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Leguminous species sequester more carbon than gramineous species in cultivated grasslands of a semi-arid area

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Abstract. The establishment of grasslands on abandoned cropland has been proposed as an effective method to mitigate climate change. In this study, five cultivated grasslands (three leguminous species and two gramineous species), one abandoned cropland, and one natural grassland were studied to examine how soil organic carbon (SOC) sequestration rate and sequestration efficiency change in a semi-arid area in China. Our results showed that leguminous grasslands had greater total biomass (above- and belowground biomass), SOC storage, SOC sequestration rate, and efficiency than gramineous grasslands, abandoned cropland, and natural grassland during the experimental period. The largest soil carbon (C) accumulation in leguminous grassland was mainly attributed to the capacity to incorporate C and the higher biomass production. Leguminous grasslands accumulated more SOC than gramineous grasslands by 0.64 Mg C ha^{-1} yr^{-1}. The average SOC sequestration efficiency in leguminous grassland (1.00) was about 2 times greater than gramineous grassland (0.34). The results indicate that cultivated leguminous grassland sequestered more SOC with higher SOC sequestration efficiency than cultivated gramineous grassland in arid and semi-arid areas. Our results provide a reference for ecological management in arid and semi-arid areas.

1 Introduction

Soil is a key component of the Earth system and contributes to services, goods, and resources to humankind (Brevik et al., 2015). Soil stores more carbon (C) than the atmosphere and vegetation (Köchy et al., 2015a; Keesstra et al., 2016). Soil organic carbon (SOC) is a key component of the global C cycle, and its potential to sink from atmosphere carbon dioxide (CO_2) has been widely discussed in the scientific literature throughout the world (Guo and Gifford, 2002; Lal, 2004; De Deyn et al., 2008; Deng et al., 2014a; Parras-Alcántara et al., 2015). In terrestrial ecosystems, SOC pool dynamics can be affected by many factors, such as climate change (Lal, 2004; Field et al., 2007), management practices (Luo et al., 2010; Ono et al., 2015), land use, etc. (Post and Kwon, 2000; Don et al., 2011; Deng et al., 2014b; Muñoz-Rojas et al., 2015).

SOC plays a critical role in controlling soil fertility and cropping system productivity and sustainability (Hurisso et al., 2013; De Moraes Sá et al., 2015), particularly in low-productivity arid and semiarid agro-ecosystems (Behera and Shukla, 2015; Willaarts et al., 2016). To develop farming methods that conserve SOC is therefore of a great importance (Lal, 2004) in this area. Cultivated grasslands have many more advantages than natural grassland regeneration, such as accelerating vegetation restoration and improving grassland productivity. Establishing artificial grassland is therefore an

effective method to restore vegetation and improve soil fertility by accumulation of SOC (Fu et al., 2010; Wu et al., 2010; Li et al., 2014). Vegetation degradation and exponential population growth have caused massive amounts of soil and water to be lost. The Chinese government has implemented the most ambitious ecological program titled "Grain-for-Green" Project (converting degraded, marginal land, and cropland into grassland, shrubland, and forest), with the objective of transforming the low-yield slope cropland into grassland, reducing soil erosion, maintaining land productivity, and improving environmental quality (Fu, 1989; Liu et al., 2008). The large scale of the project can enhance C sequestration capacity in China, especially in arid and semi-arid areas (Chang et al., 2011; Song et al., 2014).

Many prior studies about SOC have paid much attention to converting farmland to grassland, shrubland, or forest (Fu et al., 2010; Deng et al., 2014a). However, less attention has been devoted to the SOC among different species of grasslands. In this study, we focused on ascertaining the influence of leguminous and gramineous grasslands on SOC sequestration capacity and efficiency. Many studies have demonstrated that there is a significant and positive relationship on SOC and nitrogen (Deng et al., 2013; Zhu et al., 2014). Therefore, we hypothesize that leguminous grassland has higher SOC sequestration capacity than gramineous grassland. More specifically, our objectives are (i) to analyze the differences of storage efficiency under different grasslands and (ii) to determine which type of cultivated grassland might better improve SOC storage in arid and semi-arid areas.

