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Overgrazing depresses soil carbon stock through changing plant diversity in temperate grassland of the Loess Plateau

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ABSTRACT

Zhu G.Y., Tang Z.S., Chen L., Shangguan Z.P., Deng L. (2017): Overgrazing depresses soil carbon stock through changing plant diversity in temperate grassland of the Loess Plateau. Plant Soil Environ., 64.

This study mainly estimates the effect of grazing on plant diversity and soil storages on the northern Loess Plateau of China. Four grazing intensities of ungrazed (UG), light (LG), moderate (MG), and heavy (HG) grassland were selected according to the vegetation utilization across the study area, in which plant diversity, heights, above- and belowground biomass, and soil carbon (C) stock were investigated. The results showed that overgrazing negatively affected plant growth and soil C stock. Plant cover, height, litter, above- and belowground productivity, as well as soil C stock significantly decreased with the increasing grazing intensity. Meanwhile, the UG and LG had higher grasses biomass together with lower forbs ($P < 0.01$) compared with MG and HG. The abundance of dominating grasses species, such as *Stipa bungeana* and *S. grandis* were decreased through long-term grazing as grasses species are palatable for herbivores, and the dominating forbs species, such as *Artemisia capillaries* and *Thymus mongolicus* were significantly increased with increasing grazing intensities. The results indicated that grazing exclusion or light grazing had positive effects on the sustainable development of grassland ecosystems. Therefore, a balanced use and a long-term efficient management of grasslands were better measures to counteract their local degradations.

Keywords: pasturing; plant productivity; soil carbon storage; vegetation features

Grasslands can provide clean air and water, produce forage for livestock, conserve carbon (C), and support a wide diversity of plant and animal communities (UNCCD 2004). Livestock grazing is widely recognized as a primary ecosystem driver in grassland and represents an important land use of grasslands (Zhu et al. 2016). However, in arid and semi-arid regions of the world, overgrazing has been one of the most important causes of consistent degradation (Schönbach et al. 2011, Deng et al. 2014a, 2017).

Overgrazing can lead to many negative impacts, including decline in vegetation cover, biomass, species diversity and increase in undesirable vegetation. For example, grazing can destroy the structure and composition of the plant communities due to plant consumption and trampling caused by livestock (Kraaij and Milton 2006). Meanwhile, grazing decreased soil organic matter inputs, which can negatively influence soil nutrients (Deng et al. 2017). However, grazing may actually increase plant

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production due to high re-growth potentials in perennial grasslands (Loeser et al. 2004). Therefore, grazing effects on vegetation dynamics in grassland communities need to be further studied.

Soil organic carbon (OC) is roughly twice that of atmospheric CO_2, and it is also a key element in the process of trapping atmospheric CO_2 through primary production (Post and Kwon 2000). Nearly 40% of the earth's land surface are grazed by large mammals, and thus, grazing may be a key factor controlling the storage of soil carbon (McSherry and Ritchie 2013). The effects of livestock grazing on soil C stock were reported in many grassland ecosystems, but some of the results of the studies were exactly the opposite (Deng et al. 2017). Two influencing mechanisms could explain the effect of grazing effect on soil C stock changes. Grazing can directly influence soil C stock dynamics by removing plant biomass and returning C through dung and urine input (Deng et al. 2014a). Additionally, grazing can indirectly influence soil C stock from two aspects (Semmartin et al. 2010). Firstly, livestock changes plant biomass allocation patterns and thus regulate much resources that are returned to the soil (De Deyn et al. 2008); secondly, livestock changes plant species composition and thus alters soil C stock (Semmartin et al. 2010), which demonstrated to impact on litter quality and decomposability (Bardgett and Wardle 2003). Although mechanisms of the grazing effect on soil C stock were extensively studied in a wide range of ecosystems worldwide, little studies had examined the linkage between soil C stock and grazing-induced vegetation changes on the Loess Plateau.

The Loess Plateau of China is widely known for its complex terrain, drought conditions and severe soil erosion (Liu et al. 2007) mainly due to overgrazing, intensification of cultivation and other unreasonable land use (Zhou et al. 2006). Restoration of the degraded grassland, such as grazing exclusion, is regarded as the most effective measure for improving the ecological environment of the Loess Plateau (Deng et al. 2014a). However, less information is available on effects of grazing on plant diversity and productivity, as well as soil C stock in a grassland ecosystem, especially in temperate grassland of the Loess Plateau. Therefore, the objective of the study was to explore: (1) the effect of grazing on plant diversity (biomass and species composition); (2) the effects of grazing intensity on soil C; (3) the relationship between soil C and plant diversity under the grazing conditions.

