Sustainability **2015**, *7*, 1161-1171; doi:10.3390/su7021161

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Soil Warming Elevates the Abundance of Collembola in the Songnen Plain of China

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Academic Editor: Marc A. Rosen

Received: 16 September 2014 / Accepted: 13 January 2015 / Published: 22 January 2015

Abstract: The effect of soil warming and precipitation control in the context of soil warming on Collembola community was studied in Songnen grassland, China. Treatments included (1) control; (2) soil warming; (3) soil warming with low precipitation; and (4) soil warming with high precipitation. The open top chambers were used to increase the soil temperature, and the low and high precipitation were created by covering 30% of the chamber and artificial addition after rainfall through the three-year long field experiment. Soil samples were taken and collembolans were extracted in the 15th in June, August and October from 2010 to 2012. Abundance of total Collembola and dominant morphospecies *Orchesellides* sp.1 was significantly increased by soil warming. Total Collembola abundance was not affected by the precipitation. However, the abundance of *Mesaphorura* sp.1 was significantly increased by warming with low precipitation treatment. Collembola species richness, diversity and evenness were not impacted by any treatment through all the sampling times. These results suggest that more attention should be paid to the Collembola community variation under global warming in the future.

Keywords: springtail; Songnen grassland; global warming; precipitation control

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1. Introduction

Global warming is one of the most significant environmental problems with a strong influence on biodiversity [1,2]. Soil temperature and moisture are important environmental factors to soil micro-arthropods life [3], and they have directly and indirectly impact on soil biodiversity and ecosystem functions [4]. Collembola is a key group of soil arthropods, and exert regulatory control on the soil structure and soil processes, such as substrate decomposition and nutrient cycling. It is important to study the response of Collembola to global warming and other environment factors in the context of global warming.

Songnen plain is one of the most important grain and forage production base in China. Due to the excessive utilization and development in the Songnen plain, many serious ecological problems (e.g., land degeneration and biodiversity decrease) threaten this area [5]. The characteristics of the Songnen plain are drought, high saline-alkali and infertility [6]. Moreover, during the recent 50 years, Songnen plain undergoes dramatically climate warming, for the mean annual temperature, the rate of climate warming is 0.3487 °C/10 years [7,8]. Songnen plain is located in the NECT (Northeast China Transect) of the IGBP (International Geosphere-Biosphere Program), and precipitation is the limiting factor to the living creatures in this area [9]. The consequences of severe climate change will threaten the biodiversity of underground communities.

Collembola are abundant in the Songnen grassland [10]. Temperature and soil moisture are the most important environmental factors affecting Collembola communities [11]. Temperature can directly affect the development of Collembolan species, and within the range of tolerable temperatures, there is a direct and almost linear relationship between temperature and speed of development [12], and then change the life-history tactics of Collembola [13]. The drought and enhanced temperature will decrease the community stability of Collembola [14]. Focused on the effect of soil temperature and moisture changes on Collembola communities, researchers have been carrying out many studies in different regions sometimes with contradictory results. Some studies revealed that increasing temperature had only minor effects on Collembola community [4]. While other studies showed the fluctuating temperature regime increased the abundance and species richness of Collembola [15]. On the Falkland Islands and Anchorage Island, researches revealed that abundance and diversity of Collembola were unaffected by the warming treatment [16]. The long-term, multi-factor climate change experiment which was taken in a fescue field in Tennessee found that changes in soil moisture rather than warming had a significant impact on Collembola community [17]. The contradictory results of those researches indicate the complexity of the effect of soil temperature and moisture on Collembolan community.

It is already known that both warming and drought treatments resulted in significant effects on Collembola community in Europe [18]. However, in the Songnen grassland of China, which is under stressful environmental conditions, whether the Collembola community will represent distinctive response to the environment changes? Therefore, the aim of this experiment was to study the effects of locally simulated climate change involving long-lasting warming and the precipitation control in the context of warming on the Collembola communities in Songnen grassland, China. The questions addressed were whether changes in the long-term soil temperature and precipitation changes in the context of soil warming have any effect on Collembola community in Songnen grassland, China.

