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Effect of rest-grazing management on soil water and carbon storage in an arid grassland (China)

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SUMMARY

The appropriate grassland management practices play an important role for sustainable use of grassland. Rest grazing is beneficial to maintain higher grassland productivity and species diversity. However, little knowledge exists about the effects of rest grazing on soil water and carbon storages in arid regions. In the current study, we investigated the above- and below-ground community characteristics of the three-paired rest-grazing and grazing grasslands in an arid region of northern-west China. An 11-year rest grazing grassland and a continuous grazing grassland were studied to understand soil water and carbon storages. The results revealed that soil water content and carbon storage significantly increased after rest grazing, which was mainly attributable to increasing below-ground biomass density. At the 30–50 cm soil layer depth of the continuously grazing grassland, bulk density was higher and below-ground biomass was lower than the rest of the grazing grassland. This layer significantly affected the water cycle by blocking water exchange between the upper and lower soil layers. Soil carbon content did not significantly increase after rest grazing. The results indicated that rest grazing has a great potential for the recovery of soil water storage, and is an effective way to enhance grassland restoration in the arid area.

1. Introduction

The arid region of northern-west China, covering about one-fourth of the land surface, is characterized by its extremely vulnerable water resources (Zhou et al., 2011). The main grasslands in this arid region are known as oasis and oasis-desert ecotones, where contradictions between ecology and industrial and agricultural production are very conspicuous (Su et al., 2005). Over the last 50 years, overgrazing and grassland degradation rates in the Hexi corridor region in northern-west China have reached 69.10% and 46.86%, respectively (Wang et al., 2003). Ecosystem recovery, associated with rest grazing or reducing grazing intensity, has been designed and implemented by China's central government over the past three decades to control grassland degradation (Zhou et al., 2011). The key factor for ecosystem recovery in an arid ecosystem is to maintain soil water content (SWC) and soil organic carbon content (SOC) (Conant et al., 2001).

Water is a key element for building and maintaining regional ecosystems, and governing the number and size of perennial plant species in semi-arid and arid regions (Wang et al., 2003). SWC is affected by land-use type and pasture management, which control plant canopy cover, leaf area, plant evaporation and community composition (Cooper et al., 2006; Chen et al., 2008, 2010; Huang et al., 2013). Due to intensive livestock and agricultural use, the Hexi corridor region faces the consequences of widespread vegetation and soil degradation, such as lower grass yields, grassland desertification, lower carrying capacity, and loss of nutrients via wind erosion during the recent several decades (Li et al., 2009a; Pan and Chao, 2003). Meanwhile, the arid ecosystem is defined by an arid-fed environment and high rates of potential evapotranspiration (Collins et al., 2008). Precipitation in most of the arid region is, on average, less than 200 mm a year, with the lowest of <50 mm (Wang et al., 2003). A warming and drying trend in the Hexi corridor will increase the surface water stress (Piao et al., 2010; Yang et al., 2012). Soil water is the main constraint for the possibilities to permanently control desertification, and choosing the suitable way to protect the water is essential in this arid region.

Soil carbon storage (SCS) is more than twice the size of atmospheric carbon storage, thus a slight change in SCS has a large impact on atmospheric CO_2 concentration (McSherry and

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Ritchie, 2013). Regarding the large area of grassland throughout northern-west China, grassland degradation has had huge impacts on the global carbon cycle and climate change (Yang et al., 2005; Li et al., 2009a). Shifts in disturbance regimes, which are usually caused by human intervention (land use change, urbanization, cropping, pasture management, etc.), can result in long-term regional carbon loss or gain (Wu et al., 2003; Luo and Weng, 2011; Li et al., 2013). High inherent SOC in the grassland can help maintain and improve soil fertility and quality, increase soil aggregation, stabilize soil structure and reduce soil erosion ratio (Conant et al., 2001; Li et al., 2006; Shi et al., 2009). Therefore, maintaining SOC and understanding the impact of land-use change on SOC have aroused the interest for scientific research on this topic.

Restoring herbivore-disturbed ecosystems solely by reducing herbivore density requires decades to equilibrate (Zhou et al., 2011). Monitoring of vegetation and soil along a chronosequence under similar soil and climate conditions is a basic approach to study soil changes over the natural restoration time. Since there is no historical record of changes in most soil properties due to grassland restoration for the long time, chronosequence approaches offer unique opportunities to use space-for-time substitution to quantify the recovery of soil carbon and water contents (Matamala et al., 2008). Effective ways of maintaining the stability of grassland consisted of recovering the relatively stable ecological zones from the destroyed ecological rift zones, such as the rest grazing, rotational grazing and grazing exclusion for a long term (Pan and Chao, 2003; Deng et al., 2014). Recent studies have described the ecological impact of vegetation restoration on soil carbon storage (Deng et al., 2014; Wang et al., 2014a) and soil available water (Wei et al., 2007; Yang et al., 2012) in different regions, but its impact on carbon–water coupling in the arid region has not yet been described (Newman et al., 2006; Alvarez et al., 2009).

