought soil ecosystem after rainstorm, and the content of microbial biomass carbon recovery situation before water content reduced to the thresholds, which could be used to demonstrate destruction of the function and structure in soil ecosystem.

Researchers have developed some studies on effects of water stress on soil microbial abundance, composition of community and metabolized production (Davidson et al., 2012; Moyano et al., 2012; Moyano et al., 2013; Manzoni et al., 2011). 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).In recent years, 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 researches has studied these changes with alters and degradation of soil ecosystem.

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

2. Materials and methods

2.1. Site characteristics

Soil samples were collected from Daxing Test Base (116°25′E and 39°37′N), which was established by China Institute of Water Resources and Hydropower Research, located in northern Beijing, in China. The base lies at 31.3m above sea level, which has a temperate climate. The mean annual temperature is 12.1℃, from July to September, the mean temperature is approximately 25℃. Frostless period is about 185 days and the time of sunshine is about 2600h in one year. The mean annual precipitation is 540mm, but it is over 80% between June and September, and less than 10% in spring. Potential evaporation, about 1/3 concentrated between May and June, is 1900mm, which is much more than annual precipitation. Relative humidity ranges from 50% to 70% (Liu et al, 2012).

2.2. Soil characteristics

The soil in Test Base is sandy loam. The detailed description of soils is presented in Table 1, including the physical, chemical and biological properties.

2.3. Experiment design and layout

Prototype observation experiments were carried out 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 for experiments, we established rain shelter, which was constructed with stainless steel frame covered on top, and with plastic membrane affixed to all around wall. We opened plastic membrane for ventilation in sunny days, and closed in rainy days to prevent rain entering experimental field. Separation waterproof panels were laid 600mm 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. In order to investigate the rehabilitation of different drought soil ecosystems after rainstorm, we considered three test sections responding to three drought scenarios respectively which were classified with relative soil water content (Table2 and Table 3).We also had three replicates throughout the experiment, and average value was considered as the basis of our analysis.

At the beginning of experiments, mass water content of soil was around 25% in all the sections. Pooled samples were collected from each test section about every one or two days. When the relative soil water content was 47.3%, drought severity reached to moderate drought, and drought scenario of section A simulations were finished. At that time, simulations in test section A had lasted for 32 days and the mass water content of soil reached to12.7(±0.3)%.Then rainstorm was simulated in test section A, while drought scenario was remained in test section B and test section C.

Pooled samples were collected from test section B and C every one or two days. When the relative soil water content was 36.3 % and drought severity reached to severe drought, and drought scenario of test section B simulations were also finished. At that time, simulations in test section B had lasted for 43 days and the mass water content of soil reached to 9.8(±0.1)%. Then rainstorm was simulated in test section B, while drought scenario was remained in test section C.

Pooled soil samples were from test section C collected every one or two days. When the relative soil water content was 23.3 % and drought severity reached extreme drought, drought scenario of test section C simulations were finished. At that time, simulations in test section C had lasted for 55 days and the mass water content of soil reached to6.3 (±0.4)%.Then rainstorm was stimulated in test section C.

After drought scenario, all the test sections were watered with sprinkling can as like as a rainstorm process (16mm/ hour). Then the field was naturally dried. When mass water content of soil reached to around 21% (80% of relative soil water content) around, pooled samples were collected from each test section respectively every four days. Compared contents of microbial biomass carbon in the soils not watered with the soil watered, we could analysis the rehabilitation of different drought soil ecosystem after rainstorm.

2.4. Sampling

All the soil samples were collected from experiments fields at the middle of two maize and about 10cm far away from the rhizosphere of the maize at 9:00 am Beijing time (The East District Eight). From the first day of the experiment to the thirty-second day, we collected 100g soil samples from all the test sections every one or two days at 10~20cmsoil depth. Soil samples from different test sections were mixed to form a pooled sample. From the thirty-third day to the forty-third day, we also collected 100g soil samples from test section B and C every one or two days at 10~20cm soil depths which were mixed to form pooled samples. From the forty-fourth day to the fifty-fifth day, then we collected 100gsoil samples from test section C every one or two days at 10~20cm soil depth. During drought stress stage, we collected 35 pooled soil samples from all the test sections at end.

