

The impact of desertification on carbon and nitrogen storage in the desert steppe ecosystem



Zhuang-Sheng Tang^a, Hui An^{b,*}, Zhou-Ping Shangguan^{a,*}

^a State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling 712100, Shaanxi, PR China

^b Key Laboratory of Restoration and Reconstruction of Degraded Ecosystem in North-western China of Ministry of Education, United Center for Ecology Research and Bioresource Exploitation in Western China, Ningxia University, Yinchuan 750021, PR China

ARTICLE INFO

Article history:

Received 10 January 2015

Received in revised form 25 June 2015

Accepted 27 July 2015

Available online 27 August 2015

Keywords:

Desert steppe

Desertification

Carbon storage

Nitrogen storage

ABSTRACT

Desertification is one of the most severe types of land degradation. This study quantified the impact of five different desertification regimes (potential (PD), light (LD), moderate (MD), severe (SD), and very severe (VSD)) on a desert steppe ecosystem in northern China, and investigated the changes in carbon (C) and nitrogen (N) storage in relation to land desertification. The C and N content in different stages of desertification were significantly different, while there was no obvious variation of C and N in different plant components as desertification progressed. Changes in soil C and N were not in accordance with plant succession, with the soil being more sensitive to desertification than the ground vegetation. When the VSD stage was compared with the PD stage, desertification resulted in the total C and N storage in plants decreasing by 97.3% and 96.8%, respectively, and in the 0–40 cm soil layer decreasing by 58.5%, and 76.0%, respectively. The highest C and N storage levels in the desert steppe ecosystem were 1291.93 g m⁻², and 142.10 g m⁻² in the PD stage, and the lowest levels were 505.14 and 33.41 g m⁻² in the VSD stage. C and N losses through desertification were 786.79 and 108.69 g m⁻², respectively. Therefore, it was confirmed that desertification results in soil degradation and seriously decreases soil potential productivity.

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1. Introduction

In arid and semiarid ecosystems, desertification is characterized by aeolian soil erosion, which is one of the most severe types of land degradation in the world (Murdock and Frye, 1983). It not only results in soil degradation and seriously decreases the soil potential productivity (Gad and Abdel, 2000), but also can promote the emission of greenhouse gases into the atmosphere (Zhao et al., 2009). Worldwide, there is an area of about 45.6 million km² of land where desertification is occurring to some degree, and this accounts for 35% of the Earth's land surface, extends through more than 100 countries, and affects 8.5 × 10⁸ people (Zhu and Chen, 1994; Ma et al., 1998). For these reasons the effects of desertification on C and N storage in ecosystems has become a concern in recent years.

Understanding the changes in the carbon (C) and nitrogen (N) content in terrestrial ecosystems is not only critical to determining

ecosystem productivity and quality, but also to quantifying the impact of C and N cycling and storage on global climate change. During the past two decades, many studies have focused on changes of soil organic carbon (SOC) and total nitrogen (TN) in terrestrial ecosystems (Russell et al., 2005; Qiu et al., 2010; Deng et al., 2014a,b). Land degradation greatly influences soil quality, C and N cycling, and regional socioeconomic development (Eaton et al., 2008; Fu et al., 2010). Alterations to C and N cycles and pools influences the production of soil and functioning of ecosystems (Foster et al., 2003). Furthermore, C–N interactions are important for determining whether the C sink in terrestrial ecosystems can be sustained over the long term, and N dynamics are a key factor in the regulation of long-term terrestrial C sequestration (Luo et al., 2006). If the total N content does not change, it may become progressively more limiting as C accumulates in ecosystems under conditions of elevated CO₂ in ecosystems (Luo et al., 2006). Therefore, studying changes in the amounts of organic carbon (OC) and N in a desert steppe ecosystem along a land deterioration gradient, and analyzing the relationships between C and N storage following the deterioration, may not only be of importance for improving our knowledge of the sustainable management of land resources, but also for making predictions of future global C and N cycling.

* Corresponding authors at: Institute of Soil and Water Conservation, Xinong Rd. 26, Yangling 712100, Shaanxi, PR China. Tel.: +86 29 87019107; fax: +86 29 87012210; Ningxia University, Helan mountain west Rd. 489. Yinchuan 750021, Ningxia, PR China. Tel.: +86 951 2062169; fax: +86 951 2062169.

E-mail addresses: tzsxzl@126.com (Z.-S. Tang), anhui08@163.com (H. An), shangguan@ms.iswc.ac.cn (Z.-P. Shangguan).

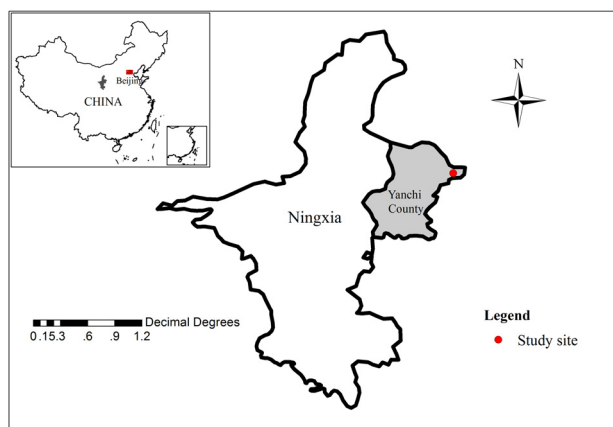


Fig. 1. Location of the study area

In arid and semiarid regions, wind erosion (Larney et al., 1998) and over-grazing (Deng et al., 2014c) are the principal reasons for land deterioration. Previous studies have reported that soil organic C and N levels in relation to desertification have confirmed that desertification occurs mainly in windy arid areas (Potter, 1990; Lopez et al., 2000). Existing studies have also suggested that with land desertification, soil organic C and N storage decreases significantly (Duan et al., 2001). However, many previous studies have focused primarily on the soil. Little is known about the changes in the C and N content and storage in both the grassland soil and plant components, and their relations to desertification in semiarid grassland areas of China. This information would be useful for estimating the temporal distribution of C and N storage and for evaluating C and N lost through desertification in semiarid regions.