2 Material and methods

2.1 Experimental site and design

The study was conducted at the Lanzhou Scientific Observation And Experiment Field Station of the Ministry of Agriculture for Ecological System in the Loess Plateau Area (103°44.342′ E, 36°02.196′ N; 1635 m a.s.l.) in Lanzhou, Gansu Province, China (Fig. 1). The site is located the temperate continental climate zone. Data from the National Meteorological Information Center of China showed that the mean annual temperature is 9.3 °C. Mean annual precipitation is 324.5 mm, of which approximately 80 % falls during the growing season (from May to September). The topography of study area is typical of the Loess Plateau and comprises plains, ridges and mounds, etc. Soil parent material is Quaternary eolian loess and the main soil type is sierozem, which is a calcareous soil and characteristic of the Chinese loess region (Li et al., 2010). Sierozem is the soil developed in the dry climate and desert steppe in warm temperate zone, which has low humus content and weak leaching (National Soil Census Office, 1998). There is a patch or pseudohyphae calcium carbonate deposition and strong lime reaction within the full sierozem profile (Shi et al., 2013).

The experimental site was originally under sorghum (*Sorghum bicolor* L.) continuously from 1970 to 2005, and it was abandoned from 2005 to 2007 (grazing exclusion). In 2007, five cultivated grasslands, one uncultivated grassland (abandoned cropland, Un-G), and one natural grassland (Na-G) were established in the study site. Five main forage grasses, widely grown across semi-arid areas, were selected to establish the five types of cultivated grassland, namely three leguminous species (*Coronilla varia* L., L-CV; *Onobrychis viciifolia* Scop, L-OV; *Medicago sativa* L., L-MS) and two gramineous species (*Poa pratensis* L., G-PA; *Agropyron cristatum* L. Gaertn., G-AC). Seeding rates in different grasslands are shown in Table 1. The different seeding rates were selected based on the germination percentage and to guarantee the equal plant density in each type of grassland. These rates were determined based on local farmland crop density reference values. We designed the experiment to be a randomized plot design. Three experimental plots (10 m × 20 m) were established randomly within each of the grassland areas. The forage grasses were planted in early April of 2007, and all plots were weeded manually and watered three times (April, June, October) annually from 2008 to 2012 to preserve the monocultures. The plots were not fertilized during cultivation. All the plots were harvested once a year in October.

2.2 Aboveground plant and belowground biomass sampling

Ten quadrats (1 m × 1 m) were randomly set up in each plot in late August every year (2008–2012). Aboveground biomass was measured by harvesting the upper plant parts (clipping their stems at the soil surface) from each quadrat. At each quadrat, all green aboveground plant parts and litter were collected with the labeled envelops. Then samples were dried at 105 °C until their mass was constant, and then their mass was weighed and recorded.

Belowground biomasses and soil samples were taken in the four corners and the center of each quadrat where the aboveground biomass sampling point was located (Fig. 1). Belowground biomass was collected using a soil drilling sampler with 9 cm inner diameter at 0–100 cm soil layer (separated into increments every 10 cm). Roots in the soil samples were obtained by a 2 mm sieve. Then the remaining roots in the soil samples were isolated by shallow trays, allowing the flowing water from the trays to pass through a 0.5 mm mesh sieve. All the roots samples were oven-dried at 65 °C until their mass was constant, and then they were weighed.

2.3 Soil sampling and determination

To collect the soil samples at each quadrat, the same layer samples as those collected for belowground biomass (every 10 cm) were mixed together to form a composite sample. The samples were passed through a 2 mm sieve to remove the