After rainstorm stimulation and mass water content was dried to around 21% in each test section, pooled samples were also collected from test sections at 9:00 am at 10~20cm soil depth every four days.

We collected 20 samples in all.

Meanwhile, we removed the surface organic materials and fine roots from pooled samples. All the pooled samples were tested for water content and then divided into two parts: one part was stored under conditions of 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 under conditions of field-moist at4℃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℃ for about 48 hours. Prior to microbial analyses, samples were adjusted to around 50% of maximum water holding capacity and pre-incubated at 22℃ 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 at first. One portion was fumigated at 25℃ for 24 hours with ethanol free $CHCl_3$. After fumigant removal, soil sample was extracted with 40ma 0.01M $CaCl_2$ by45 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℃ by infrared absorption after combustion using a Maihak Tocor 2 automatic analyser. We extracted 10 ml of $CaCl_2$, adjusted its pH to3.5 by HCl and fed it into the carbon analyser.

Microbial biomass carbon was calculated based on Eq. (1). In Eq. (1), E_C was calculated by Eq. (2) and K_C was 0.45 (Joergensen, 1995). Soil organiccarbon was determined by using the modified Walkley-Blackprocedure (Nelson and Sommers, 1982).

Microbial biomass carbon=E_C/K_C Eq. (1)

E_C =(organic carbon that extracted from fumigated soil)-(organic carbon that extracted from non-fumigated soil) Eq. (2)

2.6. Data analysis

Origin 8.0 was used to investigate physical, physicochemical, chemical and biological data. Gaussian distribution test was used to obtain significant difference among data. In order to study the relationships between water content and biological properties, nonlinear exponential regression models were established. Fitting curves were used to analysis effects of drought on soil microbial and find the demarcation points, which could 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. In Fig.1, mass water content of soil ranged from 25% to 6% and drought severity developed from not drought to extreme drought. Eq.(3) is nonlinear exponential regression model to demonstrate relationship between soil microbial biomass carbon (B) and soil water content (W), and adjust R^2 of the model was 0.87.The fitting curve was given in Fig.1. 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.

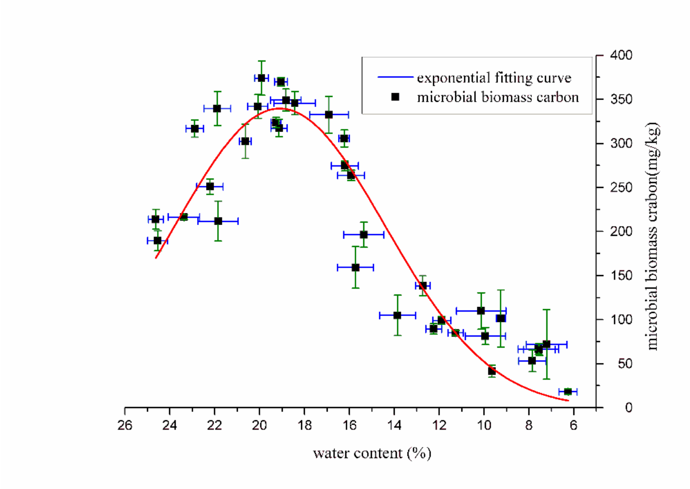

Fig.1 Dynamics and fitting curve of microbial biomass carbon along with mass water content of soil (■ and the bar indicate the mean and standard deviations of three replicates, respectively. red curve is the fitting curve of the mean values)

$$B = \exp(-1.32 + 0.73W - 0.02W^2) \qquad \text{Eq. (3)}$$

It could be clearly 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%, which indicated that when water content was higher or lower than the demarcation point, microbial biomass carbon would decline. Meanwhile, when soil moisture was higher than the demarcation point microbial biomass carbon content increased (from 200mg/kg to 400 mg/kg) with the reduction of water content. In contrast, microbial biomass carbon content declined (from 400mg/kg to 25 mg/kg) with the reduction of water content. So we could come to conclusion that 19.5% was the optimum water content for microbial biomass carbon in our experimental soil ecosystem.