In this study, we used a space-for-time method, and hypothesized that the different intensities of desertification would have different effects on C and N concentrations, storage, and the relation between C and N as desertification progresses in the desert steppe ecosystem. The purpose of the study was to evaluate the effects of desertification on C and N storage in the desert steppe ecosystem of northern China.

2. Materials and methods

2.1. Study area

The study was located in Yanchi County ($37^{\circ}04'–38^{\circ}10'N$ and $106^{\circ}30'–107^{\circ}41'E$, elevation 1450 m) (Fig. 1), on the southwestern fringe of the Mu Us sandy land in Ningxia, China. The region has a temperate, continental, semiarid, monsoonal climate. The mean multi-annual temperature is $8.1^{\circ}C$, with the lowest and highest monthly mean temperatures of $-8.7^{\circ}C$ in January and $22.4^{\circ}C$ in July, respectively. The mean multi-annual precipitation is 289 mm, with 70% of the total precipitation occurring between June and September. Mean multi-annual potential pan-evaporation is 2014 mm per year. Mean annual wind velocity is 2.8 m s^{-1} , and the prevailing winds are mainly northwesterly in April and May. Sand particles blown at velocities over 5.0 m s^{-1} occurs on average 323

times per year. Wind erosion often occurs from April to mid-June, before the rainy season begins (climate data from Yanchi Meteorological Station, 1976–2010). At the study site, the main soil types are sierozem, loess, and orthi-sandic entisols, all of which are of low fertility, loose structure, and are very susceptible to wind erosion (Liu et al., 2014). The predominant vegetation in the mobile sand land is *Agriophyllum squarrosum* (Table 1). As the mobile sand land is gradually stabilized, the herbaceous vegetation is dominated by *Salsola collina*, *Corispermum hyssopifolium*, *Artemisia scoparia*, *Pennisetum centrasiaticum*, *Aneurolepidium dasystachys*, and *Cleistogenes gracilis*.

2.2. Sampling and measurements

2.2.1. Experimental design

According to the vegetation cover, we used a space-for-time method. Fifteen sampling areas were randomly chosen from each of five different desertification stages (Ding, 2004). Table 1 gives the coverage and dominant species of the grasslands in different stages of desertification. The stages were a potential desertification stage (PD), light desertification stage (LD), moderate desertification stage (MD), severe desertification stage (SD), and very severe desertification stage (VSD). The PD stage was the control. We selected 15 study sites that exceeded $50 \times 50\text{ m}$ (approximately 100 m away from each other). For each stage of desertification three sites with a similar condition were selected. Within the center of each study site, we randomly established ten $1 \times 1\text{ m}$ quadrats. In each quadrat, the canopy cover, species composition, the above and below ground biomass, and litter were investigated.

2.2.2. Biomass measurement

A field survey was undertaken between July and August in 2013, when the biomass had reached its peak. In each quadrat, the above-ground parts of the green plants were cut and placed into envelopes by species and then tagged. All litter was also collected, placed into envelopes and tagged. All the above parts of the green plants were immediately dried for 30 min at $105^{\circ}C$, and then transferred to the lab where they were oven-dried at $65^{\circ}C$ and weighed. In each quadrat, after collecting the aboveground parts of green plants and litter, to measure the below ground biomass, a 9 cm diameter root auger was used to take three soil samples from each depth of 0–10, 10–20, 20–30, and 30–40 cm. Samples taken from the same layer were then mixed to create a single sample. The majority of the roots were found in these soil samples and were then isolated using a 2 mm sieve. By spreading the samples in shallow trays, the remaining fine roots were removed from the soil samples and isolated. The tray was overfilled with water and the outflow from it was allowed to pass through a 0.5 mm mesh sieve. No attempts were made to distinguish between living and dead roots. All of the roots were immediately dried for 30 min at $105^{\circ}C$, and then transferred to the lab where they were oven-dried at $65^{\circ}C$ and weighed.

2.2.3. Soil sampling

In each of the quadrats soil samples were taken at three points: the other two corners and the center along the diagonal on which

Table 1
Coverage and dominant species of grasslands in different stages of desertification.

Stage of desertification	Coverage (%)	Dominant species
PD	$74.02 \pm 4.50a$	<i>Lespedeza potaninii</i> , <i>Artemisia scoparia</i> Walds, <i>Pennisetum centrasiaticum</i>
LD	$71.75 \pm 2.90a$	<i>Pennisetum centrasiaticum</i> , <i>Sophora alopecuroides</i>
MD	$57.26 \pm 7.54b$	<i>Utricularia australis</i> , <i>Corispermum hyssopifolium</i>
SD	$43.74 \pm 4.99c$	<i>Agriophyllum squarrosum</i> , <i>Aneurolepidium dasystachys</i> , <i>Setaria viridis</i>
VSD	$6.63 \pm 1.64d$	<i>Agriophyllum squarrosum</i>

Table 2
Vertical distribution of soil bulk density in different stages of desertification.

