Ecological Engineering 84 (2015) 92–99

Contents lists available at ScienceDirect

Ecological Engineering

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

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

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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.

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 km^2 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 8.5×10^8 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 CO_2 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.

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http://dx.doi.org/10.1016/j.ecoleng.2015.07.023
0925-8574/

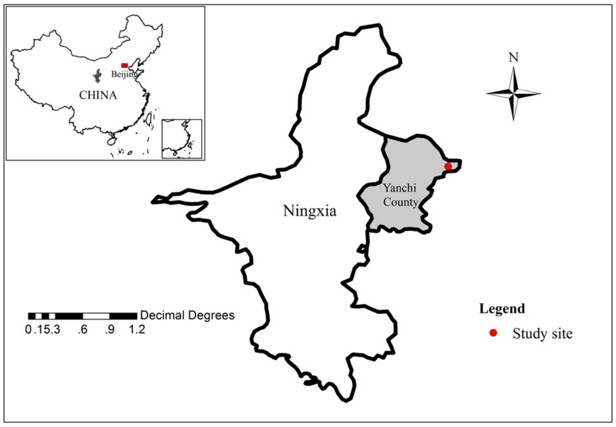

Fig. 1. Location of the study area

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 semi-arid 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°04′–38°10′N and 106°30′–107°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 °C, with the lowest and highest monthly mean temperatures of −8.7 °C in January and 22.4 °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 × 50 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 × 1 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 aboveground 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 °C, and then transferred to the lab where they were oven-dried at 65 °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 augur 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 °C, and then transferred to the lab where they were oven-dried at 65 °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 ± 4.50a	*Lespedeza potaninii, Artemisia scoparia Walds, Pennisetum centrasiaticum*
LD	71.75 ± 2.90a	*Pennisetum centrasiaticum, Sophora alopecuroides*
MD	57.26 ± 7.54b	*Utricularia australis, Corispermum hyssopifolium*
SD	43.74 ± 4.99c	*Agriophyllum squarrosum, Aneurolepidium dasystachys, Setaria viridis*
VSD	6.63 ± 1.64d	*Agriophyllum squarrosum*