MATERIAL AND METHODS

The study area located in the Dingbian county, Shaanxi, China, on the Loess Plateau, which has a latitude of 36°49'–37°53'N and a longitude of 107°15'–108°22'E, and with the altitude of 1500–1650 m a.s.l. In the area, the mean annual temperature was 8.4°C (1960–2010), and the mean annual rainfall was 352 mm (1960–2010), which was mainly distributed in July, August and September. The natural grasslands of the study area suffered from various degrees of damages because of natural factors and human activities. Based on the dominant species, the vegetation communities of the study area were mainly *Stipa bungeana*, *S. grandis*, *Thymus mongolicus*, *Artemisia capillaries*, *Agropyron cristatum*, etc. The soil type of the study area was loessial soil.

In this study, ten 1 × 1 m quadrats were chosen at every ten meters in each grassland and sampling was done at the central parts of the grassland in August 2011. Each grassland had an area of one ha at least. Soil samples were only collected in the even-coded quadrats with three repeats in each quadrat, and then the same soil layers were mixed together to make one sample. Before soil sampling, the ground litter on the surface was removed.

In addition, soil organic carbon content was assayed by dichromate oxidation (Nelson and Sommers 1982). Plant species identification, functional group, species diversity index and calculation of soil C stocks were determined according to Deng et al. (2014a).

Statistical analysis. One-way ANOVA was carried out to test for differences of biomass, plant diversity, functional group, soil C stock among the grazing intensities. When significance was observed at the $P < 0.05$ level, least significant difference (*LSD*) test was used to carry out the multiple comparisons. Pearson's correlation analysis was used to study the correlations among plant diversity and soil C stocks. All statistical analyses were performed using the software program SPSS, ver. 17.0 (SPSS Inc., Chicago, USA).

RESULTS AND DISCUSSIONS

Effect of grazing on plant diversity. Continuous grazing in degraded arid grassland had a negative effect on plant diversity and biomass production,

Table 1. Canopy cover, height Richness index, Shannon-Wiener diversity index and Evenness index of grassland communities in the four grazing intensities

	Cover (%)	Height (m)	Richness index	Shannon-Wiener diversity index	Evenness index
Ungrazed	24.24 ± 8.67^{a}	0.52 ± 0.09^{a}	9.78 ± 0.59^{b}	1.95 ± 0.04^{a}	0.86 ± 0.01^{ab}
Light grazing	31.29 ± 1.43^{a}	0.99 ± 0.41^{a}	10.78 ± 1.56^{a}	1.93 ± 0.19^{a}	0.82 ± 0.03^{b}
Moderate grazing	19.19 ± 4.51^{b}	0.18 ± 0.04^{b}	11.78 ± 0.87^{a}	2.18 ± 0.05^{a}	0.89 ± 0.01^{a}
Heavy grazing	17.1 ± 0.99^{b}	0.25 ± 0.04^{b}	9.55 ± 1.18^{b}	1.85 ± 0.08^{b}	0.84 ± 0.01^{ab}

Different lower-case letters varied significantly at 0.05 level ($P < 0.05$). Values are in the form of the mean ± standard error, sample size $n = 3$

thus potentially limiting the resilience of the grassland response to interference and environmental stress (Simons and Allsopp 2007). In our study, plant covers and heights significantly decreased with the increasing grazing intensities ($P < 0.05$, Table 1); probably due to the grazing livestock's biting effect (Medina-Roldán et al. 2012).

In addition, a significant unimodal relation was observed between the grazing intensities and the plant diversity and with the richness and height being the highest in the LG and MG (Table 1). However, Yang et al. (2016) reported no significant relationship between the richness and grazing intensity in the Tibetan Plateau. The results indicated that the magnitude of the grazing intensity may not be a key factor influencing richness (Deng et al. 2014b). Since the community was dominated by some species with strong colonization abilities (Jing et al. 2013), they caused the peaking evenness in MG.