Bulk density (g cm^{-3})	0–10 cm	10–20 cm	20–30 cm	30–40 cm
PD	$1.534 \pm 0.003\text{a}$	$1.525 \pm 0.003\text{a}$	$1.542 \pm 0.023\text{ab}$	$1.548 \pm 0.021\text{b}$
LD	$1.554 \pm 0.001\text{a}$	$1.551 \pm 0.01\text{a}$	$1.557 \pm 0.016\text{ab}$	$1.564 \pm 0.018\text{b}$
MD	$1.595 \pm 0.001\text{a}$	$1.609 \pm 0.017\text{a}$	$1.587 \pm 0.006\text{ab}$	$1.578 \pm 0.005\text{b}$
SD	$1.612 \pm 0.002\text{a}$	$1.611 \pm 0.007\text{a}$	$1.598 \pm 0.006\text{ab}$	$1.587 \pm 0.014\text{b}$
VSD	$1.621 \pm 0.001\text{a}$	$1.616 \pm 0.033\text{a}$	$1.603 \pm 0.006\text{ab}$	$1.595 \pm 0.006\text{b}$

root samples had not been collected. The soil samples, collected and mixed in three increments as described, were passed through a 2 mm screen to remove roots and other debris. Each sample was air-dried and stored at room temperature until the physical and chemical properties could be determined. Using a soil bulk sampler with a 5 cm diameter and a 5 cm high stainless steel cutting ring, the soil bulk density of each soil layer (0–10, 10–20, 20–30, and 30–40 cm) was measured (three replicates) at points adjacent to where the soil samples had been collected for chemical analysis. The original volume of each soil core and its dry mass after oven-drying at 105°C were measured.

2.2.4. Carbon and nitrogen determination

The plant and soil C content was determined by dichromate oxidation (Kalembasa and Jenkinson, 1973). The plant and soil N content was determined by the Kjeldahl procedure (Jackson, 1973).

2.2.5. Calculation of soil C and N storage

The soil samples did not have a coarse fraction ($>2\text{ mm}$). Thus, the following equation was used to calculate soil OC storage (C_s) (Guo and Gifford, 2002):

$$C_s = \text{BD} \times \text{SOC} \times D \times 10$$

where C_s is the soil OC storage (g m^{-2}); BD is the soil bulk density (g cm^{-3}); SOC is the soil OC content (g kg^{-1}); and D is the soil thickness (cm).

The following equation was used to calculate soil N storage (N_s) (Rytter, 2012):

$$N_s = \text{BD} \times \text{TN} \times D \times 10$$

where N_s is soil N storage (g m^{-2}); BD is soil bulk density (g cm^{-3}); TN is the soil TN concentration (g kg^{-1}); and D is soil thickness (cm). Table 2 gives the vertical distribution of the soil bulk density in the different stages of desertification.

2.2.6. Calculation of vegetation C and N storage

The following equation was used to calculate the vegetation C storage (Fang et al., 2007):

$$C_v = \frac{B \times C_f}{1000}$$

where C_v is the vegetation C storage (g m^{-2}), B is the vegetation biomass (g m^{-2}), and C_f is the plant biomass C content (g kg^{-1}).

The following equation was used to calculate the vegetation N storage (N_v):

$$N_v = \frac{B \times C_f}{1000}$$

where N_v is the vegetation N storage (g m^{-2}), B is the vegetation biomass (g m^{-2}), and C_f is the plant biomass C content (g kg^{-1}).

2.3. Statistical analysis

All data were analyzed using SPSS software. Multiple comparisons and analyses of variance (ANOVA) were used to determine the differences among the treatments (Sokal and Rohlf, 1995).

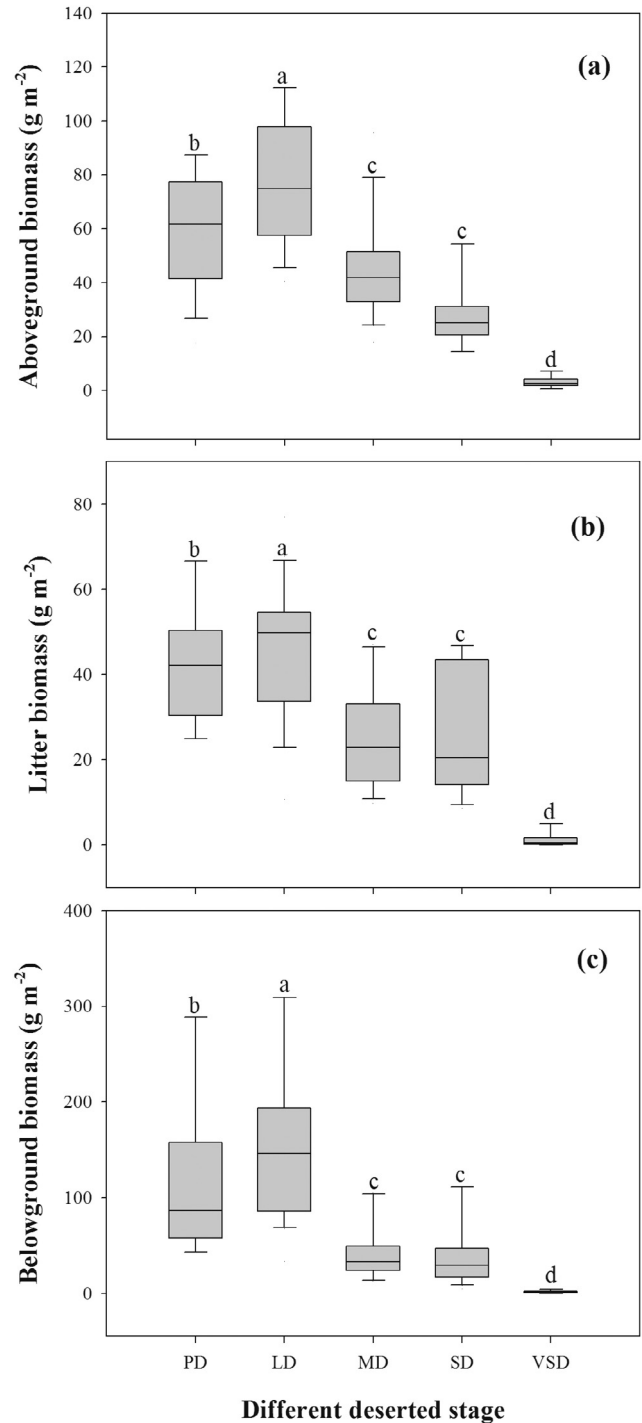


Fig. 2. Changes in the vegetation biomass in different stages of desertification. (a) Above ground biomass; (b) litter biomass; (c) below ground biomass. PD, potential desertification; LD, light desertification; MD, moderate desertification; SD, severe desertification; VSD, very severe desertification. The box is \pm SE, the whisker is the min–max value, and the horizontal line is the median. Different lower-case letters indicate variations significant at the 0.05 level ($P < 0.05$).

