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Identifying drivers of root community compositional changes in semiarid grassland on the Loess plateau after long-term grazing exclusion

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ABSTRACT

Grazing exclusion has been widely studied to have impacts on grassland aboveground community characteristics, however little is known about responses of grassland root community to long-term grazing exclusion. We selected five grasslands with different grazing exclusion time (0, 5 years, 9 years, 22 years, and 30 years) to determine root traits (biomass, length, surface area) in plant functional group and plant community level, soil properties of 0–30 cm depth and relationship between root traits and soil properties. Our results showed that grazing exclusion increased grassland root biomass, root length density and root surface area, accompanying declined plant species richness. After grazing exclusion, with perennial bunchgrasses (PB) being predominant in root community all the time, proportion of perennial rhizome grasses (PR) increased and proportion of perennial forbs (PF) declined. Grasses had higher specific root length and specific root surface area than that of forbs. Grazing exclusion significantly increased soil water content, soil organic carbon, total soil nitrogen and available soil phosphorus. Grasses were mainly correlated with soil organic carbon and nitrogen, while forbs were mainly influenced by soil phosphorus. Our results highlight the grasses' enhancing effect on grassland root productivity, and the critical role of soil nitrogen and phosphorus in regulating root community compositional changes in semiarid grassland after long-term grazing exclusion.

1. Introduction

About 90% of grassland was degraded as a consequence of overgrazing by livestock in China (Wu et al., 2009). Overgrazing induced considerable destructive effects on plant community and soil resources (Deng et al., 2014). Grazing exclusion has been proven to be a successful practice to restore degraded grasslands throughout the world (Shrestha and Stahl, 2008; He et al., 2009; Golodets et al., 2010). Many studies pointed to significant enhancing effects of grazing exclusion on plant coverage, density and aboveground biomass in the early stage, which were diluted or even reversed as grazing exclusion time increased (Wu et al., 2009; Jing et al., 2014b). Meanwhile, grazing exclusion not only significantly increased storage and availability of soil water and nutrients through more litter inputs (Wu et al., 2008; He et al., 2009; Qiu et al., 2013), but also played an important role in structuring community of soil eukaryotes (Jing et al., 2014a).

Contrasted with numerous researches on aboveground responses to grazing exclusion, researches about root responses are largely limited by the studying difficulties and complexity of plant roots. As a majority component of grassland ecosystem, roots played an essential role in acquiring soil resources (e.g. water, major and trace nutrient elements), which distributed with a high heterogeneity in time and space in natural habits (Gross et al., 1993; Jackson and Caldwell, 1993b; Fransen et al., 1998; Pärtel et al., 2012). Current studies on fenced grassland root mainly focused on root biomass and its distribution pattern in different types of grassland. For instance, 80–90% of root biomass occurred in the top 30 cm of soil and decreased exponentially with increasing soil depth (Jackson et al., 1996; Li et al., 2011). Additionally, responses of root: shoot ratio to grazing exclusion

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Table 1
Geographical characteristics of study sites.

Site [a]	Latitude (°N)	Longitude (°E)	Altitude (m a.s.l.)	Slope (°)	Dominant plant species
GG	36.2195	106.3842	1942	20	*Stipa bungeana, Potentilla acaulis, Heteropappus altaicus, Artemisia frigida, Swertia diluta*
GE05	36.2247	106.3918	1928	18	*S. bungeana, Anthoxanthum glabrum, P. acaulis, A. frigida, S. diluta*
GE09	36.1990	106.4120	1901	22	*Stipa grandis, S. bungeana, Thymus mongolicus, Artemisia sacrorum, P. acaulis*
GE22	36.2009	106.4112	1885	21	*S. grandis, Carex aridula, Potentilla bifurca, T. mongolicus, A. frigida,*
GE30	36.2428	106.3835	2098	23	*Stipa przewalskyi, S. grandis, C. aridula, T. mongolicus, A. sacrorum*

[a] GG grazing grassland, GE05 grassland with 5 years' grazing exclusion, GE09 grassland with 9 years' grazing exclusion, GE22 grassland with 22 years' grazing exclusion, GE30 grassland with 30 years' grazing exclusion.

varied with grazing exclusion time and grassland type (Deng et al., 2014; Liu et al., 2014).