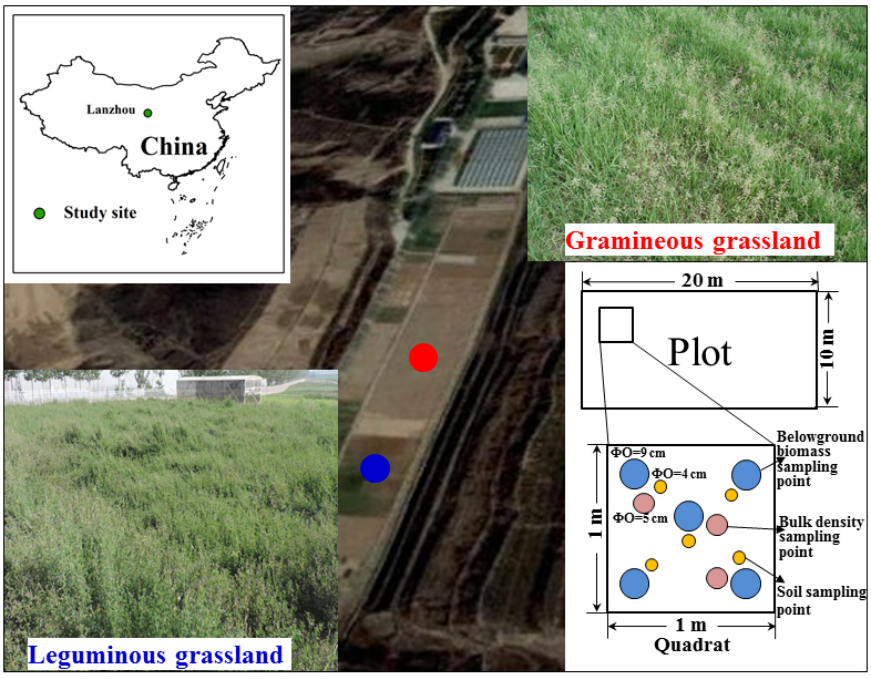

Figure 1. The studied site localization and schematic figure of the sampling strategies.

Table 1. Description of studied grassland types.

Grassland types	Species	Seeding rates ($kg\,ha^{-1}$)
Leguminous grassland	*Coronilla varia* L.	7.5
	Onobrychis viciifolia Scop.	30
	Medicago sativa L.	12
Gramineous grassland	*Poa pratensis* L.	7.5
	Agropyron cristatum (L.) Gaertn.	15
Uncultivated grassland	Abandoned cropland. Natural successional species were present, e.g., *Chenopodium album* L., *Agropyron cristatum* L.	
Natural grassland	A local native grassland community. Dominant species were *Stipa breviflora* Griseb., *Stipa aliena* Keng, *Artemisia capillaris* Thunb., *Artemisia annua* L.	

roots and other debris. A 5 cm diameter and 5 cm high stainless steel cutting ring ($100\,cm^3$) was used to measure soil bulk density (BD) at adjacent points to the soil sampling. Soil bulk density was measured at the depth of 0–100 cm (10 cm a layer and then averaged). The dry mass was measured after oven-drying at 105 °C. SOC content was measured using the method of the vitriol acid-potassium dichromate oxidation (Walkley and Black, 1934). For each sample, analyses were replicated three times.

2.4 Relative calculation

BD was calculated based on the oven-dried weight of the composite soil samples (Deng et al., 2013).

SOC stock for each soil layer was calculated using the equation as follows (Deng et al., 2013):

$$C_s = \mathrm{BD} \times \mathrm{SOC} \times \frac{D}{10}, \quad (1)$$

where C_s is the SOC stock ($Mg\,ha^{-1}$); BD is the soil bulk density ($g\,cm^{-3}$); SOC is the soil organic carbon content ($g\,kg^{-1}$); and D is the thickness of the sampled soil layer (cm).

SOC sequestration rate (SSR, $Mg\,ha^{-1}\,yr^{-1}$) was calculated as follows (Hua et al., 2014):

$$\mathrm{SSR} = \frac{C_t - C_0}{t}, \quad (2)$$

Table 2. The p values of homogeneity of variances by the Levene test and normality by the Shapiro–Wilk test in soil organic carbon content (SOC), soil C storage, and soil bulk density (BD).

	Levene test			Shapiro–Wilk test		
Grassland types	BD	SOC	SOC storage	BD	SOC	SOC storage
L-MS	0.05	0.27	0.54	0.07	0.12	0.15
L-OV	0.18	0.03	0.04	0.19	0.32	0.36
L-CV	0.17	0.84	0.10	0.53	0.18	0.18
G-PA	0.12	0.10	0.01	0.07	0.03	0.02
G-AC	0.02	0.09	0.26	0.09	0.17	0.22
Un-G	0.01	0.10	0.06	0.03	0.05	0.03
Na-G	0.78	0.27	0.37	0.03	0.31	0.44

where $(C_t - C_0)$ is SOC sequestration; C_t is the SOC stock in 2012; C_0 is the SOC stock in 2008; t was the duration of experiment (year).

The SOC sequestration efficiency was estimated using the SOC sequestration in the weight of total biomass (aboveground biomass and belowground biomass) of per unit area:

$$C_{\mathrm{se}} = \frac{\Delta C}{\frac{B_{\mathrm{T}}}{10}}, \quad (3)$$

where C_{se} is the SOC sequestration efficiency; C ($\mathrm{Mg\,ha^{-1}}$) is the SOC sequestration from 2008 to 2012; B_{T} ($\mathrm{kg\,m^{-2}}$) is the total biomass (above ground and below ground) from 2008 to 2012.

