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

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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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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 bunchgrasses (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% ($F = 183.51$, $P < 0.001$),

Table 1
Effects of different grassland managements on plant biomass, litter mass and plant diversity.

	Aboveground biomass ($g\,m^{-2}$)	Belowground biomass ($g\,m^{-2}$)	Litter mass ($g\,m^{-2}$)	Species richness	Shannon diversity index	Pielou's evenness index
Open grazing	180.0 ± 8.5 b	2404.9 ± 266.8 a	101.0 ± 10.7 a	13.3 ± 0.8 a	1.7 ± 0.1 a	0.7 ± 0.04 a
Grazing exclusion	233.1 ± 24.0 a	1953.9 ± 255.6 a	1412.1 ± 99.4 b	9.9 ± 0.9 b	1.0 ± 0.2 b	0.4 ± 0.06 b
Fenced mowing	193.6 ± 12.7 ab	2427.5 ± 213.0 a	58.2 ± 10.4 a	14.9 ± 0.9 a	1.7 ± 0.1 a	0.7 ± 0.03 a

Note: Different letters indicate significantly different managements based on Turkey's HSD tests ($P < 0.05$).

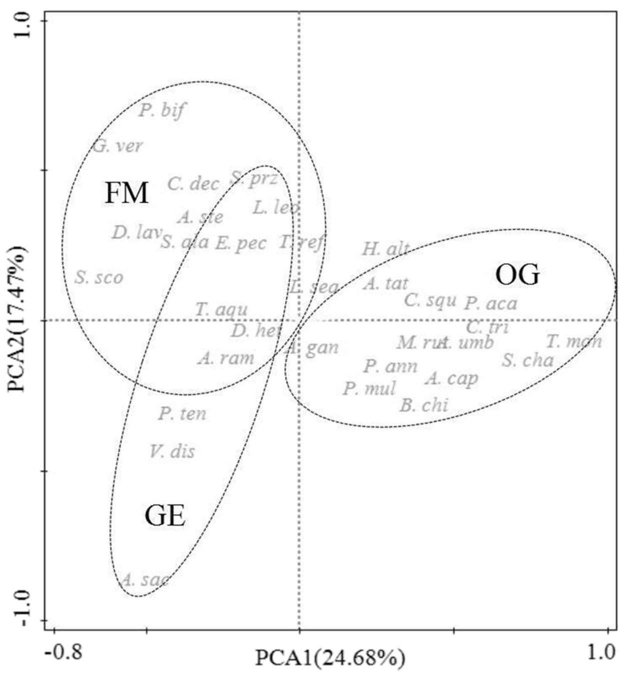

Fig. 1. Principal Components Analysis (PCA) ordinations of plant species dissimilarity based on species relative biomass. Grassland managements (OG: open grazing, GE: grazing exclusion, FM: fenced mowing) are drawn at the center. Abbreviated species names see Appendix A for the complete names.

compared to grazing exclusion. No significant differences in belowground biomass were observed among these managements. Species richness, Shannon's diversity and Pielou's evenness were lower in grazing exclusion (9.9 ± 0.9, 1.0 ± 0.2 and 0.4 ± 0.06, respectively) compared to open grazing (13.3 ± 0.8, 1.7 ± 0.1 and 0.7 ± 0.04, respectively) and fenced mowing (14.9 ± 0.9, 1.7 ± 0.1 and 0.7 ± 0.03, respectively) (Table 1). Grazing exclusion significantly reduced plant diversity, whereas fenced mowing increased it to reach levels similar to open grazing.

Plant community composition was significantly different among grassland managements (Fig. 1). The clear separation along the first axis between open grazed and fenced areas (including grazing exclusion and fenced mowing), corresponded to 26.48% of the total variation in species composition. Fenced areas were further separated along the second axis (17.47%) according to the presence or absence of fenced mowing. Most nongraminous forbs and semi-shrubs (*T. mongolicus*, *Carex tristachya* and *P. acaulis*) were associated with grazing area. *Stipa przewalskyi* and *A. sacrorum* were dominant or co-dominant species in the fenced area. Several perennial forbs and rare species (*Euphrasia pectinata*, *Corispermum declinatum*, *Adenophora stenanthina*, *Galium verum* and *Scutellaria scordifolia*) were strongly associated with mowing, while some forbs (in particular, *Viola dissecta* and *Polygala tenuifolia*) remained abundant only within grazing exclusion areas.