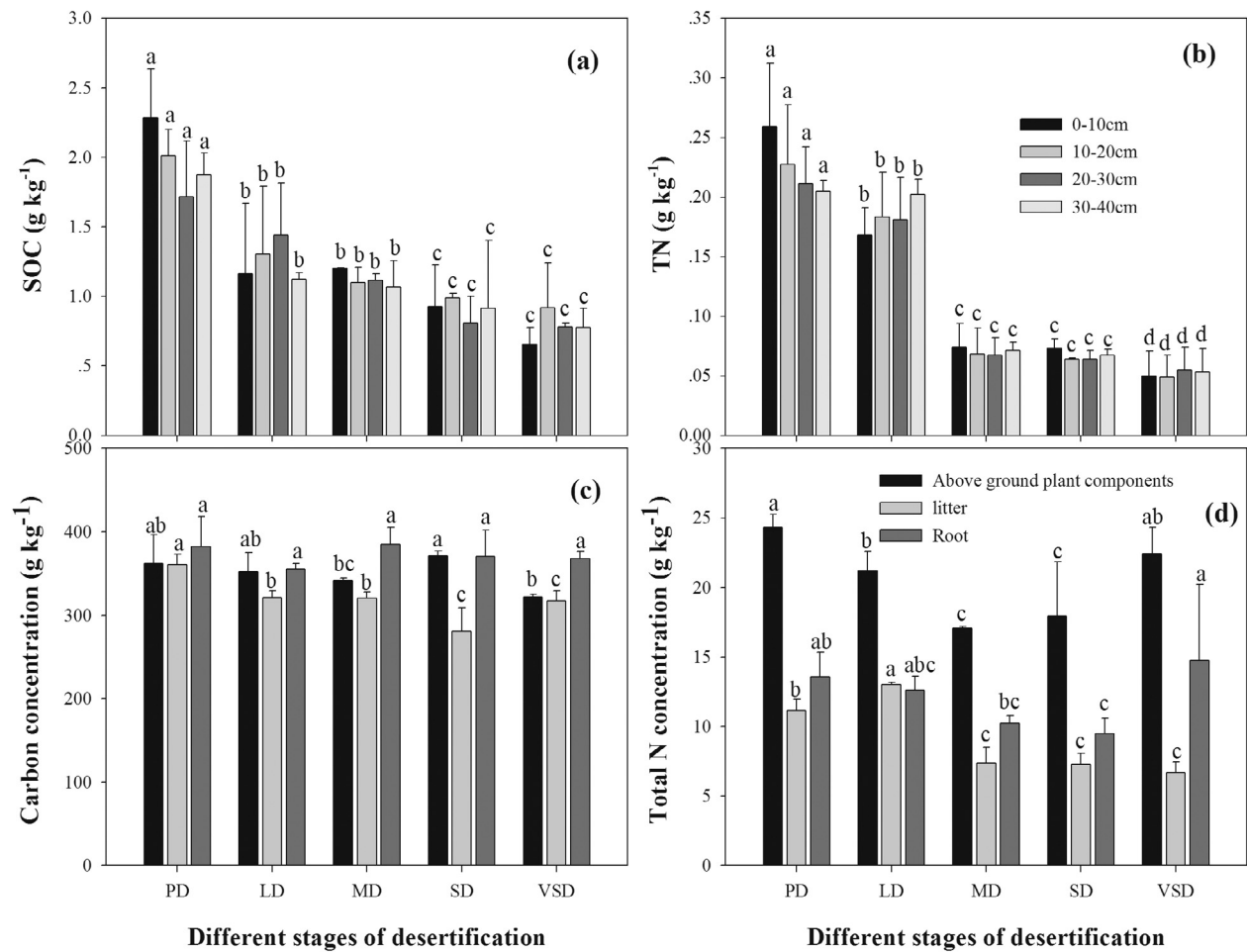


Fig. 3. Changes in the C and total N concentration in different stages of desertification. (a) SOC; (b) Total N; (c) Plant organic C concentration; (d) Total N concentration. PD, potential desertification; LD, light desertification; MD, moderate desertification; SD, severe desertification; VSD, very severe desertification. Different lower-case letters indicate variations significant at the 0.05 level ($P < 0.05$). Error bars indicate the SE.

3. Results

3.1. Changes in the above and below ground biomass

In this study, the grasslands experienced an intensifying degree of desertification. The above and below ground biomass, litter biomass, and total vegetation biomass decreased linearly with desertification (Fig. 2). Excluding the LD stage, the above and below ground biomass, litter biomass, and total biomass increased by 27%, 25%, 9%, and 23%, respectively (Fig. 2), compared with the PD stage. The highest above and below ground biomass, and litter biomass in the LD stage were 79.41, 155.58, and 45.04 g m^{-2} , respectively. The above and below ground biomass, and litter biomass decreased by 94.4%, 98.4%, and 96.7%, respectively, in the VSD stage compared with the PD stage (Fig. 2). This indicates that grassland desertification has a greater effect on the below ground biomass than the above ground and litter biomass.