2. Materials and Methods

2.1. Study Area

The research was conducted at the Chang Ling grass and pastoral ecological research station (N 44°33′, E 123°31′; elevations is 140 m above sea level) of the Northeast Institute of Geography and Agroecology (NEIGAE), Chinese Academy of Sciences (CAS), located in the western part of the Songnen Plain. The climate is a typical semi-arid monsoon, with a dry and windy spring, warm and humid summer, and a cold and dry winter. The annual air mean temperature is 4.6~6.4 °C. The annual precipitation and evaporation are 400~500 mm and 1500~2000 mm, respectively. Sixty percent of the precipitation is distributed in summer.

2.2. Experimental Design

In April 2010, homogeneous grassland which was dominated by *Chloris virgata* was selected for the experiment. *Polygonum sibiricum* is the co-occurring species. The experimental design at the site consisted of a randomized complete block design. The experiment consisted of four treatments: (1) warming; (2) warming with high precipitation; (3) warming with low precipitation; and (4) control. Each treatment was repeated six times. A total of 24 plots were established.

(1) Warming (W): The open top chamber (OTC) which was hexagon-based pyramid and made of polymethyl methacrylate sheet was used to warm the plot. The dimensions of the OTC are 50 cm height, 1.5 m open-top hexagon, 60° inclination and 2.08 m basal diameter. The detailed design was described in the Temperature Enhancement Experiments of ITEX [19]. The warming device was fixed on the ground, and the bottom margin of OTC was 1cm above the ground.
(2) Warming with low precipitation (WLP): The OTC was used to warm the plot. A 40-cm-wide polymethyl methacrylate sheet covered 30% of the OTC hexagon to reduce 30% of the precipitation.
(3) Warming with high precipitation (WHP): The OTC was used to warm the plot. Thirty percent of the precipitation was sprayed into the plot after the rain fall each time. The data of precipitation was collected from the automatic weather station of the research station which was about 500 m from the plot.
(4) Control (CK): Only the framework of the OTC was installed on the field.

In one plot of each treatment, the humidity/temperature automatic recorder (Em50 Digital Data Logger, Decagon Devices Inc., Pullman, WA, USA) was placed to monitor the soil temperature and water content of the 0 to 5 cm layer (record once per hour).

2.3. Sampling and Species Identification

Sampling was carried out on nine occasions: 15th in June, August and October from 2010 to 2012. For each sampling time, the soil auger (diameter: 6.7 cm, height: 10 cm) was used to take four soil cores randomly in each plot, and all cores from each plot were merged into one sample. These soil samples were immediately taken to the laboratory. After each sampling, the pits which was caused by soil auger were filled by soil which was taken from the nearby of plot at the same soil layer. The distance between each sampling point was at least 10 cm. The Collembola were extracted within 48 h using the Modified Macfadyen apparatus using the low-light incidence of a 25 W lamp bulb. The extracted Collembola were preserved in 95% alcohol for identification. Three samples which were taken at the sampling time of October 2012 in control treatment (CK) and October 2010 and June 2010 in warming treatment (W) were missing in the process of species identification. All of the collected Collembola were identified to the species level according to the procedures of Bellinger [20], Yin [21], Potapov [22], Pomorski [23] and Christiansen [24].

A 20 × 20 cm^2 plant sample, which included the litter, and a 20 cm × 20 cm × 10 cm soil sample were taken in each plot in August 2012. The roots were washed from the soil sample with a sieve (Φ = 0.25 mm). All of the plant litter and roots were dried at 105 °C and then weighed for biomass.

2.4. Data Analyses

For each variable, the mean value ±S.E. was calculated. Data were transformed by log(n + 1) transformation to improve normality and homogeneity of variance if needed. The treatment effects on soil temperature, soil moisture and roots biomass were tested by one-way Anovas with LSD test. The treatment effects on Collembola were analyzed by repeated measures analysis. Warming and precipitation were treated as fixed factors, and block was treated as covariate factors. Differences obtained at the level of $p < 0.05$ were considered significant. Statistical analysis was performed using SPSS 17.0 for Windows (SPSS Inc, Chicago, IL, USA).