Long-term grazing exclusion significantly improved SOC concentration compared to open grazing ($F = 51.15$, $P < 0.001$) in the soil profiles (Fig. 2a). No significant changes in soil carbon concentration were found between grazing exclusion and mowing areas ($F = 0.81$, $P = 0.380$). Soil water content increased with grazing exclusion compared to open grazed areas ($F = 129.77$, $P < 0.001$) but then decreased with fenced mowing ($F = 90.06$, $P < 0.001$) (Fig. 2b). Specifically, soil water content in mowing area was higher than those in open

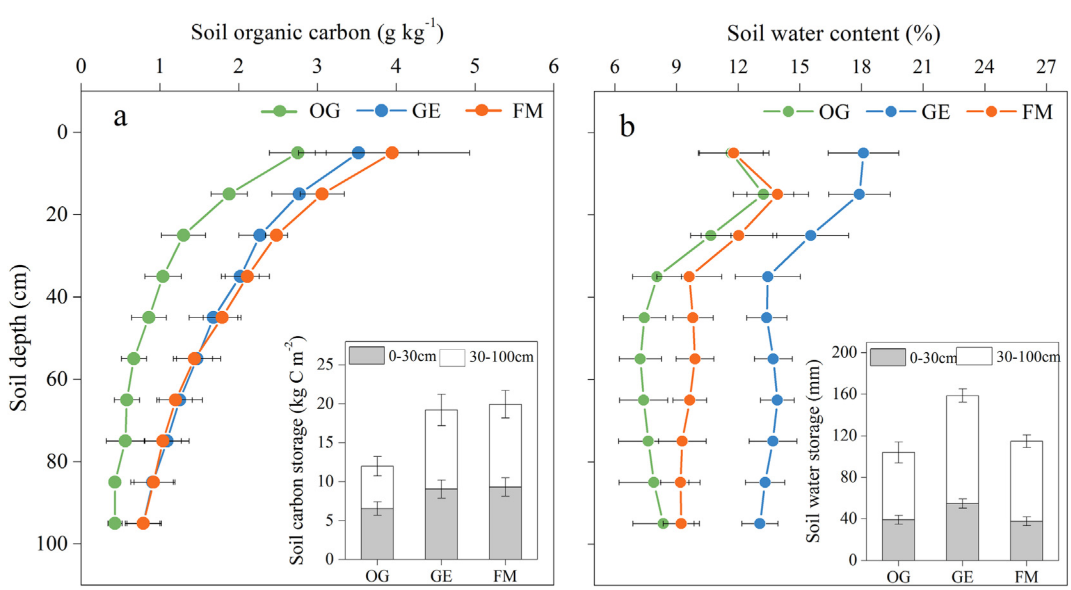

Fig. 2. Soil organic carbon and soil water content at the depth of 0–100 cm for the three grassland managements. Values are mean ± S. D. (OG: open grazing, GE: grazing exclusion, FM: fenced mowing).