3.2. Changes in the soil organic C and total N concentration

The organic C content was higher at a soil depth of 0–20 cm than 20–40 cm. Along the different stages of grassland desertification, the SOC decreased quickly and tended to be stable after the MD stage. The highest and lowest SOC contents were found in the PD and VSD stages, respectively. A similar trend was observed for soil TN with vegetation restoration (Fig. 3b). Compared to the PD stage,

in the VSD stage the organic C and total N contents decreased by 60.3% and 77.1% at a soil depth of 0–40 cm, respectively. This shows that desertification had a greater impact on soil total N than on soil organic C, but there was no difference in the effect of desertification on soil organic C and total N between the different soil layers ($P > 0.05$) (Fig. 3).

3.3. Carbon and nitrogen concentrations in plants

As can be seen in Fig. 3, along the different stages of grassland desertification the average C and N concentrations all tended to decrease, but were insignificant ($P > 0.05$), except for the litter C and N concentrations. Compared to the PD stage, the C and N concentrations decreased by 8.8% (Fig. 3c) and 10.4% (Fig. 3d), respectively, in the VSD stage. This showed that grassland desertification had a greater effect on the N concentration than the C concentration in plants. However, there was no obvious variation in the C and N concentrations in different plant components. The highest C and N concentrations were found in the roots and living portions of plants, respectively.

3.4. C and N storage in plant above and below ground biomass

The decrease in C and N storage in plant components was significantly greater than in the litter and below ground portions of plants (Fig. 4). The C storage in the above ground plant components,

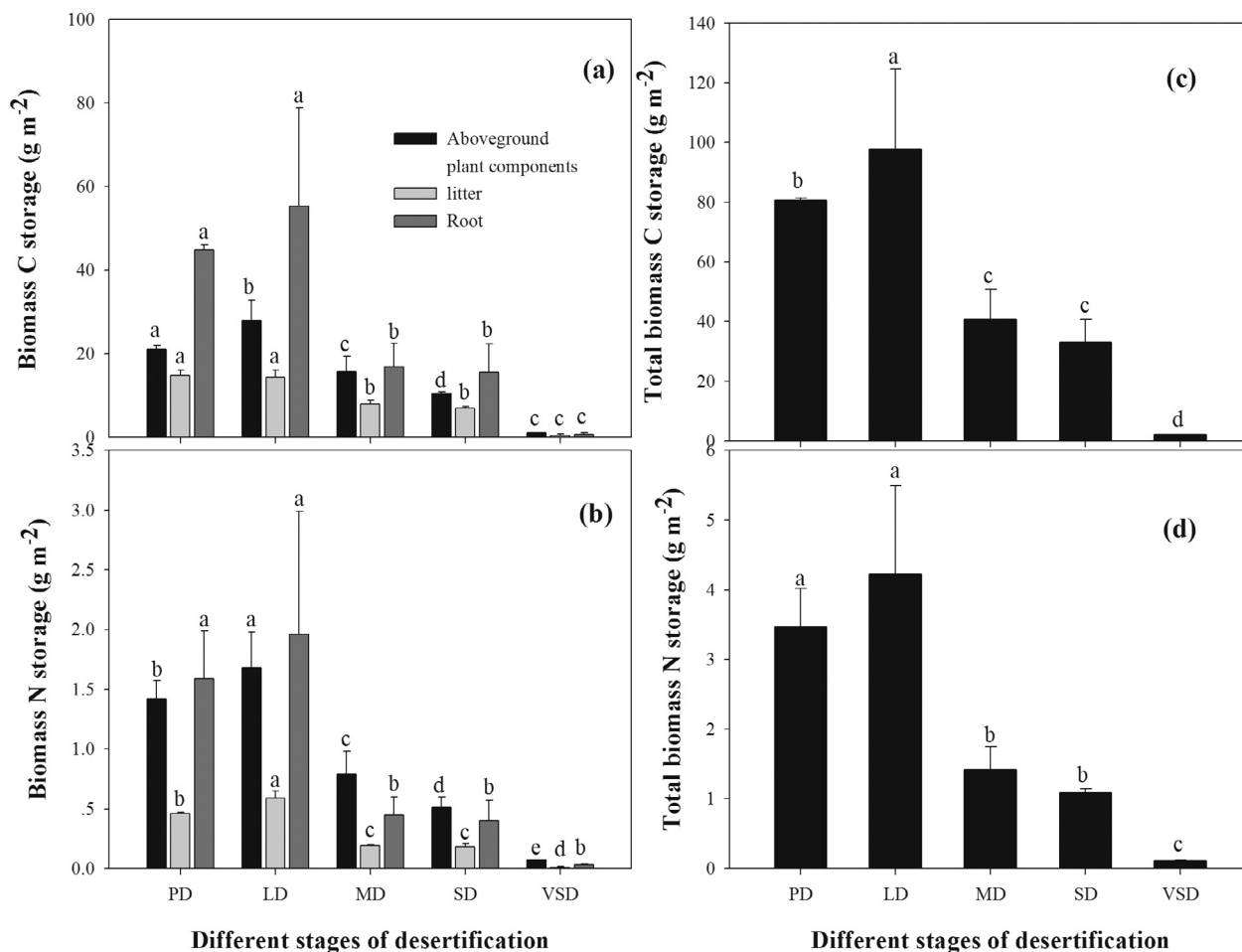


Fig. 4. Changes in the biomass C and N storage in different stages of desertification. (a) Biomass C storage; (b) Biomass N storage; (c) Total biomass C storage; (d) Total biomass N storage. PD, potential desertification; LD, light desertification; MD, moderate desertification; SD, severe desertification; VSD, very severe desertification. Different lower-case letters indicate variations significant at the 0.05 level ($P < 0.05$). Error bars indicate the SE.