2.5 Statistical analyses

Data were examined for normality using the Shapiro–Wilk test and homogeneity of variances by the Levene test before analysis (Table 2). Data non-normally distributed were log-transformed. All data were expressed as mean values ± standard error (M ± SE). The total biomass (aboveground and belowground biomass) means the average of 5 years during the experimental period. The means of SOC sequestration rate and SOC sequestration efficiency among the different grassland types were assessed using one-way analysis of variance (ANOVA). Two-way ANOVA of Type III was performed to test the influences of grassland types and time on SOC content, storage, and bulk density. Tukey's test was conducted to test the significance at $p < 0.05$ level. All the statistical analyses were performed with SPSS version 18.0 (SPSS Inc., Chicago, IL, USA).

3 Results

Between 2008 and 2012, the five cultivated grasslands had in general greater total biomass values (mean by 189.36 %) than the uncultivated grassland and natural grassland. In addition, the three grasslands cultivated with the leguminous species had greater annual total biomass (mean by 72.6 %) than two gramineous grasslands. L-MS grassland consistently had the greatest total biomass throughout the study period (Fig. 2a).

Results from two-way ANOVA showed that the plots, year, and interactions all significantly affected total biomass, SOC content, and BD ($p < 0.001$; Table 3). The average SOC content during the study period followed leguminous grasslands ($4.21 \pm 0.31\,\mathrm{g\,kg^{-1}}$), natural grasslands ($2.90 \pm 0.14\,\mathrm{g\,kg^{-1}}$), uncultivated grasslands ($2.58 \pm 0.17\,\mathrm{g\,kg^{-1}}$), gramineous grasslands ($2.46 \pm 0.15\,\mathrm{g\,kg^{-1}}$), and it increased over time in all grasslands (Table 4). The effects of grassland types on BD followed uncultivated and natural grassland ($1.44 \pm 0.02\,\mathrm{g\,cm^{-3}}$), gramineous grasslands ($1.43 \pm 0.01\,\mathrm{g\,cm^{-3}}$), leguminous grasslands ($1.40 \pm 0.01\,\mathrm{g\,cm^{-3}}$, Table 5).

SOC storage under all grassland types increased significantly throughout the study period (Table 6). The three leguminous grasslands accumulated C with an average rate of $1.00\,\mathrm{Mg\,C\,ha^{-1}\,yr^{-1}}$, which is more than the $0.34\,\mathrm{Mg\,C\,ha^{-1}\,yr^{-1}}$ in gramineous grassland, and more than the average of uncultivated and natural grasslands ($0.25\,\mathrm{Mg\,C\,ha^{-1}\,yr^{-1}}$; Fig. 2c). The mean SOC sequestration efficiency in the leguminous grassland was 0.26, which was significantly greater than other grassland types (0.13; $p < 0.05$; Fig. 2d).

4 Discussion

Grasslands can have a significant effect in arid and semi-arid areas' C cycle through changing soil C accumulation rates and turnover, soil erosion, and vegetation biomass (Deng et al., 2014a; Liu et al., 2017). Plants regulate SOC stock by controlling, assimilating, and accumulating C in the plant root system, and then through plant respiration and leaching release from soil to atmosphere (De Deyn et al., 2008; Garcia-Diaz et al., 2016). SOC inputs mostly originate from decaying aboveground and belowground plant tissue, so greater soil C accumulation can be mainly ascribed to increasing soil C input from higher biomass production (Deng et al., 2014c; Wu et al., 2016). Mutualistic symbionts (N-

