Soil & Tillage Research 166 (2017) 1–9

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Response of soil organic carbon and nitrogen stocks to soil erosion and land use types in the Loess hilly–gully region of China

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ARTICLE INFO

Article history:
Received 3 March 2016
Received in revised form 2 October 2016
Accepted 3 October 2016
Available online 7 October 2016

Keywords:
Land use
Loess hilly region
Caesium-137
Soil organic carbon
Total soil nitrogen
Soil erosion

ABSTRACT

Erosion influences the vertical and horizontal distribution patterns of soil and soil organic carbon (SOC) at a landscape scale. To further understand the effect of erosion on SOC and total soil nitrogen (TSN) stocks in relation to land use types after the implementation of the "Grain for Green" program in the Loess hill-gully region, the SOC, TSN, and Caesium-137 (^{137}Cs) contents were analyzed at three selected landscape positions under three land-use types: artificial grassland (AGL), native grassland (NGL) and artificial plantation of *Robinia pseudoacacia* (AFL). The results showed that all land uses experienced considerable net erosion since the mid-1950s, with an average total loss depth of 2.05 cm for AFL, 1.49 cm for AGL, and 0.54 cm for NGL. The SOC stocks in AFL and NGL were 72.3% and 26.2% lower, respectively, than that in AGL in the 0–100 cm soil layer, and significant positive correlation between SOC and TSN stocks on each layer in the soil profile was observed ($R^2 > 0.90$). The result showed that compared with other land-use types, AGL had a greater SOC and TSN sequestration capacity. The contents of SOC and TSN were positively correlated with the amount of ^{137}Cs in AFL and NGL ($R^2 = 0.97$, 0.97 for AFL, respectively, and $R^2 = 0.90$, 0.90 for NGL, respectively; n = 3), whereas no significant correlation was found in AGL ($R^2 = 0.41$, 0.01, respectively; n = 3). The results indicated that AGL was an optimal choice to mitigate soil carbon and nitrogen loss and to increase C and N sequestration in the Loess hilly–gully region. A complex process should be considered for the distribution patterns of SOC and TSN after afforestation since 1999.

1. Introduction

The carbon and nitrogen cycles in terrestrial ecosystems have received increasing attention worldwide over the past decades because of their emission of oxides into the atmosphere that contribute to the acceleration of global climate warming (Fu et al., 2010). Soil, as a major component of the terrestrial ecosystem, plays a vital role in maintaining plant nutrients and mitigating global warming (Post and Kwon, 2000). Soil has the largest soil organic carbon (SOC) stocks in the terrestrial ecosystem, which is about twice as much carbon found in the atmosphere (Lal, 2004) and three times the quantity found in vegetation (Zhang et al., 2013a). The previous studies indicated that the global estimate of soil organic carbon ranged from 684 to 724 Pg (1 Pg = 10^{15} g) of C in the top 0.3 m, 1462 to 1548 Pg of C in the top 1 m, and 2376 to 2456 Pg of C in the top 2 m of soils (Batjes, 1996). Soil contains the third largest global carbon stock and releases approximately 4% of its pool into the atmosphere each year (Li et al., 2014). Furthermore, soils are the largest contributors to N_2O emissions, with 6.0 Tg yr^{-1} (1 Tg = 10^{12} g) from natural soils and 4.2 Tg yr^{-1} from agricultural soils, which would exert significant impacts on the greenhouse gas nitrous oxide (Saikawa et al., 2014). Minor changes in the soil C or N stocks could have great impacts on the atmospheric carbon oxide and nitrous oxide concentrations (Wang

Abbreviations: SOC, soil organic carbon; TSN, total soil nitrogen; DOC, dissolved organic carbon; AGL, artificial grassland; NGL, native grassland; AFL, artificial forestland; C/N ratio, soil organic carbon and total soil nitrogen ratio; BD, bulk density; SWC, soil water content.

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http://dx.doi.org/10.1016/j.still.2016.10.004
0167-1987/

et al., 2014). Therefore, the maintenance of C and N stocks is a key factor in improving soil quality and in mitigating global warming, which would lead to a better facilitation of sustainable environmental restoration and ecological security.

Previous studies indicated that several main factors influenced the SOC and TSN stocks in the soil ecosystem, such as climate (Post et al., 1982), land use (Zhang et al., 2013a; Gelaw et al., 2014), management practices (Lal, 2003; Wang et al., 2014), soil and vegetation types (Fu et al., 2010; Han et al., 2010), soil sampling depth (Deng et al., 2013; Olson and Al-Kaisi, 2015), topographic feature (Yimer et al., 2006), landscape position (Lozano-García and Parras-Alcantara, 2014a,b), and soil erosion (Gregorich et al., 1998; Ma et al., 2016). Although changes in land-use alter SOC and TSN contents at different temporal and spatial scales, soil erosion is not considered in the C or N balance budgets. The overlooking of soil erosion would induce a great underestimation of soil carbon loss after land degradation or land use change, particularly in areas with complex topography (Li et al., 2014). Over the past decades, Gregorich et al. (1998) assessed soil erosion and deposition processes on the distribution and loss of soil C, indicating that soil erosion was the most widespread form of soil degradation. Ritchie et al. (2007) also indicated that erosion and geomorphic position were the two main ways to understand SOC and nutrients dynamics after investigating the relationship between SOC and soil redistribution patterns on an agricultural landscape. However, limited data are available with regard to the relationship of SOC, nutrient dynamics, and soil erosion under different land use types after an ecological vegetation restoration (Wang et al., 2011). Therefore, the changes in soil C, soil N, and soil conditions after the occurrence of soil erosion under different landscape positions should be further studied, especially where the conversion of removal lands from cultivation to afforestation and grassland took place.