3. Results and Discussion

3.1. Environmental Factors and Plant Community

The treatments significantly modified the soil temperature (one-way ANOVA, F = 2.961, $p < 0.05$), and marginally significantly modified the soil moisture (one-way ANOVA, F = 2.742, $p = 0.065$). W, WLP and WHP treatments increased the soil temperature by 0.93 °C, 1.06 °C and 0.53 °C, compared with CK respectively. WLP treatment reduced 7.37% soil moisture, and WHP treatment increased 4.07% soil moisture compared with W treatment respectively. The measurements of soil moisture along the sampling period was given in Table A1.

Before June 2010, the grassland was dominated by *Chloris virgata*. Only a few *Polygonum sibiricum* existed. At the end of the experiment, the dominant plant species were *Medicago falcate* and *Sonchus brachyotus*; however, *Chloris virgata* was completely excluded from the plant community (Table 1). Warming and precipitation control treatment had significant effect on the biomass of plant roots (one-way Anovas, F = 3.308, $p < 0.05$). Warming treatment had no effect on the biomass of plant roots compared with control treatment; while warming with low precipitation treatment significantly reduced the biomass of plant roots compared with warming and control treatment (Figure 1).

Table 1. Effect of experimental treatment on the plant community diversity.

Treatment	CK	W	WLP	WHP
Species richness	2.00 ± 0.45	2.17 ± 0.40	2.00 ± 0.26	1.50 ± 0.34
Diversity(H)	0.82	1.38	1.04	1.06
Evenness	0.62	0.96	0.93	0.80
Dominant species	*Medicago falcata*	*Sonchus arvensis*	*Medicago falcata*	*Sonchus arvensis*

CK indicates control, W indicates warming treatment, WLP indicates warming with low precipitation, WEW indicates warming with high precipitation.

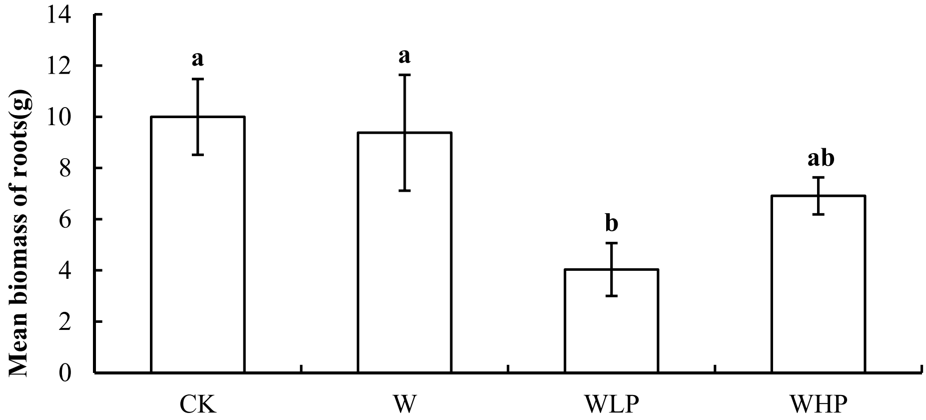

Figure 1. The mean biomass level of the roots for each treatment. CK denotes control, W denotes warming treatment, WLP denotes warming with low precipitation treatment, and WHP denotes warming with high precipitation treatment.

3.2. Composition, Abundance and Species Richness of Collembola

A total of 5612 Collembolans, belonging to 14 morphospecies, were identified in the samples. The soil warming (W, WLP and WHP) significantly increased the total abundance of Collembola (rANOVA, F = 6.465, $p < 0.01$). The abundance of the dominant species *Orchesellides* sp.1 was significantly increased by soil warming (rANOVA, F = 5.000, $p < 0.05$). The high or low precipitation treatments did not significantly affect the total Collembola abundance. However, the abundance of *Mesaphorura* sp.1 has significantly increased due to the WLP treatment (rANOVA, F = 5.971, $p < 0.01$) (Table 2).

Table 2. Total number of Collembola in the nine sampling times of the Songnen grassland.