Plant biomass was strongly affected by grazing intensity; it significantly decreased along with the increased grazing intensity (Table 2), except that the aboveground biomass had a non-significant difference with LG and MG ($P < 0.05$), but a significant difference with HG (Table 2). The potential reason was that the continuous removal of standing biomass by livestock and the corresponding decrease in above- and belowground biomass (Schönbach et al. 2011). Meanwhile, the UG and LG had more grasses and less forbs ($P < 0.01$) compared to MG and HG (Table 2), maybe the reason of the dominated species (grasses species of *Stipa bungeana* and *S. grandis*, etc.) are palatable for herbivores (Jing et al. 2013, Deng et al. 2014a) and decreased through long-term grazing (Figure 1). In addition, the dominant species of forbs, such as *Artemisia capillaries* and *Thymus mongolicus* that reproduce and spread mainly by sexual and asexual reproduction were significantly increased along with increased grazing intensities. Sexual reproduction is responsible for invasion and establishment, and asexual reproduction allows the population to spread, usually in the form of small-scale patches (Jing et al. 2013).

Effect of grazing on soil C stocks. Grazing is an important factor changing soil C input and as-

Table 2. Aboveground biomass, belowground biomass, litter, total biomass and the ratios of the aboveground biomass of two functional groups (grasses and forbs) in the four grasslands of different grazing intensities

	Ungrazed	Light grazing	Moderate grazing	Heavy grazing
Aboveground biomass (t/ha)	1.4 ± 0.22^{ab}	1.4 ± 0.09^{a}	1.2 ± 0.08^{ab}	1.0 ± 0.05^{b}
Litter biomass (t/ha)	1.9 ± 0.29^{a}	0.7 ± 0.15^{b}	0.3 ± 0.07^{c}	0.1 ± 0.02^{d}
Belowground biomass (t/ha)	11.4 ± 4.4^{a}	4.5 ± 0.8^{b}	4.0 ± 0.9^{b}	2.7 ± 0.3^{b}
Total biomass (t/ha)	12.8 ± 4.6^{a}	5.8 ± 0.9^{b}	5.2 ± 0.9^{b}	3.7 ± 0.3^{b}
Forbs (%)	57.37 ± 4.7^{b}	56.69 ± 12.74^{b}	79.79 ± 3.89^{a}	72.92 ± 3.17^{a}
Grasses (%)	42.63 ± 4.70^{a}	43.31 ± 12.74^{a}	20.21 ± 3.89^{b}	27.08 ± 3.17^{b}

Different lower-case letters varied significantly at 0.05 level ($P < 0.05$). Values are in the form of the mean ± standard error, sample size $n = 3$

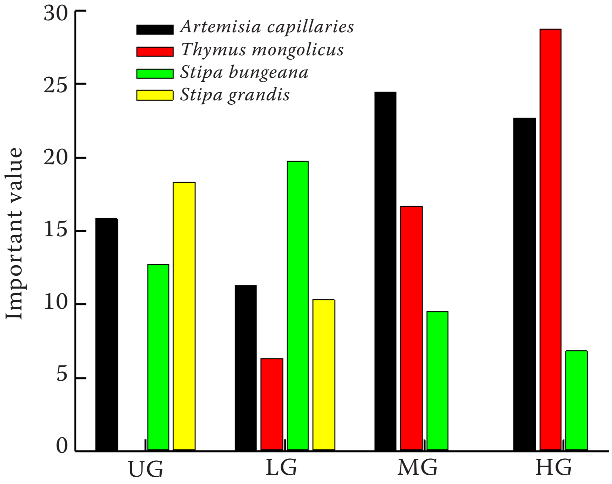

Figure 1. Dominant plant species change with grazing intensities. HG – heavy grazing; MG – moderate grazing; LG – light grazing; UG – ungrazed

sociated soil properties (Deng et al. 2017). Steffens et al. (2008) and Wiesmeier et al. (2011) indicated that soil organic C contents and stocks decreased with increasing grazing intensities. Also, in our study, it was found that soil C stock in different soil layers and soil depths both decreased along with the grazing intensities increased ($P < 0.05$, Figure 2a,b). Wu et al. (2012a) showed that MG and HG increased CO_2 emission, microbial biomass, and dissolved organic C significantly in the soil, indicating overgrazing increased soil labile organic C in the Inner Mongolia grassland, and thus increased C loss and decreased C stock (He et al. 2011). In contrast, Wu et al. (2012b) reported that long-term grazing exclusion could improve soil C stock of 0–30 cm soil depths in an alpine swamp meadow. Deng et al. (2014a) also found 0–100 cm soil C stocks increased significantly under grazing exclusion on the Loess Plateau. However, in this study it was found that in the 0–10 cm soils, LG increased soil C stock slightly compared to UG (Figure 2a). Animal manure inputting and trampling led to higher soil BD, thus causing soil C stocks increased in surface soil (Deng et al. 2014a).