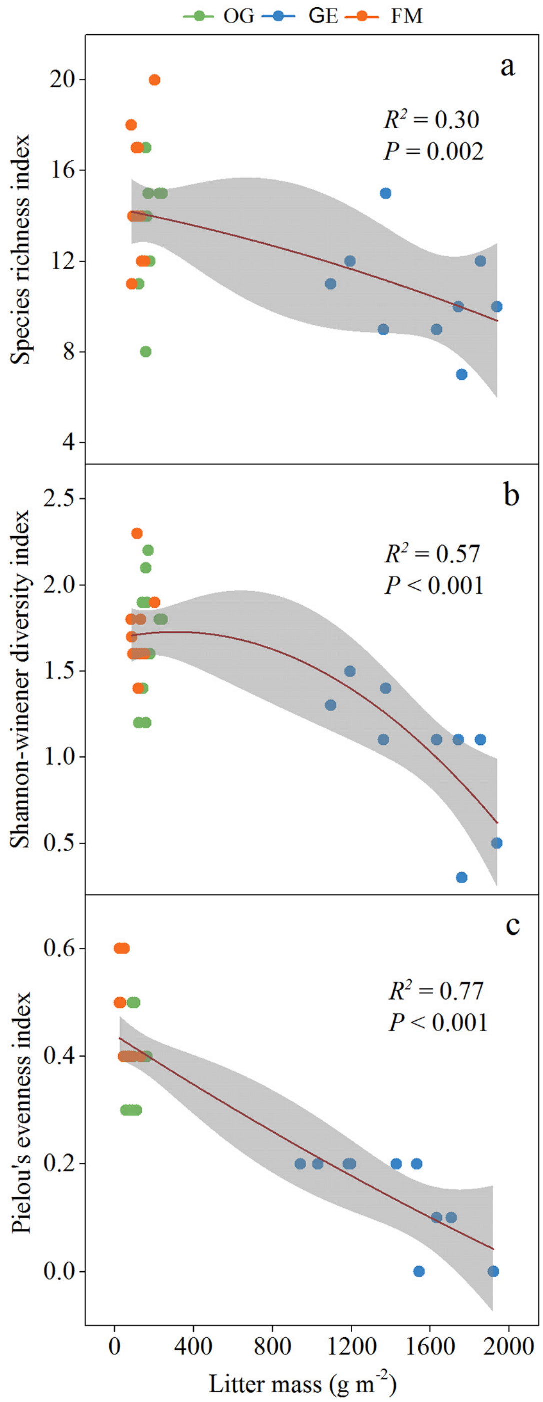

Fig. 3. Relationship between Species richness (*R*), Shannon–Wiener diversity index (*H*), Pielou's evenness index (*E*) and litter mass across the treatments. The shading indicates an approximate 95% confidence. (OG: open grazing, GE: grazing exclusion, FM: fenced mowing).

grazed area except for soil layers of the 0–30 cm. Similar shifts in soil carbon and water storage in response to grassland managements were observed in soil layers of 0–30 cm and 30–100 cm. Overall, cumulative SOC stocks (0–100 cm) under open gazing, grazing exclusion and mowing were: 12.0 ± 2.0, 19.2 ± 2.9 and 19.9 ± 2.4 kg C m^{-2}, respectively (Fig. 2a). The soil water storage in open grazing, grazing exclusion and mowing was estimated to be 104.1 ± 13.6, 158.8 ± 10.2 and 114.8 ± 9.3 mm, respectively (Fig. 2b).

4. Discussion

4.1. Long-term grazing exclusion replenishes SOC but decreases plant diversity

Grazing exclusion is a critical means for nature reserve management and ecological restoration (Cheng et al., 2016; Liu et al., 2017a). Short-term grazing exclusion can enhance biodiversity and ecosystem services (Xiong et al., 2016). However, our understanding of long-term responses of sustained exclusion is severely limited (Jing et al., 2014). As expected, 35 years of sustained grazing exclusion has led to increasing plant biomass and litter, soil carbon and soil water storage. These patterns are in line with results from similar studies executed across the Loess Plateau (Deng et al., 2014; Jing et al., 2014; Cheng et al., 2016) and other semi-arid areas (Wu et al., 2009). Grazing exclusion increased plant biomass, resulting litter deposition, consequently more carbon inputs to the soil. Additionally, thicker litter layer may eventually increase soil water storage by reducing soil water runoff and evaporation (Yan et al., 2014). We also found that the amount of below-ground biomass increased significantly at the surface soil, which can promote water penetrate to soil within grazing exclusion areas.