The Chinese Loess Plateau, characterized by a mountainous and extremely complex topography (Li et al., 2008), is known for its long agricultural history and serious soil erosion incidents (Wang et al., 2015).The average annual soil loss is 50–100 Mg ha^{-1}, even reaching a peak of 200–300 Mg ha^{-1} in some regions (Liu and Liu, 2010; Sun et al., 2014). Erosion has increasingly endangered the ecological security on the lower reaches of the Yellow River. The program of the Grain for Green Project was comprehensively initiated for soil erosion control and land quality improvement since 1999 by converting sloping croplands to forestlands or grasslands. Although field monitoring and investigations confirmed the reduction of soil and water loss in the semi-arid small catchment of the Loess Plateau (Zheng, 2006; Zhou et al., 2006), the redistribution patterns of SOC and TSN stocks along the hillslope under different land uses has not yet been fully elucidated by water erosion after vegetation restoration. Zhang et al. (2013a) reported on the distribution and storage of C and N in soils under different types of land uses, but the impact of changes in land use on SOC and TSN stocks at different eroding slope positions and depths is still unclear.

Aligned with these data, we hypothesized that in the small watershed of the Loess Plateau: (1) the distribution of SOC and TSN, as well as their stocks are significantly affected by soil erosion and soil depth and (2) a difference in soil organic C and total N sequestration capacities exist among different land use types. To test our hypotheses, we assessed the effect of soil erosion on SOC and TSN in soils from three typical land uses [artificial forestland (AFL), native grassland (NGL), and artificial grassland (AGL)] in the Qiaozi watershed in Gansu Province. The objectives of the study were as follows: (1) evaluate the influence of erosion on SOC and TSN stocks after vegetation restoration and (2) determine the difference of land use types and landscape position on SOC and TSN contents, as well as the dissolved organic carbon (DOC) concentration with respect to soil depth. This study will provide specific implications for sustainable land use management and ecological restoration in the Loess hilly region.

2. Materials and methods

2.1. Study areas

This study was conducted at the Qiaozi East watershed (105° 43′ E, 34° 36′ N), which is located in the southeast part of Gansu Province, China (Fig. 1). The watershed, which belongs to the third sub-region of the hill- and- gully region of the Loess Plateau, is a

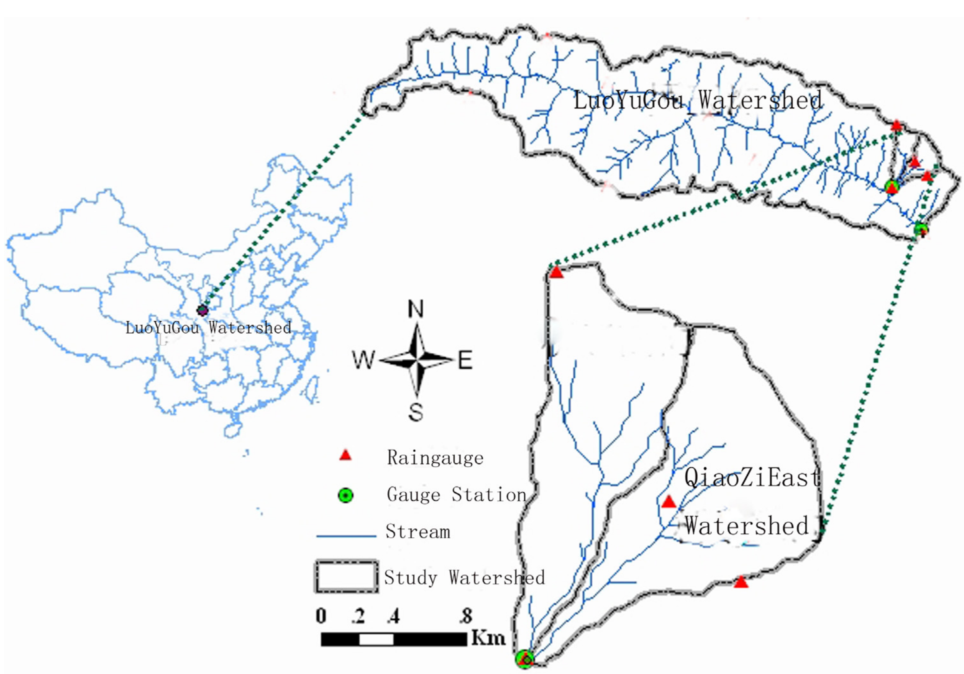

Fig 1. Location of the study catchment.