Relationship between plant diversity and soil C stock. Plant community has an impact on soil processes, and soil processes are closely related to plant dynamics (Li et al. 2009). Bach et al. (2012) reported that plants affected soil quality mainly through the inputs of organic matter. In this study it was found that soil C stocks and plant cover, height, biomass and ratios of aboveground biomass of grasses showed the same trends along with the grazing intensity. Thus, soil C stocks (0–30 cm) had significantly positive correlations with height, the ratios of aboveground biomass of grasses, and negatively correlated with the ratios of aboveground biomass of forbs ($P < 0.05$, Figure 3); soil C stocks in 0–100 cm depths were significantly correlated with cover, above- and belowground biomasses, and plant diversity (R, H, E) (Figure 3). Moreover, the top soil C stocks mainly correlated with functional groups (grasses and forbs), and the subsoil C stocks

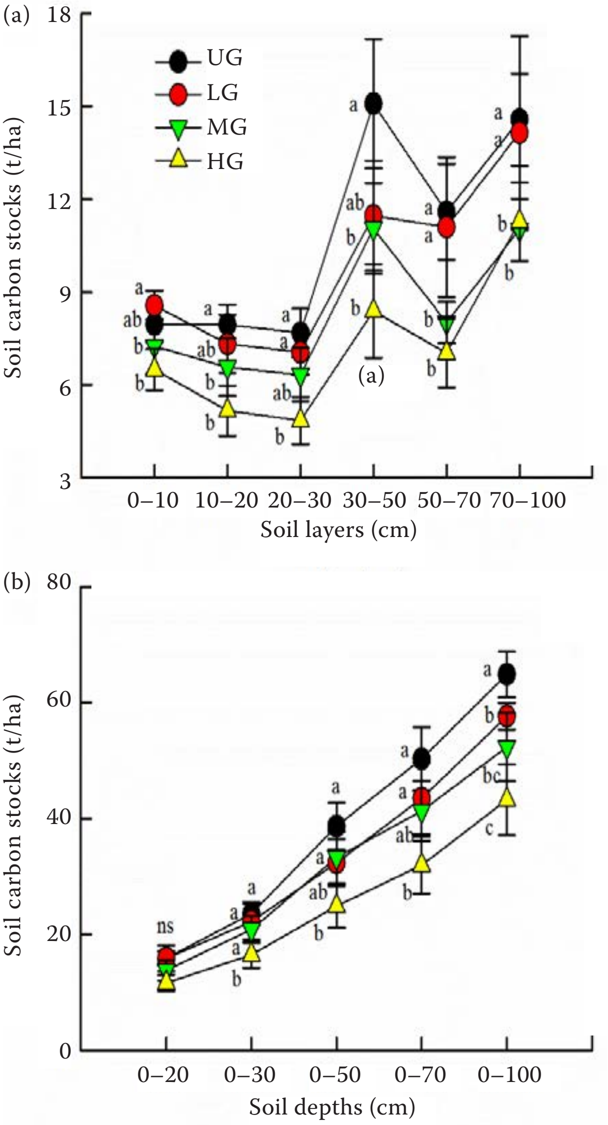

Figure 2. Soil carbon stocks in different (a) soil layers and (b) soil depths change with grazing intensities. HG – heavy grazing; MG – moderate grazing; LG – light grazing; UG – ungrazed. Different lower-case letters varied significantly at 0.05 level ($P < 0.05$) among the four grazing intensities. Error bar indicates the standard error. $n = 3$