Grassland management shapes plant community structure (He et al., 2011; Yu et al., 2015). A growing body of studies has found diverse results of grazing exclusion on plant diversity in semi-arid grasslands (Zou et al., 2014; Cheng et al., 2016; Xiong et al., 2016). Our results provide further evidence that species diversity is lower in grazing exclusion than open grazed areas, in contrast to the diversity increases within grazing exclusion (Xiong et al., 2016). The different responses could be attributed to the exclusion duration, because positive effects of herbivore absence on plant diversity vanished or reversed over time in grasslands (Khishigbayar et al., 2015; Xiong et al., 2016; Liu et al., 2017b). Given that plant species diversity peaks at an intermediate disturbance level, the sustained long term grazing exclusion triggers diversity losses (Yuan et al., 2016). In addition, the significantly negative relationships between plant diversity and litter mass (Fig. 3) may suggest that litter accumulation within grazing exclusion may be a key driver for species loss. Litter can occupy potential microsites for seed germination and seedling establishment, and thus decrease species diversity in the long term (Ruprecht et al., 2010). This effect can be more accentuated in semi-arid grassland of open structure, where species usually adapt to excessive light and bare surfaces during the recruitment phase (Ruprecht et al., 2010).

In our study, smaller, ephemeral taxa would be out-competed by the dominant species, as biomass of involved species was negatively correlated (Fig. 4). Furthermore, our analysis also revealed that community composition changes depended on the responses of different plant functional groups to litter accumulation (Fig. 5), with negative effects for PF and PR, but positive effects for SS and indistinct effects for others. As a result, *A. sacrorum* increased and was upgraded to subdominant status, although the dominance of *S. przewalskyi* remained relatively stable in the community under exclosure (Fig. 6). The spread of *A. sacrorum* result in an impoverishment of the grassland quality for livestock farming owing to low foraging value (Cheng et al., 2014). If herbivore absence prolong, significant changes in community composition (such as species reordering and species turnover) are expected to have much great consequences for ecosystem structure and function (Yu et al., 2015).

4.2. Fenced mowing safeguards plant diversity but induces soil drying

Unexpectedly, mowing marginally promoted SOC compared to grazing exclusion. This result can be explained by suppressed soil respiration, because mowing can reduce soil labile carbon and affect microbial community structure (Shahzad et al., 2012; Ma et al., 2013). In an area adjacent to our experimental site, Wei et al. (2016) found that mowing significantly reduced soil respiration by 11.4–14.7%. Fu