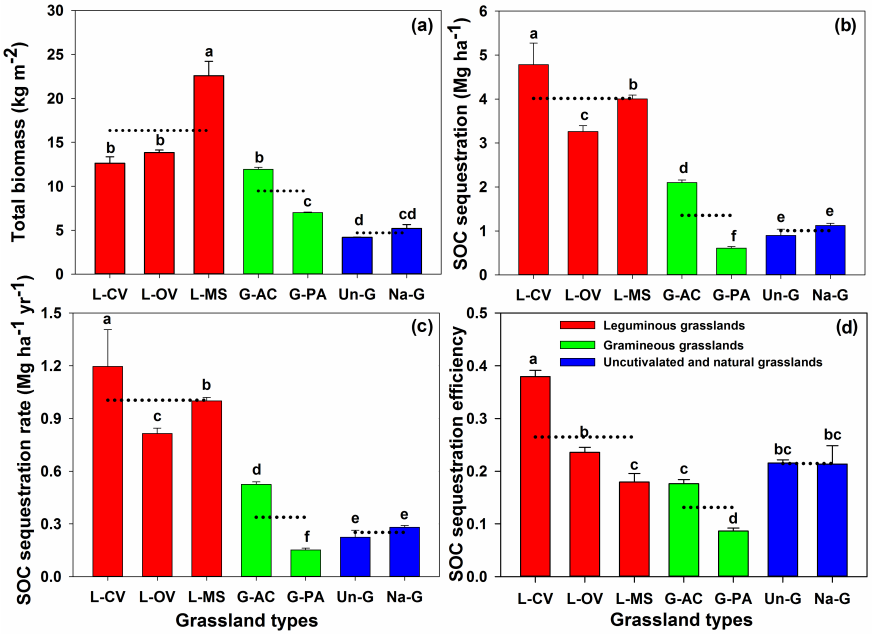

Figure 2. Total biomass **(a)**, SOC sequestration **(b)**, SOC sequestration rate **(c)**, and SOC sequestration efficiency **(d)** for different grasslands from 2008 to 2012. The grassland types are L-CV, *Coronilla varia*; L-OV, *Onobrychis viciifolia*; L-MS, *Medicago sativa*; G-PA, *Poa pratensis*; G-AC, *Agropyron cristatum*; Un-G, uncultivated grassland; Na-G, natural grassland. Bars indicate mean ± standard error. Bars with the different lowercase letters above them indicate there was significant difference between the means at $p < 0.05$ level. The dotted lines indicate the means of the same grassland types.

Table 3. Two-way ANOVA F and p values for the effects of plot types, year, and interactions on total biomass (TB), soil organic carbon content (SOC), soil C storage, and soil bulk density (BD).

		TB		SOC		C storage		BD	
Factor	df	F	p	F	p	F	p	F	p
Grassland types	6	296.19	< 0.001	40.52	< 0.001	42.03	< 0.001	42.48	< 0.001
Year	4	100.67	< 0.001	49.37	< 0.001	41.05	< 0.001	7.24	< 0.001
interaction	24	32.57	< 0.001	2.30	0.001	2.00	0.001	7.36	< 0.001

fixing bacteria and mycorrhizal fungi) are also an important source of C input to soil, especially in actively growing plants (Bardgett et al., 2005). In grasslands, atmospheric C (CO_2) is sequestrated through photosynthesis and respiration. Then, C fixes in a stable SOC pool or releases back into the atmosphere (Post and Kwon, 2000). Therefore, studying the C sequestration in grassland ecosystems can help to identify the magnitude of global C sinks and sources (Li et al., 2014). Our results showed that leguminous grassland had greater SOC contents and storage efficiency than gramineous grassland. Different species may incorporate more or less C according to their specific metabolism. Legumes have been identified as a key driver of C sequestration in many studies (Fornara and Tilman, 2008; Wu et al., 2016). These species live in symbiosis with *Rhizobium* bacteria, which fix atmospheric N. Moreover, many previous studies have demonstrated that soil C and total nitrogen are significantly and positively correlated (Deng et al., 2013; De Oliveira et al., 2015). Since mycorrhizal fungi can immobilize C in their mycelium and improve C sequestration in soil aggregates (Rillig and Mummey, 2006), it might be expected that the cultivated leguminous grasslands significantly improved soil N content that led to larger C sequestration ability than the non-leguminous grasslands.

The biomass fraction resulting in SOC build-up (plant residuals) was possibly strongly affected by management practices including the selection of plant species (Don et al., 2011). Species composition may have had a critical role in determining the aboveground productivity (Liu et al., 2016). Over a relatively long time, the proportion of the aboveground biomass enters soil as organic matter and incorporates into soil through physical and biological processes. Some leachates from plant material in the litter layer, root exudates, solid decomposed litter, and fragmented plant struc-

Table 4. Soil C concentration ($M \pm SE\,g\,kg^{-1}$, average value of 100 cm soil depth) in different years and grassland types. The grassland types are L-CV, *Coronilla varia*; L-OV, *Onobrychis viciifolia*; L-MS, *Medicago sativa*; G-PA, *Poa pratensis*; G-AC, *Agropyron cristatum*; Un-G, uncultivated grassland; Na-G, natural grassland. Values followed by different lowercase letters within columns and uppercase letters within rows are significantly different at $p < 0.05$.