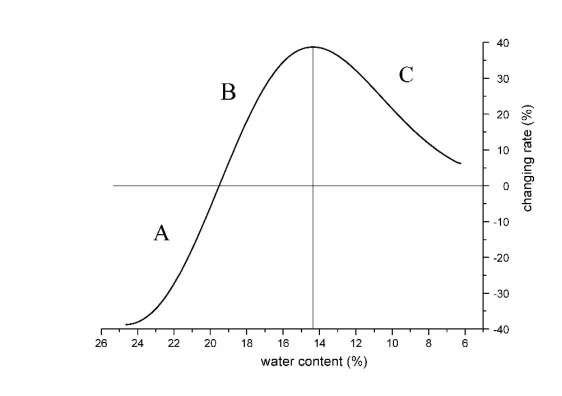

Fig.2 Chang rate curve of microbial biomass carbon along with mass water content of soil

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. From Fig.2, We could 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 increased or decreased of microbial biomass carbon, while the demarcation point of 14.3% was the position of fast or slow 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 with the development of drought. In section C decrease rate of microbial biomass carbon became slower as drought stress becoming 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

Fig.3 gave dynamic of the proportion of microbial biomass carbon in soil organic carbon during the whole drought process. It was obvious that microbial biomass carbon comprised only about 1~4 % of soil organic carbon. On the one hand, the proportion of microbial biomass carbon in soil organic carbon changing trend was similar with microbial biomass carbon along with 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 decreasing water content. In contrast, when soil moisture was lower than the demarcation point, the proportion decreased from 3.9% to 1.0% with decreasing 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 that of microbial biomass carbon (19.5 %).

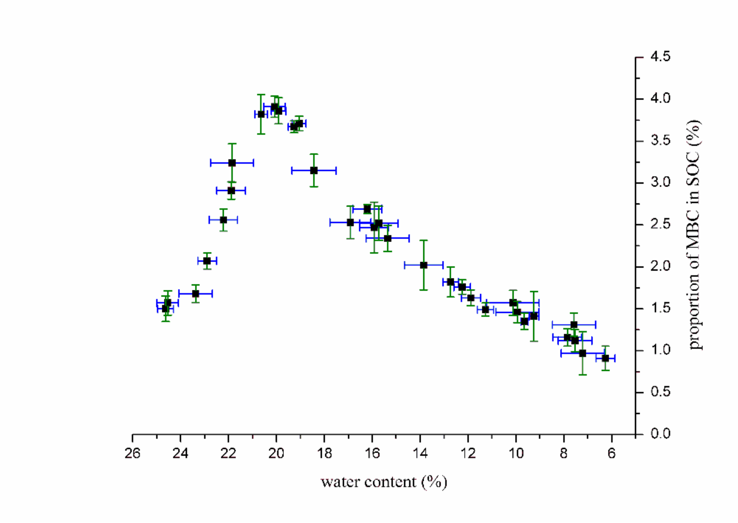

Fig.3 Dynamics of proportion of microbial biomass carbon in soil organic carbon along with mass water content (■ and the bar indicate the mean and standard deviations of three replicates, respectively)

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 showninFig.4 (A). From Fig.4, We could see that microbial biomass carbon recovered at about 16% of mass water content, before water content reduced to 14.3%, and relative water content was 60% and soil ecosystem was not stressed by drought. On one hand, for the same water content which was lower than 16%, compared with before rehydration, content of microbial biomass carbon in watered soil was a little higher after rehydration. On the other hand, when water content was lower than 15%, content of microbial biomass carbon increased with increasing water content, and microbial biomass carbon had highest value at the point 15% water content. Moreover, when soil water content was decreased to 12%, the content of microbial biomass carbon was equal to that of the 15% of water content in the soil before watered.

The rehabilitation of soil microbial biomass carbon under severe drought scenario after rainstorm stimulation was shown in Fig.4 (B). The results showed that content of microbial biomass carbon increased gradually and barely recovered until soil water content decreased to around 14%.When water content was lower than the point, content of microbial biomass carbon in rehydrated soil was almost equal to that in the soil before watered.