Collembola	CK (*N* = 53)	W (*N* = 52)	WLP (*N* = 54)	WHP (*N* = 54)
Orchesellides sp.1	532 a	867 b	1190 b	1024 b
Entomobrya sp.1	17 -	2 -	61 -	5 -
Mesaphorura sp.1	54 a	97 ab	279 b	128 ab
Heterosminthurus sp.1	38	33	16	35
Bourletiella sp.1	41	33	49	51
Ptenothrix sp.1	12 -	3 -	4 -	2 -
Ptenothrix sp.2	78 -	41 -	42 -	76 -
Friesea sp.1	25	42	24	35
Arrhopalites sp.1	0 -	0 -	1 -	0 -
Arrhopalites sp.2	2 -	1 -	2 -	3 -
Isotomiella sp.1	83	104	194	102
Proisotoma sp.1	16	19	30	33
Lepidocyrtus felipei	1 -	11 -	3 -	0 -
Entomobrya sp.2	12	19	29	11
Total	911	1272	1924	1505

The six measurements of each sampling time were added together, and the abundance of nine sampling times were compared with the Paired Sample Test. CK denotes control, W denotes warming treatment, WLP denotes warming with low precipitation treatment, and WHP denotes warming with high precipitation treatment. The "-" indicates that the data are not adequate for running the analysis.

The warming treatment had a significant impact on the mean number of Collembola during the sampling time of June, August and October of 2010, June and August of 2011, and June of 2012 (Figure 2a). Comparing the mean numbers of the Collembola individuals of three precipitation control treatments, there was no significant difference between the precipitation control and the Collembola abundance. In the sampling of June 2012, the mean number Collembola of the WLP treatment was significantly higher than that of the other treatments, and there was no significant difference in the mean number of Collembola among the other sampling times (Figure 2b). There is no significant difference in the Collembola species richness, diversity and evenness between each treatment through all the sampling times (Table 3).