Grassland types	2008	2009	2010	2011	2012
L-CV	2.31 ± 0.04dE	3.09 ± 0.05cD	4.22 ± 0.04bC	4.91 ± 0.02bB	5.92 ± 0.05bA
L-OV	2.70 ± 0.04bE	3.33 ± 0.02bD	3.96 ± 0.02cC	4.69 ± 0.08cB	5.44 ± 0.12cA
L-MS	2.92 ± 0.06aE	3.62 ± 0.05aD	4.38 ± 0.02aC	5.55 ± 0.09aB	6.13 ± 0.05aA
G-AC	1.90 ± 0.01gE	2.13 ± 0.03fD	2.56 ± 0.04eC	2.94 ± 0.03eB	3.46 ± 0.06dA
G-PA	2.03 ± 0.01fE	2.14 ± 0.02fD	2.26 ± 0.02fC	2.57 ± 0.01fB	2.65 ± 0.02fA
Un-G	2.20 ± 0.08eCD	2.35 ± 0.02eC	2.42 ± 0.04efC	2.81 ± 0.01eB	3.16 ± 0.02eA
Na-G	2.53 ± 0.08cB	2.71 ± 0.10dB	2.80 ± 0.12dB	3.18 ± 0.13dA	3.26 ± 0.06eA

Table 5. Soil bulk density ($M \pm SE\,g\,cm^{-3}$, average value of 100 cm soil depth) in different years and grassland types. The grassland types are L-CV, *Coronilla varia*; L-OV, *Onobrychis viciifolia*; L-MS, *Medicago sativa*; G-PA, *Poa pratensis*; G-AC, *Agropyron cristatum*; Un-G, uncultivated grassland; Na-G, natural grassland. Values followed by different lowercase letters within columns and uppercase letters within rows are significantly different at $p < 0.05$.

Grassland types	2008	2009	2010	2011	2012
L-CV	1.41 ± 0.01dAB	1.42 ± 0.01bA	1.39 ± 0.01cB	1.37 ± 0.01cdC	1.35 ± 0.01dD
L-OV	1.51 ± 0.01aA	1.46 ± 0.01aB	1.40 ± 0.01bcdC	1.36 ± 0.01dD	1.33 ± 0.01eE
L-MS	1.47 ± 0.15bcA	1.47 ± 0.01aA	1.43 ± 0.02abAB	1.39 ± 0.02bcBC	1.36 ± 0.01cC
G-AC	1.45 ± 0.01cA	1.46 ± 0.02aA	1.46 ± 0.01aA	1.45 ± 0.01aA	1.39 ± 0.01bB
G-PA	1.47 ± 0.01bcA	1.46 ± 0.01aA	1.39 ± 0.01cB	1.38 ± 0.01cdC	1.34 ± 0.01eD
Un-G	1.48 ± 0.01bA	1.47 ± 0.01aB	1.43 ± 0.01abC	1.42 ± 0.01bD	1.40 ± 0.01aE
Na-G	1.49 ± 0.01abA	1.48 ± 0.01aB	1.42 ± 0.01bcC	1.42 ± 0.01bCD	1.41 ± 0.01aD

ture materials could have been the main sources of soil organic matter (Jones and Donnelly, 2004; Novara et al., 2015). The amount of plant residuals returned to the soil may have affected the SOC (Musinguzi et al., 2015; Wasak and Drewnik, 2015). Mostly perennial plants were managed with high planting densities to produce greater biomass exports (Hobbie et al., 2007; Köchy et al., 2015b). Deng et al. (2014c) found that plant biomass is the key driver in soil C sequestration. In this study, SOC increased dramatically in leguminous grassland most likely due to the greater total biomasses of the leguminous grasses, which result in the increasing soil C inputs from the litter layer and root biomass (De Deyn et al., 2008; Wu et al., 2010; Novara et al., 2015). Moreover, symbiosis might have increased plant productivity through enhancing the acquisition of limited resources. Our results demonstrate that a key variable associated with higher SOC content in leguminous grasslands compared to gramineous grasslands is the greater total biomass accumulation. The leguminous grasslands had both higher above- and belowground biomasses than gramineous grasslands. Total biomass was $16.35\,kg\,m^{-2}$ in leguminous grasslands, which was $9.47\,kg\,m^{-2}$ higher than in gramineous grasslands from 2008 to 2012. The grasslands in our study harvested the aboveground biomass once annually, so all the stubble and plant litters input to soil as a C supply.

