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Plant, microbial community and soil property responses to an experimental precipitation gradient in a desert grassland

Lihua Zhang[a,*], Zhongkui Xie[b], Ruifeng Zhao[a], Yubao Zhang[b]

[a] College of Geography and Environment Science, Northwest Normal University, 967 Anning East Road, Lanzhou 730070, China
[b] Northwest Institute of Eco-Environment and Resources, CAS, 320 West Donggang Road, Lanzhou 730000, China

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ABSTRACT

Major changes in precipitation regimes can be predicted, but the effects of such changes on terrestrial ecosystem functioning are largely unknown. To investigate the effects of changes in precipitation regimes on the plant community, soil properties, soil respiration and bacteria community composition in an arid grassland, we conducted a three-year precipitation manipulation experiment (i.e., ambient precipitation as a control, ± 20% and ± 40% of ambient precipitation) in a desert grassland in the western Loess Plateau, China. The species richness, density, mean height, aboveground biomass and litter biomass were reduced in the −40% precipitation treatment. Soil water content at a depth of 0–20 cm peaked in the +40% precipitation treatment. The influences of precipitation treatment on dissolved organic carbon (DOC), microbial biomass carbon (MBC) and soil nutrients were small. Soil respiration varied along the experimental precipitation gradient and peaked in the +40% precipitation treatment. NO_3^--N was highest in the −40% precipitation treatment. *Bacteroidetes* had a higher relative abundance in the increased precipitation and control groups, while the abundance of *Actinobacteria* was higher in the decreased precipitation treatment in the wet year. The differences among precipitation treatments were not detected in the dry year. Thus, increased soil respiration along the precipitation gradient resulted from the positive responses of root growth, reflected in the plant community properties, and microbial respiration, reflected in the bacterial community composition. Different responses of ecosystem components to precipitation manipulation emphasize the necessity of studying the relationships between these components under climate change.

1. Introduction

Anthropogenic emissions of greenhouse gases are expected to cause significant changes in global climate in this century (IPCC, 2013). It has been suggested that climatic warming alters the amount and distribution of precipitation by increasing the water-holding capacity of the atmosphere, enhancing the evaporation rate and disrupting air circulation patterns (Trenberth, 2011). This had led to intensified intra- and inter-annual variations in precipitation in recent years (Min et al., 2011; Donat et al., 2013). Shifts in precipitation regimes, especially in arid and semi-arid environments where water determines primary production, may have an even greater impact on ecosystem dynamics than the singular or combined effects of rising CO_2 and temperature (Loarie et al., 2010). A better understanding of the effects of increased or decreased precipitation on the structure and function of ecosystems is critical for predicting how ecological services will change under future climate change scenarios.

A change in the precipitation amount would affect both the temporal and spatial distribution of water availability and potentially alter the structure and function of biotic communities (Tomiolo et al., 2015). Changes in precipitation patterns could also change the diversity, primary productivity and functional composition of plant communities, and ultimately alter the quantity and quality of carbon (C) inputs into soils (Hooker et al., 2008). However, small or delayed responses of plant community structure to long-term precipitation manipulation have been detected in water-limited temperate grasslands (Grime et al., 2000; Collins et al., 2012; Tielbörger et al., 2014). These were attributed to the tremendous temporal and spatial heterogeneity under which the plants have evolved.

The labile organic carbon pool is the most active fraction of soil organic matter and acts as a direct reservoir of readily available nutrients for plants and microbes (Schimel et al., 2007). It exerts considerable control on soil C flux and ecosystem functioning (Allison and Treseder, 2008). These have been shown to be sensitive to changes in management practices (Rui et al., 2011). However, there is uncertainty over the effect of altered precipitation on dissolved organic carbon

* Corresponding author.
E-mail address: zhanglihualz@126.com (L. Zhang).

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(DOC) and microbial biomass carbon (MBC). Some studies have found that increased precipitation could increase DOC and MBC (Zhang et al., 2013; Zhou et al., 2013; Huang et al., 2015; Zhao et al., 2016), and others have observed decreased MBC after increased precipitation (Sherman et al., 2012; Zhang and Zak, 1998). Insignificant differences in MBC (Cregger et al., 2014) and DOC (Sherman et al., 2012) were also found between altered precipitation levels. Therefore, uncertainties still exist in the feedbacks of the soil C pool in response to varied water availability under global change scenarios.

Microorganisms play key roles in soil biogeochemical processes, including organic matter decomposition and nutrient mineralization (Cregger et al., 2014). A higher precipitation is reported to increase the availability of respiratory substrates (Zhou et al., 2013), which could also change microbial C use and stimulate microbial growth and physiological activities (Zhou et al., 2013; Zhao et al., 2016). However, some studies have seen moisture-related changes in soil microbial community composition (Fierer et al., 2007; Barnard et al., 2013; Maestre et al., 2015), and others have observed few or no differences in the microbial community structures of wet and dry soils (Landesman and Dighton, 2010; Zhang et al., 2013; Curiel Yuste et al., 2014). More evidence concerning microbial community composition is necessary for understanding the general response of soil microorganisms to a greater variability in precipitation.