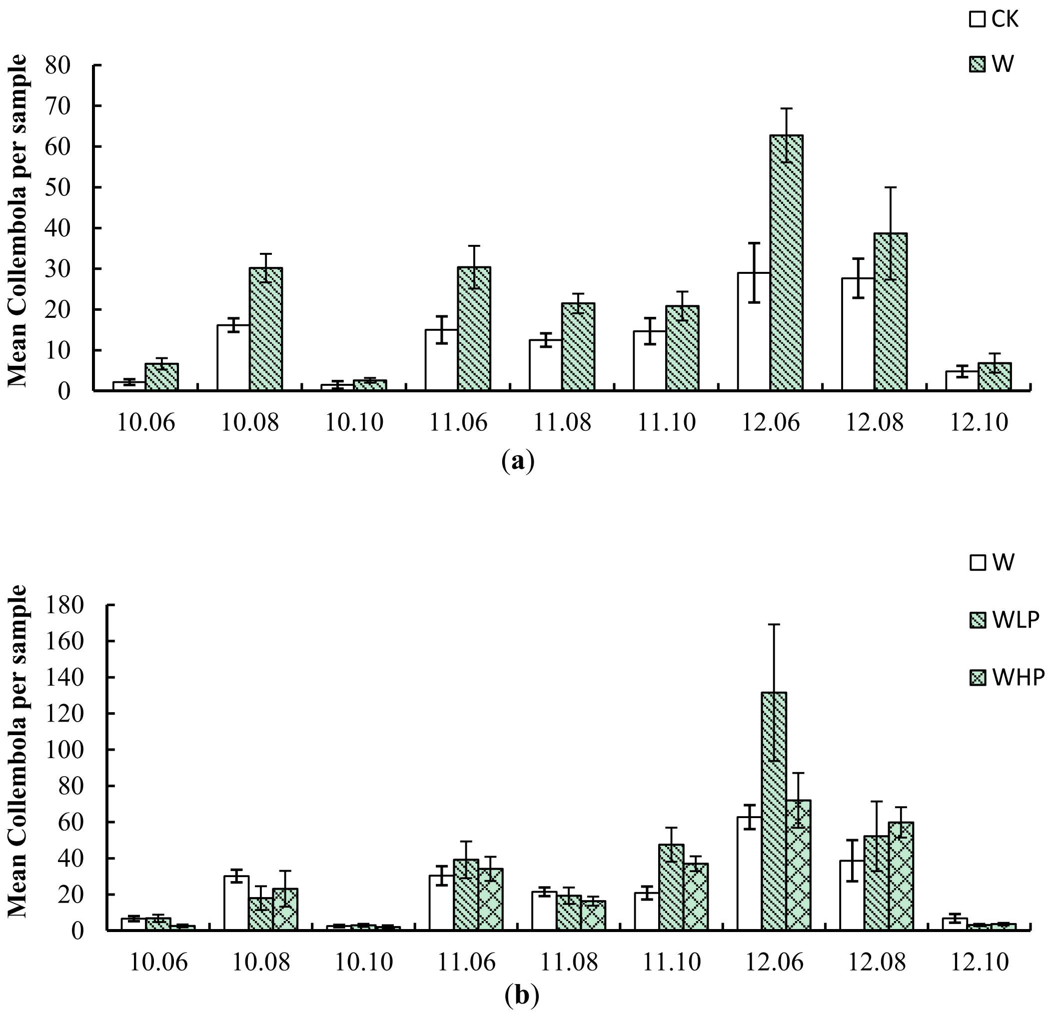

Figure 2. The mean number of Collembola of the nine sampling times with soil auger in warming and control precipitation plots of the Songnen grassland (CK denotes control, W denotes warming treatment, WLP denotes warming with low precipitation treatment, and WHP denotes warming with high precipitation treatment).

Both warming and altered precipitation could impact soil fauna [25]. Previous studies found that global warming could impact Collembola in different regions [26,27]. Their results are not the same as the results in present study. For the study of Haimi and colleagues, increasing temperature had only minor effects, so the authors considered the effect of the enclosure caused by the closed chambers as the main factor [4]. In this study, soil warming increased the total individuals of Collembola, especially the dominant morphospecies *Orchesellides* sp.1. Compared with the control treatment, the warming treatment enhanced the abundance of Collembola in six samples times. The soil warming caused by the OTC had a positive effect on the abundance of the Collembola community. Generally, low temperatures delayed embryonic development, while high temperatures accelerated the developmental process [28]. Within the temperature tolerance range, the growth rate of Collembola exhibited a nearly linear correlation with temperature [12], and high temperatures shortened the developmental process. For example, the mean lifecycle of *Folsomia candida* is 240 days at the temperature of 15 °C, which was shortened to 110 days at 24 °C [29]. In this study, soil warming increased the abundance rather than diversity of the Collembola. This result is in line with the study of Sinclair that climate change may cause changes in the abundance but not the diversity [27]. Each species of Collembola has its own preferred temperature range between which it will settle if placed in a gradient [11,30]. It gave us a small hint that Collembola abundance could be increased consequently.

Table 3. Characteristics of the Collembola communities for each treatment. CK denotes control, W denotes warming treatment, WLP denotes warming with low precipitation treatment, and WHP denotes warming with high precipitation treatment.

Treatment		**CK**	**W**	**WLP**	**WHP**
Species richness	2010	1.53 ± 0.17	1.82 ± 0.18	1.47 ± 0.17	2.2 ± 0.28
	2011	4.18 ± 0.32	3.71 ± 0.33	3.83 ± 0.28	4.11 ± 0.28
	2012	2.31 ± 0.25	2.53 ± 0.36	2.89 ± 0.32	2.67 ± 0.29
Diversity (H)	2010	0.78	0.79	0.95	1.06
	2011	1.67	1.60	1.35	1.43
	2012	0.93	0.95	1.08	0.89
Evenness	2010	0.72	0.66	0.77	0.76
	2011	0.80	0.84	0.70	0.68
	2012	0.66	0.68	0.70	0.62
Dominant Species and Dominant percent	*Orchesellides* sp.1	58.4	68.2	61.9	68.0
	Mesaphorura sp.1	5.9	7.6	14.5	8.5
	Ptenothrix sp.2	8.6	-	-	-
	Isotomiella sp.1	9.1	8.2	10.1	6.8

The dominant species are those comprising 5% or more of the total Collembola found for each treatment.