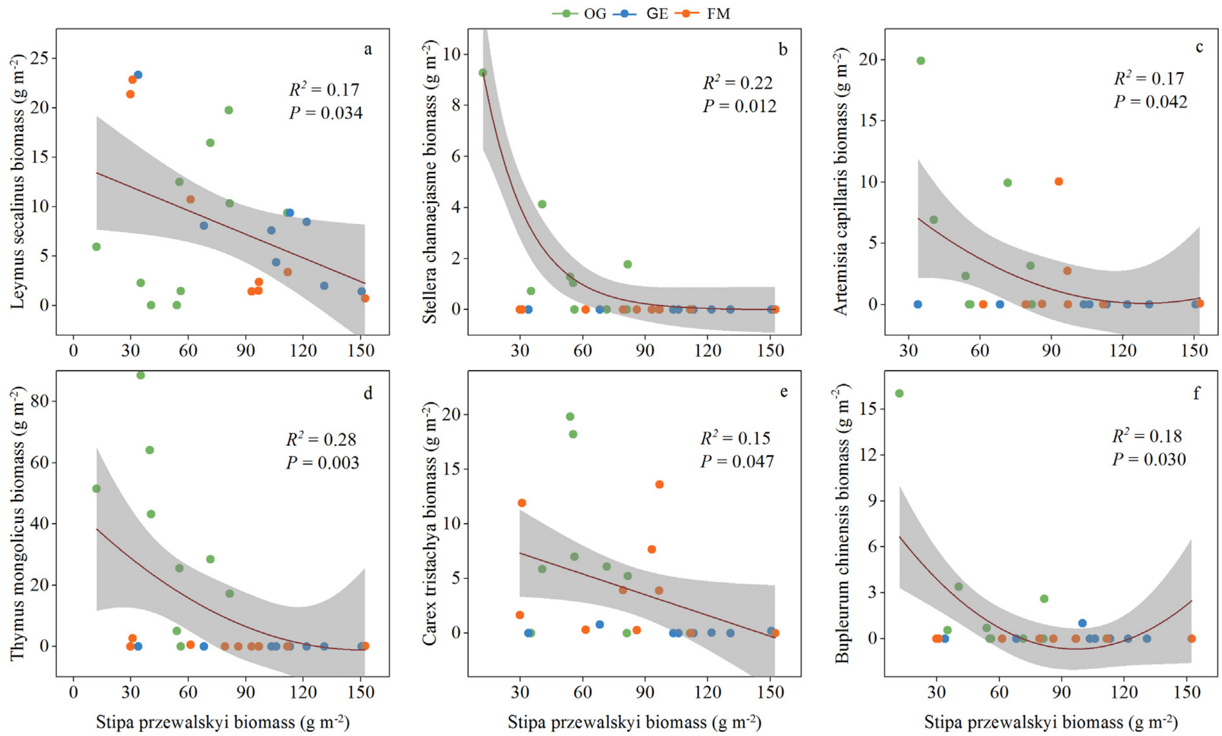

Fig. 4. Relationship between dominant species biomass and other species biomass across the treatments. The shading indicates an approximate 95% confidence. (OG: open grazing, GE: grazing exclusion, FM: fenced mowing).

et al. (2013) also proved that clipping activities could reduce respiration by 6.9%–36.9% because of reduced above-ground biomass. On the other hand, changed plant production may influence soil carbon storage, which is the primary driver of soil carbon input. In this study, above-ground biomass was 16.9% (i.e. 39.5 $g\,m^{-2}$, Table 1) lower in mowing than grazing exclusion. Therefore, we speculate that the weak effects of mowing on SOC may be caused by similar magnitude of carbon input and carbon losses.

As above-ground biomass was removed, mowing can cause a reduction in litter cover and an increase in bare ground, increasing water loss by runoff and soil evaporation (Shao et al., 2012). In line with the study from Alcántara et al. (2011), we found that mowing significantly reduced soil moisture. Additionally, above ground biomass and surface soil moisture (0–30 cm) were positively correlated in our study (Fig. 7), suggesting that soil drying under mowing would consequently feedback into plant production, since that water is important resource for plant growth in semi-arid grasslands.

Consistent with our hypothesis, mowing tended to increase community plant diversity in the present study. This is in agreement with the result by Lepš and Wan (2014), and they pointed out that mowing had positive effects on species diversity and led to spatially homogeneous plant composition in most cases via a 15-year field experiment. Increase in species diversity from mowing is attributed to alleviated interspecific competition and decreased litter accumulation, which increase ground-level light availability in a variety of grassland ecosystems (Shi et al., 2015). In our study, mowing significantly reduced litter accumulation by 95.9% (Table 1). The increase in diversity was caused primarily by a gain of native annual forbs (*E. pectinata* and *C. declinatum*), which germinate in early spring and are expected to be especially sensitive to light availability (Marone et al., 2000). Many empirical and theoretical studies have shown that increasing species diversity tends to enhance biomass temporal stability (Ma et al., 2017). Given that mowing increased species diversity, people might think that mowing promoted temporal stability of plant community biomass production. However, most of the gained species in response to mowing were rare species with lower height and canopy that accounted for only a small fraction of community biomass. Moreover, plant individuals were likely to allocate more biomass to belowground than aboveground (Table 1) for maximum resources use and optimal growth (Liu et al., 2014). Therefore, mowing simulated diversity in our study may contribute relatively little to community biomass stability. More importantly, mowing is just done based on the average canopy height, resulting in an increased synchronous response of species to environmental conditions, although these species have different morphological and physiological traits. This species synchronous response may reduce community biomass stability (Shi et al., 2015; Zhang et al., 2017), even though mowing increased species diversity.