The habilitation of soil microbial biomass carbon under extreme drought after rainstorm stimulation was shown in Fig4 (C), suggesting that soil microorganism could not recover within a short time under extreme drought stress and concentration of microbial biomass carbon was kept at a low level (less than 100 mg/kg).

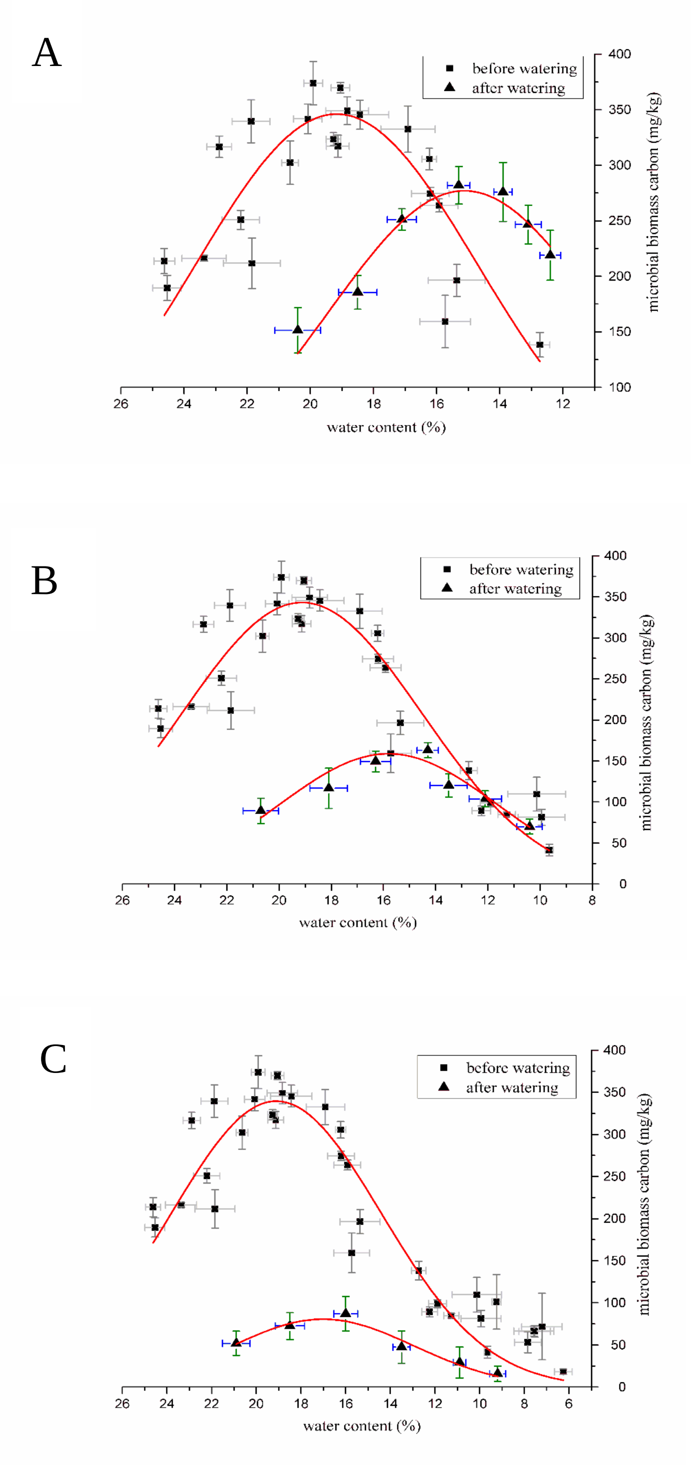

Fig.4 Rehabilitation of microbial biomass carbon after rainstorm stimulation in moderate drought scenario (A), severe drought scenario (B) and extreme drought scenario (C); ■and the gray bar indicate the mean and standard deviations of three replicates before rehydration under drought scenarios; ▲ and the color bar

indicate the mean and standard deviations of three replicates after rehydration; Red curves are the fitting curves between microbial biomass carbon and mass water content of soil.

