Catena 172 (2019) 781–788

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Optimizing management to conserve plant diversity and soil carbon stock of semi-arid grasslands on the Loess Plateau

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ARTICLE INFO

Keywords:
Long-term grazing exclusion
Mowing
Plant composition
Soil carbon

ABSTRACT

Grassland recovery from degradation is increasingly occurring worldwide. Diverse managements have been considered as effective ways to restore degraded grassland, but it remains unclear how semi-arid grasslands respond to long-term grazing exclusion and fenced mowing. Here, a study was conducted under open grazing, grazing exclusion and fenced mowing in a semi-arid grassland on the Loess Plateau. We measured plant species composition and diversity, plant production, surface litter and soil water and carbon content. Shifts in grassland management led to significant divergence in plant community composition. Long-term grazing exclusion (35 years) significantly increased plant biomass, surface litter, soil water and carbon storage, but suppressed plant diversity compared to open grazing. Conversely, fenced mowing significantly increased plant diversity accompanying with a weak effect on soil carbon. Moreover, mowing significantly reduced surface litter and soil moisture, which have strong implications for nutrient depletion and soil drying. Our results suggest that introducing disturbances are necessary to safeguard biodiversity, and continuous mowing (5 years) belongs to over exploitation of the long-term protected grassland. Therefore, it is essential to optimize management with dual objectives of biodiversity and soil carbon sequestration in the future.

1. Introduction

Grasslands world-wide cover approximately 40% of the global land area, and are important in preserving plant diversity and soil organic carbon (SOC) (West and Post, 2002). Grassland managements exert significant impacts on plant diversity, primary productivity, and soil carbon stocks (McSherry and Ritchie, 2013; Hoffmann et al., 2016). Inappropriate managements (e.g. overgrazing) have been credited to grassland degradation (Dlamini et al., 2016). Dlamini et al. (2016) found that overgrazing significantly reduced SOC stocks by 9% using 628 soil profiles from 55 studies. And they speculated that grassland soil would lose 4.05 Gt C if 30% of grasslands were degraded globally. Conversely, enormous quantity of carbon could be stored back to soils if implementing adequate managements (Deng et al., 2017). It is especially important to adopt appropriate managements to counter grassland degradation trends.

Grazing exclusion is increasingly implemented throughout the world to restore degraded grasslands (Hu et al., 2016; Deng et al., 2017). However, there is no consistent response found across grazing exclusions trials. A short-term grazing exclusion (< 5 years) did not significantly alter plant diversity (Wu et al., 2014) and soil nutrient contents (Lu et al., 2015) on the Tibetan grasslands. In contrast, at natural ecosystems of southeastern Iran, the 6 years' grazing exclusion obviously promoted plant diversity and abundance of perennial grasses (Ebrahimi et al., 2016). Other studies have also showed that grazing exclusion is in favor of enhancing plant diversity and SOC stocks (Golodets et al., 2010; Fernandez-Lugo et al., 2013). However, these patterns have not necessarily been sustained over time (Xiong et al., 2016; Yu et al., 2016), and long-term protection might have negative effects (Zou et al., 2014). The accumulated litter can reduce species diversity with the prolonging grazing exclusion time (Lamb, 2008). Long-term grazing exclusion can also alter plant community structure by changing species composition and its dominance (He et al., 2011). Such inconsistent and even opposite results illustrated that varying

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https://doi.org/10.1016/j.catena.2018.09.034
Received 28 January 2018; Received in revised form 6 June 2018; Accepted 18 September 2018

grazing exclusion duration and different study sites may have different implications, but few studies have evaluated long term management-related grassland conditions of species diversity and SOC stock (Xiong et al., 2016).

Recently, grasslands with grazing exclusion are usually perceived as underused resource (Shao et al., 2012). The accumulation of flammable litter due to long-term grazing exclusion increases the risk of wildfires (He et al., 2011; Yu et al., 2015). Therefore, mowing is an alternative option for balancing the demand of grassland utilization and conservation. Effects of mowing have been studied across different grassland types (Socher et al., 2013; Kotas et al., 2017). Mowing can preserve high species diversity in temperate grasslands and subalpine grasslands (Benot et al., 2014; Kotas et al., 2017). Mowing can also mitigate soil respiration and enhance soil carbon (Shahzad et al., 2012; Wei et al., 2016). However, frequent or incorrect mowing practices may cause undesirable consequences (Shao et al., 2012; Socher et al., 2013). For example, plant diversity was decreased with increasing mowing intensity across 1500 grasslands in Germany (Socher et al., 2013), and above-ground biomass was reduced across three alpine meadows (Fu and Shen, 2017). Therefore, better understanding how mowing affects the plant community structure and ecosystem function is an urgent issue for developing sustainable managements.

Numerous studies have considered different managements to restore degraded grasslands, but to date there have been few side by side comparisons (Chaplot et al., 2016), especially on the semi-arid Loess Plateau. Semi-arid grasslands on the Loess Plateau went through severe degradation processes due to overgrazing in the past decades (Zhu et al., 2017). Now degraded grasslands restoration efforts are put forward. Historical and proposed new managements adopted side by side at the Yunwu Mountain Natural Grassland Reserve offer the opportunity to investigate the management-related grassland condition. In this study, we assessed the influences of open grazing, long-term grazing exclusion and fenced mowing on plant community and grassland functions of this semi-arid grassland on the Loess Plateau, China. Specifically, we hypothesized that (1) long-term grazing exclusion would exert detrimental effects on plant diversity, but replenish soil carbon due to litter accumulation, (2) fenced mowing would reduce the amount of soil carbon as a result of plant biomass removal, while promote plant diversity.