To investigate the effects of precipitation on plant communities, the labile organic C pool, soil respiration and microbial composition, a field experiment with five levels of precipitation manipulation (i.e., ambient precipitation as a control, ± 20% and ± 40% of ambient precipitation) that cover the natural range in precipitation variation was conducted in a temperate desert grassland in the western Loess Plateau starting in 2013 for three years. Given the known differences in the responses of ecosystem components to prolonged precipitation manipulation, we hypothesized the following: 1) Species richness and community biomass would increase with increasing precipitation and decrease with decreasing precipitation, 2) DOC, MBC and mineralized nitrogen would increase with increasing precipitation, and 3) Microbial community compositions would differ among precipitation treatments.

2. Materials and methods

2.1. Site description and experimental design

The experimental sites are at the Gaolan Experiment Station for Ecology and Agriculture Research, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences. The station (36°13″ N, 103°47″ E) is located in Gaolan county, Lanzhou city in Gansu province, northwest of the Loess Plateau. The altitude is approximately 1780 m. The climate is a drought-prone, semi-arid, continental climate. The average annual precipitation is 263 mm with 70% falling between May and September. The mean annual temperature is 8.4 °C, with a maximum mean monthly temperature of 20.7 °C (July) and a minimum mean monthly temperature of −9.1 °C (January). Mean annual pan evaporation is 1786 mm. The average soil organic carbon and total nitrogen are 0.75% and 0.1%, and pH is 8.52. The soil in this region is developed from wind-accumulated loess parent material, with a uniform silt loam texture and is classified as a *Haplic Calcisol* in the FAO/UNESCO classification system. The site is dominated by typical desert steppe vegetation, including the semi-shrub *Ajania fruticulosa* (Ledeb.) Poljak, *Reaumuria soongarica* (Pall.) Maxim and perennial grass *Stipa breviflora* Griseb. Common perennial herbaceous species include *Peganum harmala* L., *Zygophyllum mucronatum* Maxim, *Artemisia capillaris* Thunb and *Cleistogenes squarrosa* (Trin.) Keng. Annual herbaceous plants are less abundant and the most common species is *Salsola ruthenica* Iljin (Supplementary Table S1).

The experiment used a randomized complete block design with five treatments: −40% and −20% of the ambient precipitation, ambient precipitation as a control, and +20% and +40% of the ambient precipitation. The inter-annual precipitation variation was from −41.1% to +39.2% over the past 50 years in the study area. Precipitation frequency and timing were not changed within our treatments. Each treatment was replicated three times, and each replicate plot was 2.5 × 2.5 m^2. The precipitation treatments were applied from May to September each year from 2013 to 2015.

The rainout shelter is consisted of a fixed-location shelter with a roof made of transparent acrylic bands that block different amounts of rainfall and minimally affect other environmental variables (Yahdjian and Sala, 2002). The mean height of the shelter was 0.50 m. Light transmittance through the acrylic is very high compared to plastic or PVC, and the amount of photosynthetically active radiation intercepted is less than other shelter designs. Greenhouse effects are possibly eliminated due to the unconstrained air movement. The appropriate volume of rain intercepted in the decreased precipitation plots was added to the increased precipitation plots manually within 8 h of each precipitation event.

2.2. Plant community investigation

Two frames (0.5 × 0.5 m), each with 50 equally distributed grids, were placed above the canopy at the center of each plot and were used to measure plant species richness, density of each species, height and coverage once a month from late May to late September in 2013, 2014 and 2015. Species richness was recorded as the number of plant species in the quadrat. Density was calculated as the sum of the individual numbers for all species. The mean height was the average value of all species' heights. Meanwhile, the senescent litters of the two subplots were collected and oven-dried to obtain a biomass measurement.

Aboveground biomass was assessed using a harvesting method at the time of peak biomass (early September). All plants were clipped to the soil surface by species in another two quadrats (0.5 × 0.5 m) in each plot. After oven drying for 48 h at 65 °C, the dry mass was weighed to determine the biomass (g m^{-2}) of each species. Community aboveground biomass (g m^{-2}) was estimated from the sum of all species' aboveground biomass. The aboveground biomass was sampled in the same two quadrats in the first 2 years and in another two quadrats in the third year.

2.3. Soil respiration measurement

To measure soil respiration, two PVC collars (11 cm in internal diameter and 5 cm in height) were inserted 3 cm into the soil at two opposite corners in each plot. All living plants inside the soil collars were removed by hand at least 1 day prior to the measurements. Soil respiration was measured using an LI-6400-09 soil chamber (Li-Cor, Inc., Lincoln, NE, USA). The observation length was 2–3 min on each collar. The values of the two collars in each plot were averaged as one replicate. Soil respiration was measured every 2 h between 8:00 and 18:00 from June-September in 2013, 2014 and 2015.

2.4. Soil sampling and edaphic properties

Soil samples were collected from all 15 plots on August 15th of 2013, 2014 and 2015 and June 15th of 2014. In each plot, three soil cores at each depth (0–5, 5–10 and 10–20 cm depth; 5 cm diameter) were randomly taken using an auger and were mixed to obtain one composite sample per plot. After visible roots and stones were removed by hand, the soil was then passed through a 2 mm sieve. Subsamples passing through a 1 mm sieve were placed in an icebox and transported to the laboratory for microbial analysis. Other subsamples were air-dried for chemical analysis.

Dissolved inorganic nitrogen (NH_4^+-N and NO_3^--N) was extracted from 10 g of fresh soil with 50 ml of 2 M KCl and was measured with a Flow Injection Analyzer (Skalar, Breda, the Netherlands) (Zhao et al., 2016). Soil microbial biomass carbon and nitrogen (MBC and MBN)