SOC sequestration rates in the leguminous grasslands were significantly higher than those found in the gramineous grasslands (Fig. 1c). This maybe resulted from the different decomposition rates in soils, because the leguminous and gramineous grass species result in multifarious nutrient conditions. Litter and fragmented plant parts at the soil surface are decomposed by micro-organisms and are gradually incorporated into the soil through some complex processes, such as humification and mineralization (Novara et al., 2015). Legumes have the ability to develop root nodules and to fix nitrogen in symbiosis with compatible rhizobia, which can improve the soil nutrient status and microbial community (Hurisso et al., 2013). Root nodules promote the symbiosis with micro-organisms, which are responsible for the decomposition of the plants and therefore constitute the key of the transmission of the stored C into the soil. Furthermore, the increasing fertility of the soils in the leguminous grasses should facilitate the increasing productivity of the plants (Wu et al., 2016). Our results showed that SOC sequestration efficiency under leguminous grassland was evidently greater than that in the gramineous grassland (Fig. 1d). It is noteworthy that L-MS grassland had the highest total biomass of $22.59\,kg\,m^{-2}$, which is 2.38 times as much as the average of gramineous grasslands (Fig. 2a). Moreover, SOC sequestration in L-MS

Table 6. SOC stock ($M \pm SE$ Mg C ha^{-1}) at the depth of 0–100 cm in different years and grassland types. The grassland types are L-CV, *Coronilla varia*; L-OV, *Onobrychis viciifolia*; L-MS, *Medicago sativa*; G-PA, *Poa pratensis*; G-AC, *Agropyron cristatum*; Un-G, uncultivated grassland; Na-G, natural grassland. Values followed by different lowercase letters within columns and uppercase letters within rows are significantly different at $p < 0.05$.

Grassland types	2008	2009	2010	2011	2012
L-CV	31.49 ± 0.31dE	43.10 ± 0.60cD	57.92 ± 0.87abC	66.67 ± 0.17bB	79.34 ± 0.80bA
L-OV	40.05 ± 0.36bB	48.57 ± 0.41bAB	55.41 ± 0.41bAB	63.89 ± 1.09bAB	72.66 ± 1.38cA
L-MS	43.75 ± 0.87aE	53.69 ± 0.89aD	63.20 ± 1.28aC	77.50 ± 1.62aB	83.77 ± 0.76aA
G-AC	27.11 ± 0.27fE	30.87 ± 0.60fD	37.10 ± 0.60cC	42.53 ± 0.33cB	48.10 ± 0.82dA
G-PA	29.29 ± 0.06eC	30.80 ± 0.36fB	31.35 ± 0.19dB	35.38 ± 0.06eA	35.36 ± 0.37fA
Un-G	32.03 ± 0.65dD	33.83 ± 0.18eC	33.83 ± 0.52cC	38.72 ± 0.17dB	43.25 ± 0.22eA
Na-G	36.25 ± 0.61cB	38.40 ± 1.25dB	39.26 ± 1.61cB	44.74 ± 2.00cA	45.20 ± 0.98eA

grassland was 3 times higher than the average of gramineous grasslands (Fig. 2b).

Despite the indications from this study of higher SOC sequestration rate and efficiency in leguminous grassland, specific research is still needed to determine the potential mechanisms of each species in sequestrating C. Many studies have demonstrated that legumes are high water-consuming plants compared to gramineous ones in arid and semi-arid areas, so it is necessary to balance the ecological effect of grassland for rational utilization of resources.

5 Conclusion

Leguminous grassland had greater SOC storage, sequestration rate, and efficiency than gramineous grassland. The greater soil C accumulation of leguminous grasslands was mainly ascribed to the capacity to incorporate C and the higher biomass production. Leguminous grasslands accumulated an average rate of 0.64 Mg C ha^{-1} yr^{-1} more than gramineous grasslands. The average SOC sequestration efficiency in leguminous grasslands was 2 times greater than that in the gramineous grasslands. Our results provide a reference for ecological management in arid and semi-arid areas.

6 Data availability

The data are not publicly available due to copyright issues.

Competing interests. The authors declare that they have no conflict of interest.

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