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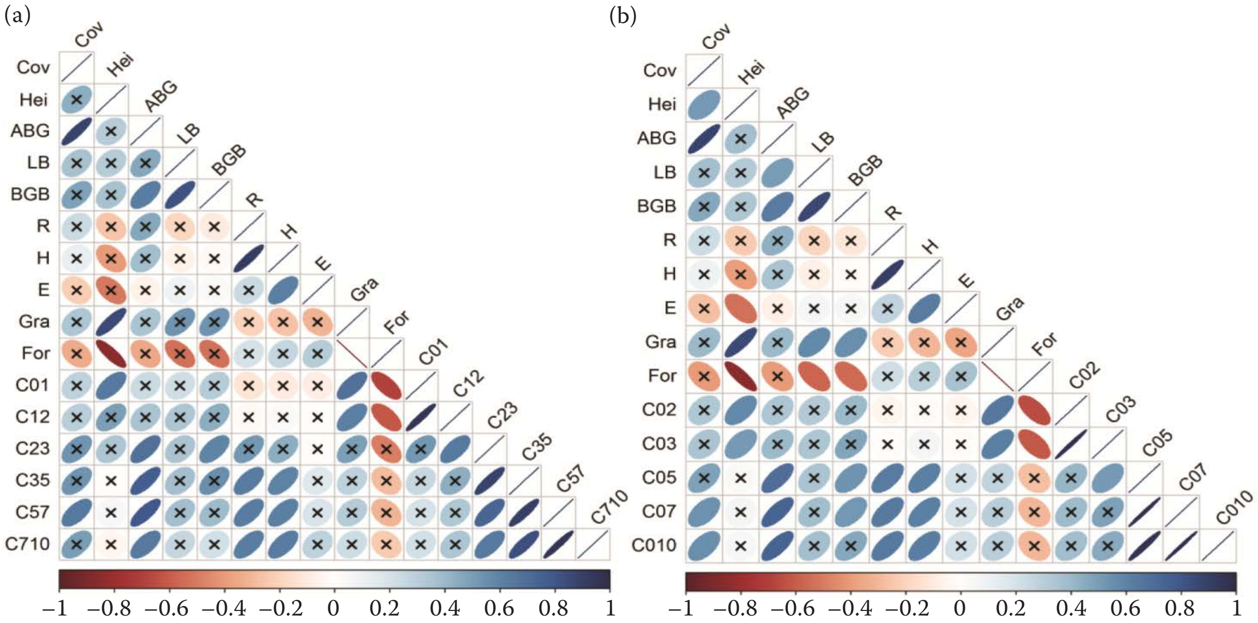

Figure 3. Correlation matrix between soil properties in different soil layers (a), soil properties in different soil depths (b) and plant properties. $N = 9$. × – correlation is non-significant ($P > 0.05$); blue indicates positive correlations and red indicates negative. Cov – cover; Hei – height; ABG – aboveground biomass; LB – litter biomass; BGB – belowground biomass; R – Richness index; H – Shannon-Wiener diversity index; E – Evenness index; Gra – grass; For – forb; C01 – 0–10 cm soil carbon stock; C12 – 10–20 cm soil carbon stock; C23 – 20–30 cm soil carbon stock; C35 – 30–50 cm soil carbon stock; C57 – 50–70 cm soil carbon stock; C710 – 70–100 cm soil carbon stock; C02 – 0–20 cm soil carbon stock; C03 – 0–30 cm soil carbon stock; C05 – 0–50 cm soil carbon stock; C07 – 0–70 cm soil carbon stock; C010 – 0–100 cm soil carbon stock

mainly correlated with the aboveground biomass (Figure 3). This indicated that soil C stocks in the top soils were driven by plant composition, and deep soil C stocks were driven by plant productivity. Zhou et al. (2010) reported that different plant species can influence soil microbial processes such as mineralization due to exhibited varied growth rates and root functioning. Liu et al. (2011) found that lower aboveground biomass of the dominant species was found under the HG than at lighter grazing intensities. The reason is that there was not a higher plant uptake in the HG plots leading to higher level of soil C mineralization (Iyyemperumal et al. 2007). Grazing increased labile C availability by promoting rhizosphere microbial metabolism and resulted in an enhanced soil C mineralization (Hamilton and Frank 2001).

In conclusion, overgrazing negatively affected plant growth and soil C stock. Plant cover, height, litter, above- and belowground productivity, and soil C stock significantly decreased with the increasing grazing intensity. Meanwhile, the UG and LG had higher grasses biomass together with lower forbs ($P < 0.01$) compared with MG and HG. The abundance of dominating grasses species, such as *Stipa bungeana* and *S. grandis* were decreased through long-term grazing as grasses species are palatable for herbivores, and the dominating forbs species, such as *Artemisia capillaries* and *Thymus mongolicus* were significantly increased with increasing grazing intensities. In general, grazing exclusion or light grazing had positive effects on the sustainable development of grassland ecosystems.

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