litter, and below ground plant components in the LD stage were higher than in the PD stage. The N storage in the above and below ground plant components in the LD stage were higher than in the PD stage. The C and N storage in below ground plant components were higher than in the above ground plant components and litter. The C and N storage in the above ground plant components decreased significantly as desertification progressed ($P < 0.05$). Excluding the LD stage, the total C and N storage increased by 32.5% and 18.3%, respectively. Compared to the PD stage, the C and N storage in above ground plant components decreased by 95.0% and 95.1%, respectively, in the VSD stage, while the litter C and N storage decreased by 97.1% and 97.8%, respectively. The C and N storage in below ground plant components decreased by 98.4% and 98.1%, respectively, in the VSD stage compared to the PD stage (Fig. 4). Total C and N storage decreased by 97.3% and 96.8%, respectively, in the VSD stage compared to the PD stage (Fig. 4).

3.5. Changes in C and N storage in the soil

The soil C storage in the different soil layers decreased as desertification progressed. Carbon storage in the surface soil (0–10 cm) gradually decreased prior to the MD stage, and then decreased to its lowest level in the VSD stage (Fig. 5a). Carbon storage in the 10–20, 20–30, and 30–40 cm soil layers decreased linearly as desertification progressed. Carbon storage decreased by 69.8%, 51.7%, 52.7%, and 57.3% at the soil depths of 0–10, 10–20, 20–30, and 30–40 cm, respectively, in the VSD stage compared with the PD stage (Fig. 5a).

Along the grassland desertification gradient, the soil N storage decreased quickly and tended to be stable after the MD stage. Before the LD stage, the soil N storage at soil depths of 0–10, 10–20, 20–30, and 30–40 cm decreased significantly as vegetation succession progressed ($P < 0.05$). The highest and the lowest N storage contents were in the 0–10 cm soil layer in the PD stage and the 10–20 cm soil layer in the VSD stage. The N storage decreased by 79.4%, 77.3%, 73.0%, and 73.4% at soil depths of 0–10, 10–20, 20–30, and 30–40 cm, respectively, in the VSD stage compared with the PD stage (Fig. 5b).

The soil C and N storage at different soil depths also varied as grassland desertification progressed. Soil C and N storage at soil depths of 0–10, 0–20, 0–30, and 0–40 cm decreased significantly before the MD stage, but tended to be stable after the MD stage (Fig. 5).

3.6. C and N storage in desert steppe ecosystems

The C and N storage in the whole ecosystem decreased significantly as desertification progressed ($P < 0.05$). The highest C and N storage in the whole ecosystem was in the PD stage, with values of 1291.93 and 142.10 g m⁻², respectively. The lowest C and N storage was in the VSD stage, with values of 505.14, and 33.41 g m⁻², respectively (Fig. 6). Soil N storage in the whole ecosystem decreased significantly before the MD stage, but tended to be stable after the MD stage (Fig. 6b).