SWC is dynamic and not stored in a stable form for long-terms. However, soil water storage (SWS) is temporally stable in the different land-use types in the arid and semi-arid regions (Li and Shao, 2014). In this study, we use one-time measurement data to compare the SWC difference between in the grazing grassland (GG) and rest-grazing grassland (RGG). Additionally, we also evaluated GG to ascertain the impact of soil water and carbon content, and of the plants and soil properties on the SWS and SCS response to rest grazing in arid regions of the Hexi corridor in northern-west China.

2. Materials and methods

2.1. Study site

The study region (99°22.6′–99°25.8′E, 39°26.8′–39°36.9′N; 1374–1385 m elevation), depicted in Fig. 1, is located in Gaotai county, Hexi corridor, Gansu Province, China, and has a typical desert climate, characterized by cold winter and hot dry summer. According to data from the National Meteorological Information Center of China available for the period from 1992 to 2012, the mean annual air temperature was 8.5 °C and the mean annual accumulated precipitation was 115.9 mm (Fig. 2). The main soil type is classified as grey brown desert soil according to the Chinese Soil Taxonomy, which is equivalent to the Aridisols in terms of the USDA soil taxonomy classification (Group of Chinese Soil Taxonomy, Institute of Soil Science, Chinese Academy of Sciences, 2001).

The study was conducted in three paired RGG sites and GG sites in the flat region without slope (Fig. 1). Rest grazing was started from the year 2002 (Yang, 2004). Before rest grazing, the permanent grasslands were used as grazing land. Both RGG sites and GG sites were in similar initial conditions and had similar characteristics before 2002, such as altitude, soil type, grazing intensity, predominant plant species, and topography. No fertilizer or herbicides had been applied to the grasslands prior to the experiment. The particle size distribution and soil chemical properties before the rest-grazing are listed in Table 1. The grazing intensity of the GG was 2–3.5 sheep ha^{-1} from May to September, and 1–2 sheep ha^{-1} from October to April of the following year. The vegetation coverage ranged from 5% to 25%, and the predominant plant species were *Achnatherum splendens, Agropyron cristatum, Phragmites australis.* In each of the 6 sample sites, five quadrats were set up along a 100-m line transect. The 100-m line transects of each paired GG site and RGG site were parallel, and the distance between the line transects was about 40 m (Fig. 1).

2.2. Plant sampling

In each quadrat, the vegetation was cut to ground level, including plant litter (standing dead parts). The green above-ground plant parts or above-ground net primary productivity (ANPP) and litter were separated. Three soil samplings were taken from each soil layer with depths of 0–5–10–20–30–50–70–100 cm in each quadrat by a 9-cm diameter root auger to measure below-ground biomass (BGB). After the obvious roots were taken out from the soil samples, the rest was isolated using a 0.5-mm sieve. The ANPP, litter and BGB were dried at 65 °C for 48 h and weighed to determine dry mass.

2.3. Soil sampling and determination

One soil sample was taken at five points from each quadrat (four corners and the center of the quadrat) by a 4-cm diameter soil drilling sampler at depths of 0–5–10–20–30–50–70–100 cm. Soil samples were air-dried and then passed through a 0.25-mm sieve. A total of 210 soil samples (30 quadrats with 7 soil layers) were measured for bulk density (BD), pH, SWC and soil carbon content. Each RGG and GG has 105 soil samples. Soil pH was determined at a soil–water ratio of 1:5. Soil BD ($g\,cm^{-3}$) of the different soil layers was measured using the soil cores (volume, 100 cm^3) by the volumetric ring method (Wu et al., 2010). Part of the fresh soil samples were dried at 105 °C for 48 h to determine SWC, and then multiplied by bulk density to calculate the volumetric SWC. The SOC was assayed by dichromate oxidation (Nelson and Sommers, 1982). Each analysis was performed in duplicates. We used the following equation to calculate SCS (Deng et al., 2013)

$$SCS = SOC \times BD \times D$$

where, SCS is soil organic carbon storage ($kg\,m^{-2}$); BD is bulk density ($g\,cm^{-3}$); SOC is soil organic carbon content ($g\,kg^{-1}$); and D is soil thickness (cm).

The following equation was used to calculate SWS:

$$SWS = SWC \times D \times 100$$

where SWS is soil water storage (mm); SWC is volumetric soil water content ($m\,m^{-1}$); and D is soil thickness (cm).

Below-ground biomass density (BGBD, $g\,m^{-3}$) was calculated by the equation:

$$BGBD = BGB/D \times 100$$

where BGBD is below-ground biomass density ($g\,m^{-3}$); BGB is below-ground biomass ($g\,m^{-2}$); and D is soil thickness (cm).