2. Material and methods

2.1. Study area

This study was conducted within the Yunwu Mountain Natural Grassland Reserve (36°10–17′N, 106°21–27′E, 1800–2100 m a.s.l.) of the Ningxia Hui Autonomous Region, China. The reserve is the largest remnant of typical steppe on the Loess Plateau, which occupies 6660 ha on montane grey-cinnamon soils (Cheng et al., 2016). The annual mean temperature is 6.9 °C with average monthly temperatures ranging from −14 °C in January to 24 °C in July. The annual mean precipitation is 425.4 mm with 60–75% falling during the growing season from July to September. The dominant plant species in this typical steppe include *Stipa grandis*, *Artemisia sacrorum*, *Thymus mongolicus*, *Potentilla acaulis*, *Stipa bungeana*, and *Androsace erecta*. Most of the areas have been excluded from grazing since 1982. Prior to that, the exclosures were subject to heavy grazing (> 50 sheep ha^{-1}). Small areas outside the fences are designated as 'open grazed', a kind of communal grazing regime, with a stocking rate of 4 sheep ha^{-1} during the whole year. The fenced mowing stripes (5 m wide) are originally for fire prevention, running along the slope within exclosures. Mowing began in 2012 and took place once per year in late September at the stubble height of approximately 10 cm, after which plants were allowed to grow until the next mowing.

2.2. Field sampling and measurement

Sampling took place in open grazed, long-term grazing exclusion and mowing area in August 2016. As we have no replications for these treatments, a survey transect (100–120 m) paralleling to the contours of the hill-slope was established within each treatment area. Plots were evenly spaced along the survey transect, with five 40 m^2 replicate plots per transect to ensure that the sampling area is big enough to represent the spatial heterogeneity. Above-ground biomass was sampled from two quadrats (50 cm × 50 cm) of each plot by clipping all plants at ground level. Clipped plant materials were sorted to individual living species or litter, dried (at 60 °C for 48 h), and weighted. All living plants were also divided into different functional groups based on their functional forms: perennial rhizome grasses (PR), perennial bunch-grasses (PB), perennial forbs (PF), shrubs and semi-shrubs (SS), and annuals and biennials (AB). The species richness (R) was recorded as the occurrence of the number of plant species in the quadrats. We calculated the Shannon-Weiner diversity index (H) and evenness (E) based on species biomass data (Cheng et al., 2016).

From the center of each quadrat, root biomass was sampled by taking a soil core (9 cm diameter) to a depth of 100 cm with 10 cm intervals. After washing soil through a 0.25 mm mesh sieve, root were oven dried at 65 °C for 48 h and weighted. One composite soil sample was prepared from three subsamples gathered with a soil corer (3 cm diameter) from each layer. Visually identifiable roots and organic debris were removed by hand. Fresh soil samples were homogenized and sieved through a 2 mm mesh. One set of subsamples were oven dried at 105 °C for 24 h for determining soil gravimetric water content. The other set of subsamples were air-dried, ground to measure SOC concentration by the potassium dichromate oxidation method. We also randomly selected one quadrat of each pair within a plot to measure soil bulk density for each layer, which we used to estimate soil water and carbon storage.

2.3. Data analysis

We used the one-way analysis of variance (ANOVA) in SPSS 17.0 (SPSS Inc., Chicago, IL, USA) to examine differences of ecosystem properties (i.e. plant biomass and diversity, soil water and carbon content) among different managements. Before performing the statistical analysis, datasets were verified whether satisfies normality distribution and they were log-transformed if necessary. We also evaluated the relationship between plant community structure (species or functional groups abundance and diversity) and litter mass through linear or non-linear regression analysis for the best-fit. All regression analysis and curve fitting were done with Origin 9.3 (OriginLab, Corp., Northampton, MA, USA).

The divergence of communities among different grassland managements was analyzed using principal components analysis (PCA) after log-transformation of species relative biomass data. Species that occurred occasionally (< three times) were taken out from the data in order to mitigate the impact of rare species on the analysis results (Hartley and Mitchell, 2005). The ordinations model was tested using Permutation test (Monte Carlo) and the significance was evaluated based on 999 permutations. PCA were conducted using CANOCO 5.0 (Microcomputer Power, Ithaca, NY, USA).

3. Results

Grassland managements had significant effects on plant biomass and diversity. The long-term grazing exclusion resulted in an average of 29.5% increase in above-ground biomass (F = 4.17, P = 0.030) and increased litter mass by 1311.1 g m^{-2} than under open grazing (F = 171.99, P < 0.001) (Table 1). In contrast, 5 years of continuous mowing generally reduced above-ground biomass by 16.9% (F = 2.12, P = 0.101) and litter accumulation by 95.8% (F = 183.51, P < 0.001),