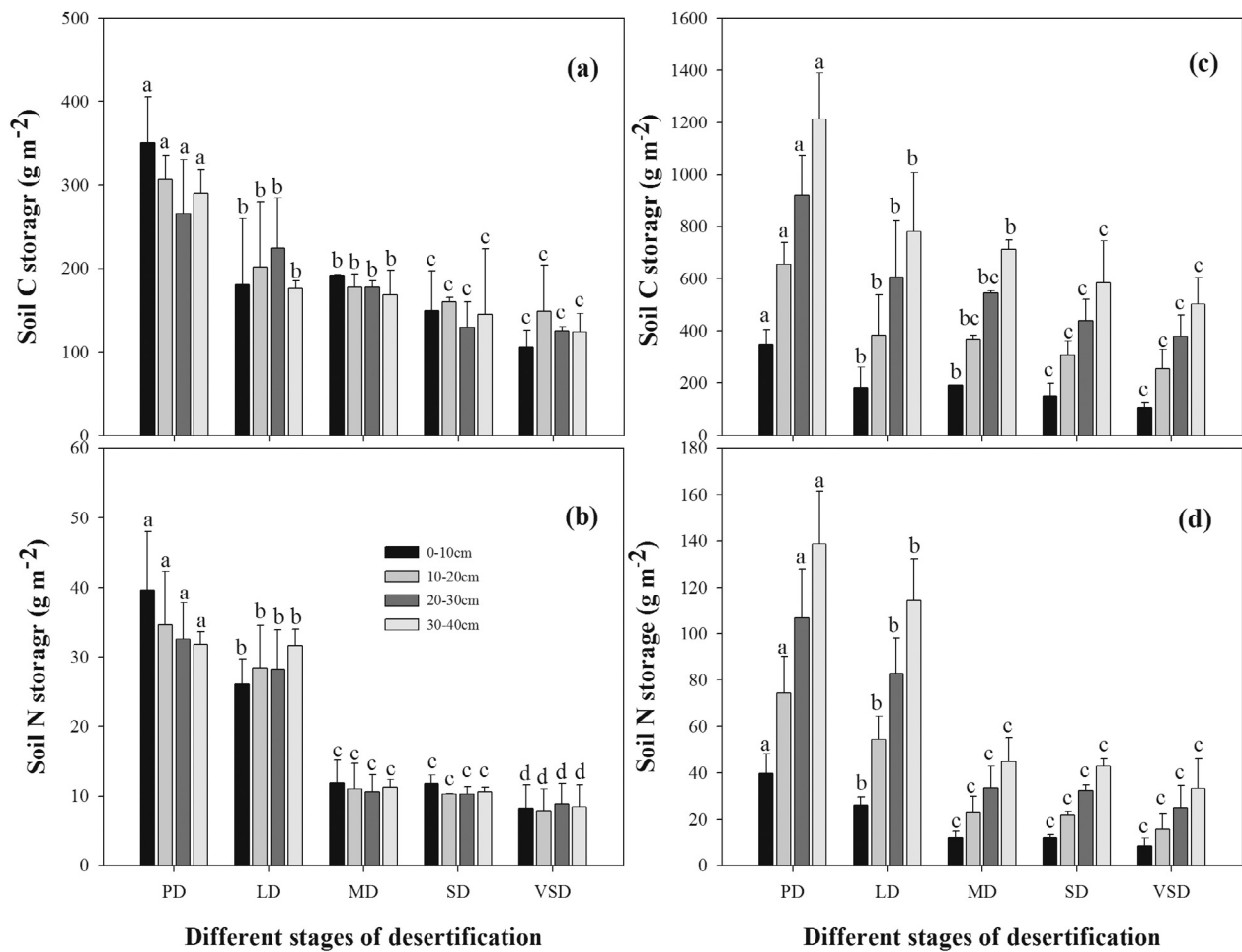


Fig. 5. Changes in the soil C and N storage in different stages of desertification. (a) Soil C storage in different soil layers; (b) Soil N storage in different soil layers; (c) Soil C storage at different soil depths; (d) Soil N storage at different soil depths. PD, potential desertification; LD, light desertification; MD, moderate desertification; SD, severe desertification; VSD, very severe desertification. Different lower-case letters indicate variations significant at the 0.05 level ($P < 0.05$). Error bars indicate the SE.

4. Discussion

Grasslands account for more than 20% of the Earth's terrestrial area, and are an important pool of C and N. In arid and semiarid regions, land desertification, facilitated by aeolian soil erosion, has resulted in a decrease of the grassland C and N pool, because erosion can lead to a reduction in crop production by the selective removal of the finest soil particles, which are rich in organic C and N (Lowery et al., 1995; Larney et al., 1998). In this study, the C and N content decreased significantly along the different stages of desertification, while there was no obvious variation in different plant components as desertification progressed. The C and N content in the soil 0–40 cm layer decreased significantly, whereas there was no significant decrease in the average C and N concentration in plants. This showed that grassland desertification had greater effects on SOC and the total N content than on the plant C and N contents. This is consistent with the results of Feng et al. (2002). Previous studies have reported that overgrazing is the primary cause of grassland desertification, because it reduces plant cover and exposes the soil to erosion by wind in arid and semiarid regions (Zhao et al., 2006; Wang et al., 2014; Deng et al., 2013a,b). The loss of soil C and N resulted mainly from a decrease in nutrient-rich fine soil particles that are eroded by wind (Zhou et al., 2008). In addition, the C and N content in below ground plant components (0–40 cm) were higher than above ground plant components and litter. This showed that grassland desertification had a larger impact on the C and N content in below ground rather than above ground plant components

and litter. This also confirms the results of Zhou et al. (2008). In this study, plant biomass began to decrease after the LD stage of desertification, while the soil C and N content decreased after the PD stage. These results demonstrate that changes in soil C and N were not in accordance with plant succession. The response of a sandy soil was more sensitive to desertification than the response of ground vegetation. This is consistent with the results of Ardhini et al. (2009).

In arid and semiarid ecosystems, the soil organic matter content is one of the most important factors in the storage of nutrients in generally nutrient-poor sandy soils, and is also among the main limiting factors of plant productivity in desert ecosystems (Wezel et al., 2000). In this study, soil C and N storage decreased along the grassland desertification gradient. This is consistent with the results of Zhou et al. (2008) and Shang et al. (2013). In addition, in our previous study of changes in the plant community and soil physical properties during grassland desertification of steppes (Tang et al., 2016), it was found that as desertification proceeded, the organic-rich clay-silt fraction tended to decrease most significantly. Furthermore, in the desert steppe, aeolian erosion breaks up soil aggregates, decreases total soil porosity, and accelerates the composition and mineralization of soil organic matter (SOM), making it accessible to microbial attack (Marticorena et al., 1997; Shepherd et al., 2001). The study also found the trends of soil C and N storage to be the opposite of those for soil bulk density (BD). Previous studies of soil C and N storage have emphasized the role of physical protection from different particle fractions (sand, silt, and