4.3. Implications for sustainable grassland management

The impacts of alteration in management in this semi-arid grassland are profound, due to not only the impact on plant community structure, but also the impact on ecosystem functions. At first glance, the positive long-term impacts of the grazing exclusion on soil carbon content and plant production may be perceived as good news for managers. However, caution is recommended when considering the suppression of plant diversity, which could destabilize plant communities, potentially hindering the ability of grasslands to provide reliable ecosystem services for humanity. These negative outcomes are congruent with grassland conservation objectives. Moreover, simple exclosures does not result in a perpetual carbon sink (Smith, 2014). As generally reported in recent studies, both soil carbon content and vegetation biomass arrive at steady state after 15–20 years of grazing exclusion in temperate grasslands (Qiu et al., 2013; Hu et al., 2016; Deng et al., 2017). Together, there is an urgent need to introduce a judicious management for securing ecosystem function and services of the long-term protected grassland on the Loess Plateau. Mowing is one of the oldest and most widespread practices in grassland management because it produces hay, which can be stored and transported for on-farm and agricultural use (Zhang et al., 2017). In the present study, annual mowing increased plant diversity, and soil carbon was relatively stable across the short duration (i.e. 5 years). However, these patterns would

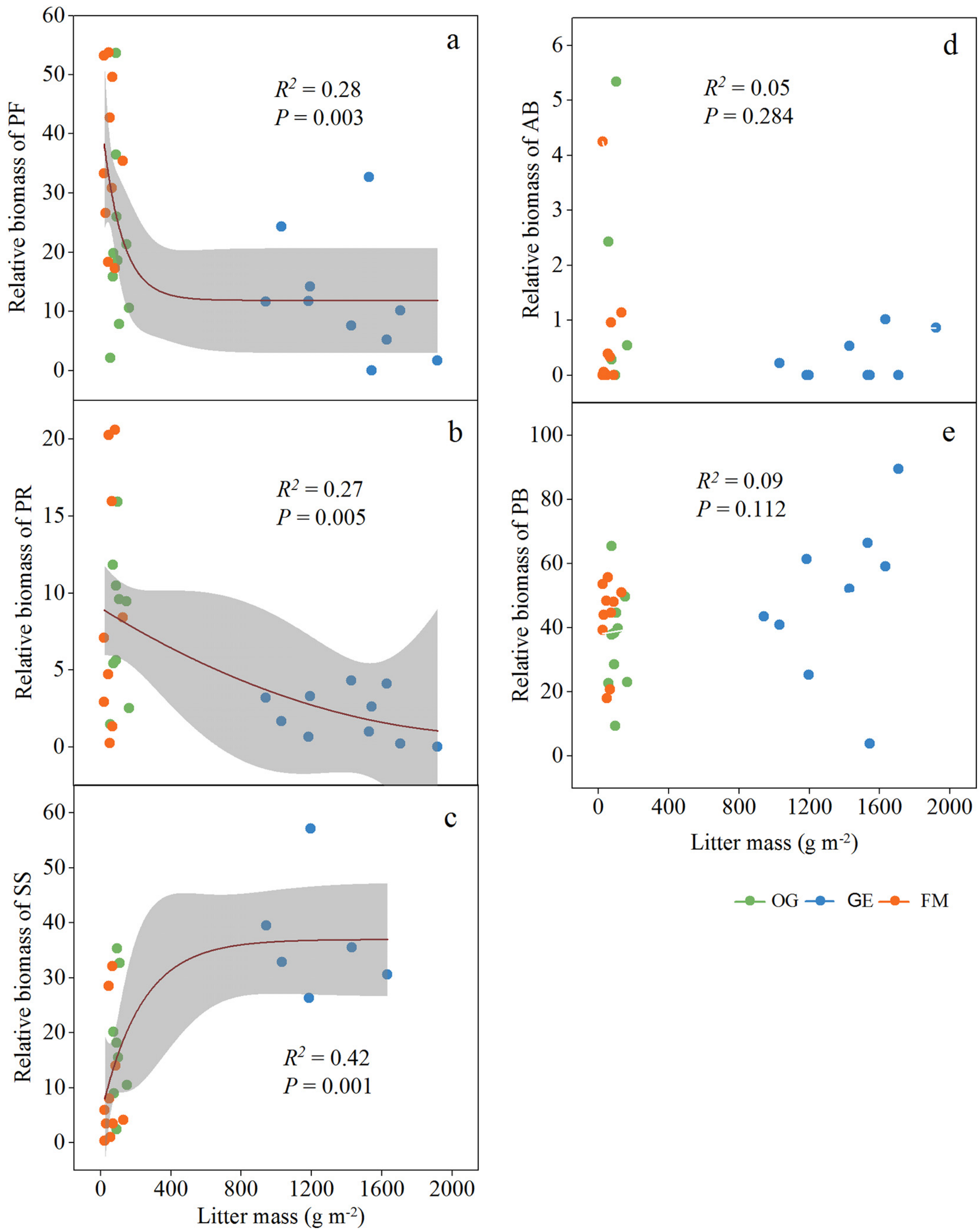

Fig. 5. Relationship between relative biomass of perennial forbs (PF), perennial rhizome grasses (PR), annuals and biennials (AB), shrubs and semi-shrubs (SS), perennial bunchgrasses (PB) and litter mass across the treatments. Only significant relationships ($P < 0.05$) are shown, and the shading indicates an approximate 95% confidence. (OG: open grazing, GE: grazing exclusion, FM: fenced mowing).