Comparing A, B and C of Fig.4, we could see that at same soil water content after rehydration, microbial biomass carbon was higher in moderate drought stressed soil than that in severe drought stressed soil, which was higher than that in extreme drought stressed soil. Moreover, with the development of drought stress, changing rate of microbial biomass carbon decreased 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 under each drought scenario condition.

4. Discussion

4.1. Response of microbial biomass carbon to extreme drought stress

From section B of Fig.3, decrease rate of microbial biomass carbon became 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 would disappear under the adverse condition when they could not adapt to drought stress (Van Meeteren et al., 2008; S. Hueso et al., 2012). It had been considered that dry fields have a highly heterogeneous distribution of nutrients and its availability may affect biomass and activity of soil microbial (Housman, D.C. et al., 2007). Therefore, the results might attribute to reduced diffusion of soluble nutrient, microbial mobility and consequent access to nutrient (Van Meeteren et al., 2008; Bastida et al. 2006).Soil sodicity might be another factor to the reduction of microbial biomass and retardation of activity. Drought influenced soluble salt concentrations and there was a significant negative relationship between sodicity and microbial biomass (Rietz and Haynes, 2003; Yuan et al. 2007; K. Singh et al. 2013). Rietz(2003) and Tejadaet 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 with development of drought. There were two possible reasons: 1) some drought tolerant soil microorganisms had already adapted to drought stress and its ratio had increased in the whole microorganism, which might attribute to C/N variation of microbe. It had 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 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 mg/kg) 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).From Fig.1 and 3, it showed that changing tend of proportion of microbial biomass carbon in soil organic carbon lagged 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. It had been indicated that, as a response to drought, some soil bacteria were able to synthesize exopolysaccharides (Kohler et al., 2009), resulting in soil organic carbon increase. From the above result, it obtained that change of microbial biomass carbon proportion in soil organic carbon lagged behind was 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 but negative in extreme drought. The results in Fig.4 (A) showed that soil microbial biomass carbon interfered by moderate drought could recover before water content reduced to 14.3% after rainstorm, 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, and their tolerance to drought and ratio in all soil microorganisms were both improved. Content of microbial biomass carbon appeared 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 accordingly. Results in Fig.4 (B) 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.4 (C)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, which could not recover after 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 varies with 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 trend 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 has been proved that when soil moisture content was lower than 55%of field capacity, farmland should be irrigated. When field capacity of experimental soil was 27% and the threshold for irrigation was about 14.9%accordingto that theory, which 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, in order to maintain high productivity of soil ecosystem, soil mass water content should be higher than 14.3%. Besides, according to the research in 3.3, the soil ecosystem must be irrigated when 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 within 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 decrease 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 as water content decline from 19.5% to 14.3% while it became slower as water content was lower than 14.3%, which was attributed to microbial structure changes in soil ecosystem. The changing trend 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 trend of proportion of microbial biomass carbon in soil organic carbon was similar but lagged 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 interfered by moderate drought could recover after rainstorm and well tolerated to moderate drought stress, its function and activity might be improved accordingly. 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 be kept above 10% to avoid destroying function and structure. In order to maintain high productivity, soil ecosystem should be watered when mass water content was lower than 14.3%.

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±0.7	-
organic matte	20~153	%
total nitrogen	0.075±0.03	%
available nitrogen	0.121±0.06	mg/kg
total phosphorus	1.912±0.57	%
available phosphorus	38.04±5.21	mg/kg
total potassium	58.41±7.96	%
available potassium	134.62±12.02	mg/kg
microbial carbon	18.2~373.9	mg/kg
microbial nitrogen	49.45±8.61	mg/kg
unit weight of soil	2.78±0.33	g/cm^3
clay	12.83±0.91	%
silt	28.92±3.39	%
sand	58.25±5.67	%
soil field capacity	27±1.11	%

Table 2Standard of classification for drought severity

drought severity	relative soil water content
not drought	R＞60%
mild drought	60≥R＞50%
moderate drought	50%≥R＞40%
severe drought	40%≥R＞30%
extreme drought	30%≥R