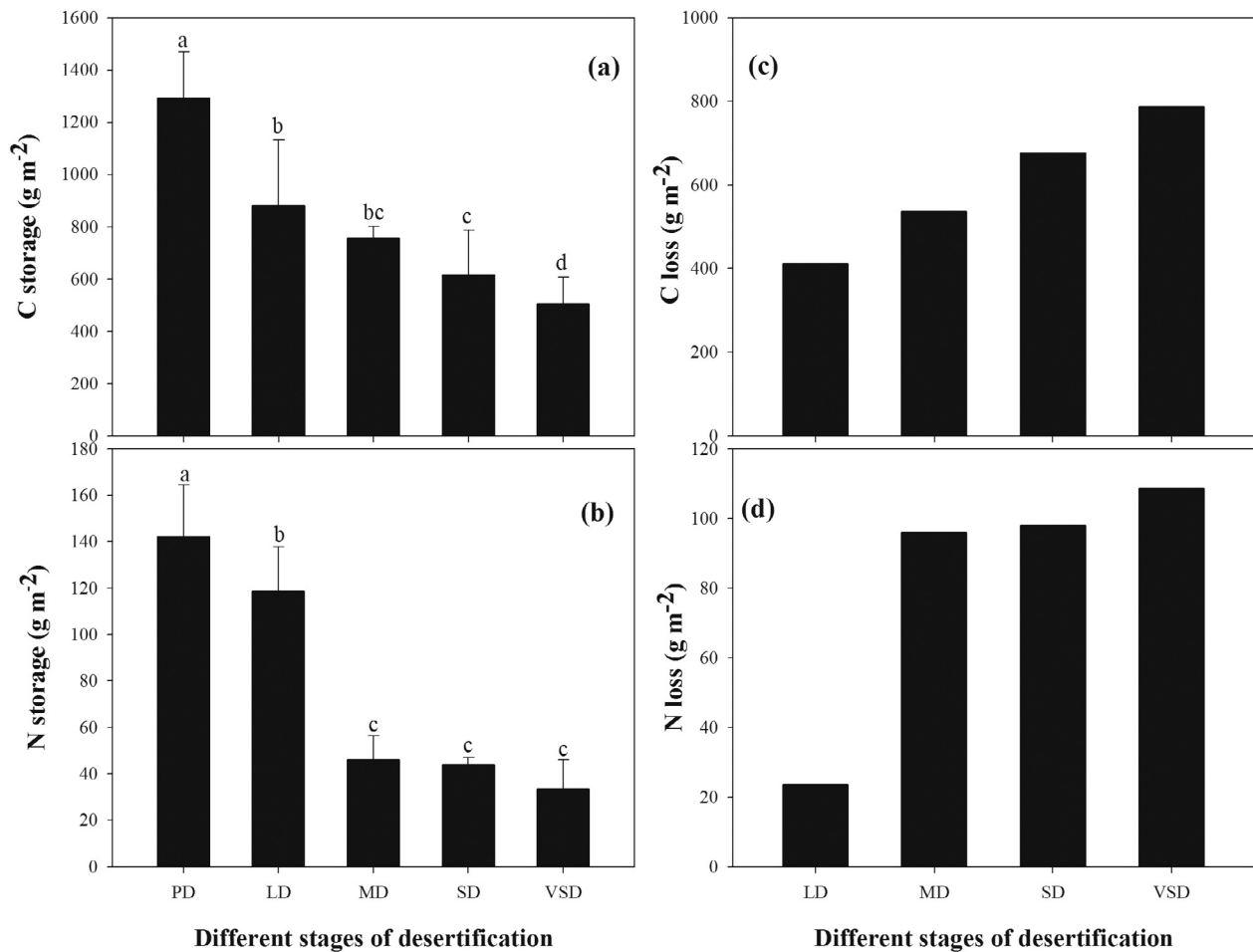


Fig. 6. Changes in soil C and N storage in the desert steppe ecosystem. (a) C storage; (b) N storage; (c) C loss; (d) N loss. PD, potential desertification; LD, light desertification; MD, moderate desertification; SD, severe desertification; VSD, very severe desertification. Different lower-case letters indicate variations significant at the 0.05 level ($P < 0.05$). Error bars indicate the SE.

clay). Wang et al. (2011) reported a negative relationship between soil BD, and SOC and TN. Deng et al. (2013a,b) found that SOC and TN were significantly greater, while BD was significantly lower during the abandonment of farmland on the Loess Plateau. In addition, the return of biomass and litter to the above and below ground areas (dead roots, mycorrhizae, and exudates) leads to an increase in soil C and N storage, because SOC and N inputs are mainly derived from the decomposition of litter, and primary productivity is the main driver of increases in soil C and N. (Wang et al., 2011; De-Deyn et al., 2008; Wu et al., 2010a,b). In this study, C storage in the above and below ground plant components, and litter, was higher in the LD stage than in the PD stage. Nitrogen storage in the above and below ground plant components was higher in the LD stage than in the PD stage. In addition, in the LD stage total C and N storage increased by 21.4% and 22.7%, respectively, compared to the PD stage. The reason for this was most probably that the dominant species was *Sophora alopecuroides*, which can be derived the symbiotic fixation of N, and would be expected to have a concomitant positive effect on both C and N additions to the soil (Wu et al., 2006). This also confirms the results of Zhu and Chen (1994), who reported that the effects of desertification on ecosystem C and N contents were significantly different at different stages of desertification. Furthermore, the dominant functional group is one of the important factors that affect C and N storage of soil (Wu et al., 2011a).

The ecosystem C and N pools were mainly composed of two parts, i.e., plants and soil. Both the plant and soil dynamics of

an ecosystem influence its structure and function (Phoenix et al., 2012). The study showed that in a desert steppe ecosystem, both C and N storage in the ecosystem decreased as desertification progressed, with the highest C and N storage in the PD stage, after which the storage of both elements decreased. It can be seen (Fig. 6) that the C and N loss in the whole desert steppe ecosystem was highest in the VSD stage. The C and N storage in the whole desert steppe ecosystem decreased by 60.9% and 76.5%, respectively, in the VSD stage compared with the PD stage. The value of the total amounts of C and N lost as the grasslands experienced intensifying desertification were 786.79 g m^{-2} (Fig. 6c) and 108.69 g m^{-2} (Fig. 6d), respectively. Large losses of C and N represent substantial environmental degradation in two important respects. Because C and N are lost from the ecosystem, land productivity deteriorates, and the release of greenhouse gases from plants contributes to global climate change (Duan et al., 2001). High quality grassland not only has a higher moisture and nutrient content, and vegetation coverage, but is also rarely eroded by wind (Deng et al., 2013a,b; Zhao et al., 2006; Wu et al., 2011b, 2010a,b, 2014). However, overgrazing and trampling by livestock not only decreases vegetation height and cover in grasslands, but can also destroy the soil crust resulting in soil erosion by the wind (Zhao et al., 2005). For these reasons, the PD stage has a better soil quality and nutrient content than grassland undergoing desertification, and more C and N are then available to be lost through desertification.

Acknowledgements

The study was financially supported by the National Natural Science Foundation of China (41390463; 31260125), and the National Sci-Tech Basic Program of China (2014FY210100).

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