Precipitation is the main environmental restriction factor for the Songnen grassland ecosystem, which belongs to the North-east China Transect (NECT). Focusing on the precipitation, some research studying the Songnen grassland found that low precipitation can reduce the biomass and resources allocations in the plant community [31] and change the water-use efficiency of the plants [32] or the plant functional types [33]. It might also do harm to Collembola community in reduced soil water content caused by low precipitation. In our experiment, however, low precipitation did not reduce the abundance or the species richness of Collembola. What's more, low precipitation enhanced the abundance of Collembola in some samples. Thus, the result did not support the hypothesis. Collembola have several strategies for coping with dry conditions, such as morphological and physiological adaptations to tolerate low humidity, anhydrobiosis and ecomorphosis, and the use of desiccation-resistant eggs, which can hatch when the humidity increases [34]. The result of our study demonstrates the ability of Collembola to adapt to drought conditions. The reduced precipitation diminished the biomass of plant roots, and it might cause a decreased Collembola abundance due to the food resource reduction.

4. Conclusions

In this study, soil warming increased the abundance of the Collembola community but did not significantly affect the diversity. This might be because the long term land deterioration and the low background diversity, and the Collembola in Songnen grassland had strong resistant ability to the environmental disturbance, so the warming treatment had no significant effect on the diversity of Collembola. The increase in Collembola abundance might support the accumulation of Collembola for the appropriate temperature, but further controlled experiment is still needed to test this. In our experimental range, both the reduced and elevated precipitation treatments did not have a significant effect on the abundance or diversity of Collembola community, *i.e.*, enhancing or reducing the precipitation by 30% had no significant effect on the abundance or diversity of Collembola community of the Songnen plain. The evaporation of Songnen plain is very high, so the effect of elevating precipitation is limited. However, further work is required to explore the adaptation mechanism of Collembola in the Songnen plain.

We used open top chambers to simulate the global warming and artificially controlled the precipitation to estimate the impact of climate change on Collembola community of Songnen grassland. Through the experiment, we found that soil warming elevated the abundance of Collembola in the Songnen plain of China. But the data we got from this experiment is insufficient for analysing the responding mechanism of Collembola community. The lack of information about the development of Collembola individual restricts the future result analysis of most of the research on Collembola included this experiment. Thus, for the future study more attention should be paid on the life cycle of Collembola individual.

Acknowledgments

We thank Feng Zhang from Nanjing University, Louis Deharveng from the Muséum national d'Histoire naturelle and Xin Sun from the Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, for identifying the Collembola species. We thank Bing Zhang, Jing Liu and Lihong Song from the Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, for helping us to perform the farm work in this experiment. The present study was supported by the National Basic Research Program of China (No. 2010CB951304), the National Natural Sciences Foundation of China (No. 41430857, 31070467, 31200331, 31301862) and Chinese Academy of Sciences Visiting Professorship for Senior Foreign Scientists (No. 2013T2Z0010).

Author Contributions

The authors contributed equally to this work. All authors have read and approved the final manuscript.

Appendix

Table A1. The soil moisture of each sampling times. The data is the mean of soil moisture which is collected five days before each sampling time.

Sampling time	CK	W	WLP	WHP
June 2010	15.38	20.56	13.94	22.94
August 2010	8.27	15.40	6.35	11.50
October 2010	20.43	25.44	18.54	28.47
June 2011	14.07	16.12	16.99	16.62
August 2011	17.19	12.74	10.31	17.90
October 2011	ns	ns	ns	ns
June 2012	23.86	24.35	21.14	28.81
August 2012	27.46	25.39	21.39	30.57
October 2012	22.60	20.43	15.59	24.14

CK indicates control, W indicates warming treatment, WLP indicates warming with low precipitation, WEW indicates warming with high precipitation. There was a equipment fault during the sampling time of October 2011, and ns indicated no data available.

Conflicts of Interest

The authors declare no conflict of interest.

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