not necessarily been sustained as the time length of the experiment increases, because that the amount of surface litter and soil water content were significantly decreased under mowing. These underlying ecosystem processes would eventually reduce soil health (e.g. nutrient depletion and soil desiccation), which would thereby limit plant diversity and productivity (Kotas et al., 2017). Therefore, we suspect that 5 years or more of annual mowing may be over exploitation for this fenced semi-arid grassland. This continuous mowing may deplete residual biomass below the minimum required for adequate plant and soil protection. Several studies conducted in semi-arid grasslands showed that infrequent mowing enhanced nutrient cycling, and stimulated overcompensation of plant productivity, even though have less impact on soil moisture (Niu et al., 2010; Wei et al., 2016; Kotas et al., 2017; Zhang et al., 2017). Previous studies also demonstrated that infrequent mowing can be compatible with the maintenance of plant diversity and the soil carbon sequestration in grasslands (Niu et al., 2010; Kotas et al., 2017). These findings should be taken into account when deciding to include mowing as a grassland management strategy. However, the effects of mowing are likely to be vegetation community- and climatic condition-specific (Niu et al., 2013; Socher et al., 2013). Therefore, there is a basic need for research related to ecosystem function and mowing regime adapted to regional and local circumstances. Specific information on the minimum residual biomass or minimum recovery time after disturbance for protecting plant and soil is needed to set safe mowing intensity.

