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Responses of soil microarthropods to warming and increased precipitation in a semiarid temperate steppe

Tingjuan Wu, Fanglong Su, Hongyan Han, Yue Du, Chengde Yu, Shiqiang Wan *

State Key Laboratory of Cotton Biology, Key Laboratory of Plant Stress Biology, College of Life Sciences, Henan University, Kaifeng,Henan 475004, China

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ABSTRACT

Soil microarthropods are an important component in soil food webs and their responses to climate change could have profound impacts on ecosystem functions. As part of a long-term manipulative experiment, with increased temperature and precipitation in a semiarid temperate steppe in the Mongolian Plateau which started in 2005, this study was conducted to examine effects of climate change on the abundance of soil microarthropods. Experimental warming had slightly negative but insignificant effects on the abundance of mites (−14.6%) and Collembola (−11.7%). Increased precipitation greatly enhanced the abundance of mites and Collembola by 117 and 45.3%, respectively. The response direction and magnitude of mites to warming and increased precipitation varied with suborder, leading to shifts in community structure. The positive relationships of mite abundance with plant cover, plant species richness, and soil microbial biomass nitrogen suggest that the responses of soil microarthropods to climate change are largely regulated by food resource availability. The findings of positive dependence of soil respiration upon mite abundance indicate that the potential contribution of soil fauna to soil CO_2 efflux should be considered when assessing carbon cycling of semiarid grassland ecosystems under climate change scenarios.

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1. Introduction

Soil microarthropods play a crucial role in regulating ecosystem processes and functions by influencing litter decomposition, nutrient mineralization, and microbial activity (Bardgett and Chan, 1999; Wardle, 2002; De Deyn et al., 2003; Cole et al., 2006; Kaneda and Kaneko, 2008; A'Bear et al., 2012). Mites and Collembola are the most important and abundant soil microarthropod groups. Although soil mites and Collembola have similar body size, they differ substantially in life history traits such as lifespan, reproduction strategies, dispersal ability, and habitat specialization. For example, collembolan species exhibit faster recovery after summer drought than Oribatid mites in Norway spruce (Lindberg and Bengtsson, 2005). Distinct responses or recovery rates of different soil microarthropod functional groups to environmental change were also observed in other climate change manipulative experiments (Haimi et al., 2005; Briones et al., 2009; Hagvar and Klanderud, 2009; Kardol et al., 2011). Diverse responses of the functional groups can lead to altering community composition and diversity of soil fauna and consequently influencing ecosystem functions they carry out (Bradford et al., 2002; Carrillo et al., 2011; A'Bear et al., 2012). Soil microarthropod-triggered changes may feedback to impact other ecosystem components, e.g., plants (Bardgett and Chan, 1999; Wardle et al., 2004; Eisenhauer et al., 2010) and soil microbes (Wardle et al., 2004; Kaneda and Kaneko, 2008). Therefore, a better understanding of the responses of soil microarthropods to climate change will facilitate predicting the future states of terrestrial ecosystems.

Given the controls of soil temperature and moisture content over their feeding and development rate, climate change may have a strong impact on the abundance and community structure of soil microarthropods (Kaneda and Kaneko, 2008). Previous studies have reported that climate warming and changing precipitation regimes can directly affect the soil microarthropod abundance (Arnold et al., 1999; Wardle et al., 2004). For example, the feeding activity and growth of Collembola increase with soil moisture due to the positive responses of their metabolic activity (Kaneda and Kaneko, 2011). In addition, soil microarthropods rely on the quantity and quality of plant-derived substrate inputs and soil microbes for food. Effects of climate warming and changing precipitation regimes have well been documented to influence plant productivity (Rustad et al., 2001; Lin et al., 2010) and soil microbial biomass and community structure (Zhang et al., 2005; Liu et al., 2009). Nevertheless, our knowledge of how altered food resources (plants and soil microorganisms) mediate the responses of soil microarthropods to climate change is extremely limited.

* Corresponding author. Tel.: +86 371 23881006; fax: +86 371 23882029.
E-mail address: swan@henu.edu.cn (S. Wan).

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Hence, elucidating the direct and indirect effects of climate change on soil, microarthropods will help us mechanistically understand soil fauna responses under climate change scenarios.

The impacts of climate change on soil microarthropods remain controversial (Wardle et al., 2004). Experimental warming has little or even a negative effect on soil microarthropods, but changing soil water availability through manipulated drought and irrigation has strong impact on soil microarthropods (Convey et al., 2002, 2003; Kardol et al., 2011). The effects of both warming and changing soil water availability are mainly exerted through aggravating or alleviating soil water stress and vary with ecosystem types. In general, the warming-induced reductions of soil microarthropods are likely to occur in colder and drier climates whereas the stimulations of soil microarthropods under increased precipitation are often observed in drier climates (Blankinship et al., 2011). In addition, the impacts of manipulated climate change factors on soil microarthropods vary with the duration and direction of experimental treatments (Blankinship et al., 2011). Thus, insight into the long-term soil microarthropod response is needed for finding general patterns of terrestrial soil biota under climate change, especially in arid and semiarid grasslands with water limitation.