Since root morphology and/or physiology traits and plasticity determined plants' capability of foraging soil nutrients, they have received considerable attentions in recent studies (Jackson and Caldwell, 1993a; Hutchings and de Kroon, 1994; Li et al., 2014). It's now recognized that plants proliferate root by producing high root length density in nutrient-rich patches (Fransen et al., 1998, 1999; Li et al., 2014), and increase specific root length by decreasing root diameter in response to nutrient deficiency (Hill et al., 2006; Maestre and Reynolds, 2007; Fort et al., 2014). There is a considerable difference in roots traits and plasticity among different plant species, normally with greater ones in graminaceous species (Hill et al., 2006; Pohl et al., 2011; Li et al., 2014). The hierarchy of root trait values and plasticity among species and plant functional groups in the vegetation could drive early-stage competition for water and nutrients, which ultimately made an effect on vegetation succession (Johnson and Biondini, 2001; Fort et al., 2014).

However, major knowledge gaps still exist concerning responses of plant root morphological traits to changes of soil characteristics in restored grassland after grazing exclusion, which are vital for understanding the causes and current status and predicting further trend of vegetation succession in response to grazing exclusion. To provide a new perspective of biodiversity restoration and the basis for management of degraded grassland in semiarid areas, our study was conducted with a spatial series representing temporal series method in semiarid grasslands with different grazing exclusion time scales on the Loess Plateau, we aimed to: (1) determine effects of grazing exclusion on grassland root biomass and morphological traits and their distribution pattern in plant functional groups; (2) examine the changes of soil properties after grazing exclusion; (3) identify the relationship between root traits and soil properties in PFG level and community level.

2. Materials and methods

2.1. Study sites

This study was conducted in Yunwushan National Natural Grassland Protection Zone in Ningxia Hui Autonomous Region, China. Since 1982, the grassland has had been protected as a long-term monitoring sites for restoration of degraded grassland. The site is located at an elevation from 1800 to 2100 m and has a total area of 6660 ha. The study area has a climate of semi-arid within the middle temperate zone. The mean annual temperature is 7.01 °C, and the frost-free season averages 137 days. The mean annual precipitation is 425.42 mm, with 60–75% of rainfall falling from July to September. The annual evaporation is 1017–1739 mm. Soil type in the study area is montane grey-cinnamon soil. The vegetation community consists of 297 plant species and is dominated by *Stipa* plants (*Stipa bungeana*, *S. grandis*, *S. przewalskyi*), and main forbs include *Artemisia sacrorum* and *Thymus mongolicus*.

2.2. Experimental design and sampling

Five experimental sites along a chronosequence of grassland restoration were selected in August 2012, when peak aboveground biomass occurred. Four sites have been fenced with goat proof wire mesh since year 1982, 1990, 2003 and 2007, with grazing exclusion for 30 years (GE30), 22 years (GE22), 9 years (GE09) and 5 years (GE05), respectively, and the rest site has been continuously grazed at a medium density during the whole year (4 sheep/ha) as a control (GG). Before grazing exclusion, all the study sites had been heavily grazed (>50 sheep/ha) by sheep (Jing et al., 2014b), and *S. bungeana* accounted for 45% of vegetation community with other main species being *Potentilla acaulis* and *Heteropappus altaicus* (Jing et al., 2013). Before grazing exclusion, grassland soil in 0–20 cm layer showed following properties: soil water content at 9.81%, soil organic matter content at 9.82 g/kg and total soil nitrogen at 0.85 g/kg. More details on soil properties before grazing exclusion can be found in literatures by Jing et al. (2013); Jing et al. (2014b). The chosen plots in all sites have similarities in soil type, slope degree, slope direction, topography, and altitude (Table 1).

A transect of 300 m × 100 m with representative vegetation was selected as the study area within each site, in which three pseudo-replicated plots (30 m × 30 m) were established. And three subplots (2 m × 2 m) were set up with a minimum interval of 15 m in each plot for field sampling. With aboveground plant parts being attached, a soil block of 50 cm long × 50 cm wide × 30 cm deep was excavated in each subplots, then was gently loosen by hand to get the intact root–soil mixtures with minimal breakage. Root-soil mixtures with attached aboveground parts were carefully carried to the laboratory and stored in 4 °C for further root identification and analysis of root biomass and morphology traits.

In each subplot, a pit of 0.8 m long × 0.7 m wide × 0.5 m deep was dug, and stainless-steel cutting cylinders (5.0 cm diameter × 5.0 cm high) and aluminum specimen boxes were used for the collection of soil samples at the depth of 0–10, 10–20 and 20–30 cm. The soil samples were dried in 105 °C for 48 h, and then weighed to calculate soil water content and soil bulk density.

In each subplot, three soil samples were collected at the depth of 0–10, 10–20 and 20–30 cm by using a bucket auger (5.0 cm in diameter), then soil samples of the same layer were mixed into one sample. One part was passed through 2 mm mesh sieve to remove roots, then kept fresh in 4 °C for measuring soil pH, available N and soil microbial biomass. The second part was air-dried, and grounded to pass through 0.25 mm mesh sieve for measurements of other soil properties.