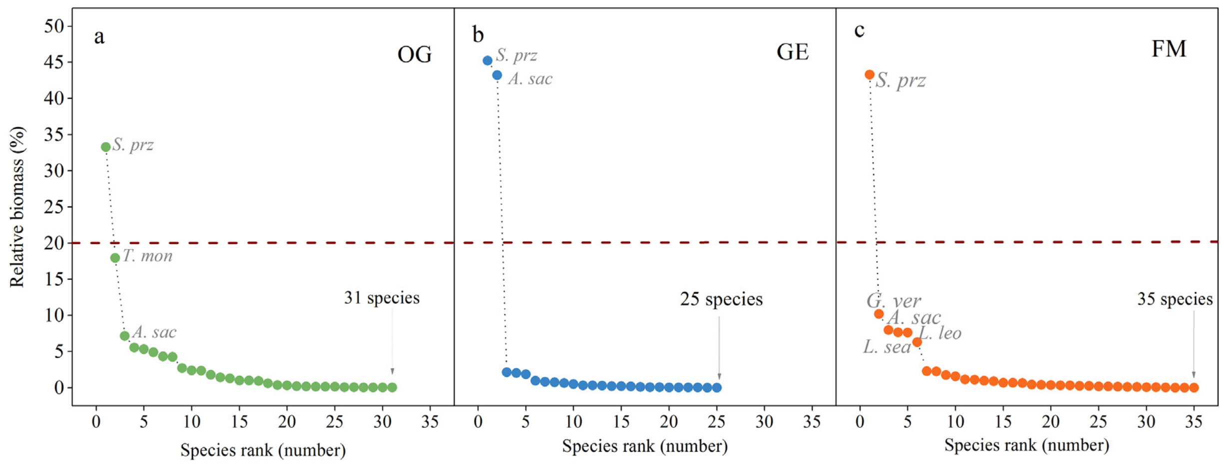

Fig. 6. Relative biomass of individual species for the three grassland managements. The species were ranked by relative contributions to the total biomass. Arrows represented the number of species occurring at least once in each treatment. The horizontal dotted lines indicate the species relative biomass of 20%.

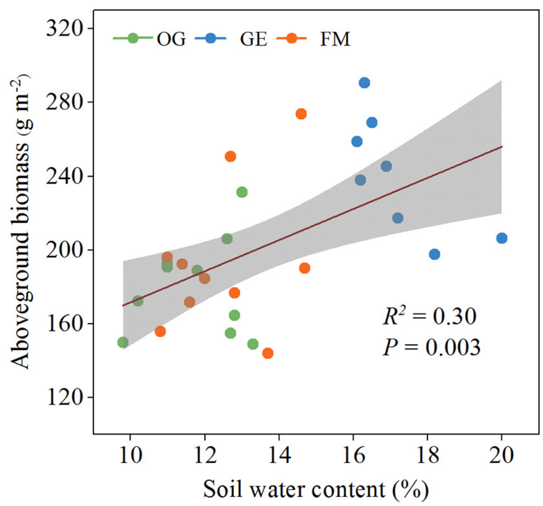

Fig. 7. Relationship between above-ground biomass and soil water content (0–30 cm) across the treatments. The shading indicates an approximate 95% confidence region. (OG: open grazing, GE: grazing exclusion, FM: fenced mowing).

4.4. Uncertainties and limitations

This study provides valuable estimates of different management-driven responses of plant diversity and SOC stocks in the semi-arid grassland, however, it remains some limitations. This field survey was conducted only once at a grassland reserve on August 2016, which did not consider the complexity of grassland responses to management. The management-dependent grassland responses were regulated by experiment duration, vegetation/climatic contexts (Klein et al., 2007; Fu et al., 2012, 2014, 2015). For example, Fu and Shen (2017) found that mowing significantly or marginally significantly influence plant biomass and production across three different growing seasons on the Northern Tibetan Plateau. Therefore, comprehensive designs incorporating these temporal and spatial variabilities are needed to derive smart managements to conserve grassland plant diversity and soil carbon stock. As the present study site is the largest remnant of typical steppe and longest reserve area on the Loess Plateau, our results provided useful information for evaluating the effects of managements on grassland conditions in this region.

5. Conclusions

Complementing previous studies indicating that grazing exclusion improved plant production and soil carbon stock, our results showed that plant diversity was significantly decreased after 35 years of grazing exclusion. We suggest that extending grazing exclusion on semi-arid grasslands should be approached with caution when restoration or maintenance of biodiversity is an aim. While 5 years annual mowing enhanced plant diversity and had little change in soil carbon, we found that surface litter and soil moisture were substantially decreased, suggesting major shifts in underlying ecosystem processes. These findings provide insights into the management of fenced grasslands when gearing towards safeguarding biodiversity and soil carbon sequestration.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.catena.2018.09.034.

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