As part of a long-term multi-factor global change experiment initiated in 2005, this study was conducted in 2011 and 2012 to examine the responses of soil microarthropods to increased temperature and precipitation in a temperate steppe in Inner Mongolia, China. Located in semiarid temperate climate zone, Inner Mongolia grasslands are water-limited and sensitive to climate change (Niu et al., 2008; Liu et al., 2009; Yang et al., 2011; Xia and Wan 2012). Our previous studies in this system have revealed that warming decreases but rainfall addition enhances plant root productivity (Bai et al., 2010), species richness (Yang et al., 2011), and soil microbial biomass carbon and nitrogen (Liu et al., 2009). As a result, we hypothesize that warming will reduce but increased precipitation will stimulate the abundance of soil microarthropods through affecting their food resources (plants and microbes) and habitat.

2. Materials and methods

2.1. Study site

The study site is located in a semiarid grassland (42°02′N, 116°17′E and 1324 m a.s.l) in Duolun County, Inner Mongolia, which is 180 km north of Beijing, the Capital of China. Long-term (1953–2012) mean annual precipitation and temperature are 379 mm and 2.2 °C, respectively. The soil is Haplic Calcisols (FAO classification) with mean bulk density of 1.31 g cm^{-3} and pH of 6.84. The vegetation at the experimental site is typical steppe. The dominant plant species are perennial herbs, including *Stipa krylovii, Artemesia frigida, Potentilla acaulis, Cleistogenes squarrosa, Allium bidentatum,* and *Agropyron cristattum*.

2.2. Experimental design

The experiment used a paired, nested design with precipitation as the primary factor and warming as the secondary factor (Niu et al., 2008; Liu et al., 2009). Three 44 × 28 m blocks were randomly selected with Block 1 being less than 50 m from Blocks 2 and 3. Blocks 2 and 3 were adjacent with each other. In each block, there were two 10 × 15 m plots with a 1 m buffer zone between the two plots. In each block, one plot was assigned as increased precipitation treatment and the other one as control. Within each plot, there were four 3 × 4 m subplots with two subplots used for warmed treatment and the other two subplots for unwarmed treatment. The distance between any two subplots was 1 m. Therefore, there were 24 subplots assigned to 4 treatments: control (*C*), warming (*W*), increased precipitation (*P*), and warming plus increased precipitation (WP), with 6 replications for each treatment.

In each increased precipitation plot, 6 sprinklers were arranged evenly into 2 rows with a distance of 5 m between any 2 sprinklers to cover the 10 × 15 m area. Each sprinkler covered a circular area with a diameter of 3 m. In July and August, 15 mm of water was added weekly to the increased precipitation plots in early morning when wind speed was low. Therefore, a total amount of 120 mm water (approximately 30% of mean annual precipitation at the study site) was supplied every year. Interannual fluctuations of precipitation in the local area varied from −34% to +34% above the long-term average over the past 60 years (1953–2012, data from Chinese Meteorological Administration). Each of the warmed plots was heated continuously (24 h) since April 28, 2005 using one 165 × 15 cm MSR-2420 infrared radiator (Kalglo Electronics, Bethlehem, PA, USA) suspended 2.5 m above the ground. The effect of infrared radiators on soil temperature was spatially uniform within the warmed plots (Wan et al., 2002). In each control plot, one 'dummy' heater with the same shape and size as the infrared radiator was suspended at the same height to mimic the shading effects of the heater.

Soil temperature (ST) at the depth of 5 and 10 cm was measured with thermocouple and recorded with a CR1000 data logger (Campbell Scientific, Logan, UT, USA) at 1 h intervals from June 4, 2005 to November 15, 2007 and from middle March to middle November since 2008. Soil moisture content (SM) at a depth of 0–10 cm was measured 2–4 times (2005–2009) or 6 times (2010–2012) per month from May to October using a portable soil moisture device (Diviner 2000, Sentek Pty Ltd. Balmain, Australia). Daily means of ST in each month were averaged to get the monthly mean value for each treatment. Soil moisture contents were also averaged to calculate monthly mean soil moisture contents. The monthly mean ST and SM were averaged to calculate the seasonal (from May to October) mean ST and SM.

2.3. Sampling, extraction, and identification of soil microarthropods

On August 11, 2011 and August 9, 2012, 3 soil cores (5 cm in diameter) were taken randomly in each plot at 0–10 cm and 10–20 cm depths, respectively. The three soil cores from each depth were combined to a compound sample prior to extracting the microarthropods. The soil samples of 0–10 cm included the litter layer. The soil samples at each depth were divided into two subsamples, one was used to extract soil microarthropods and the other was stored in iceboxes and transferred to the laboratory to measure the soil microbial carbon (MBC) and nitrogen (MBN). Tullgren funnels were used to extract soil microarthropods. Each funnel containing150 g fresh soil was put under a 60 W bulb for 48 h. After extraction, the numbers of mites and Collembola (included juveniles and adults) were counted under a dissection microscope. Then the microarthropods were preserved in 70% ethanol. Collembola were identified to genus level (Yin, 1992, 1998). Mites were identified to suborders levels (Yin, 1992, 1998). In this study, only adult mites and Collembola were identified.

2.4. Soil respiration, plant, and microbial variables

Two PVC collars (11 cm in internal diameter and 5 cm in height) were permanently inserted 2–3 cm into the soil at two opposite corners of each subplot for soil respiration (SR) measurements. A LI-8100 portable soil CO_2 fluxes system (Li-Cor Inc., Lincoln, NE, USA) was used to measure soil respiration 4 times a month in 2011 and 2012 between 09:00 AM to 12:00 AM local time during the growing seasons (May to October). Measurements were taken by putting the LI-8100 chamber on the PVC collars for 1–2 min. The values of two collars in each subplot were averaged as one replicate.

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