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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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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

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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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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

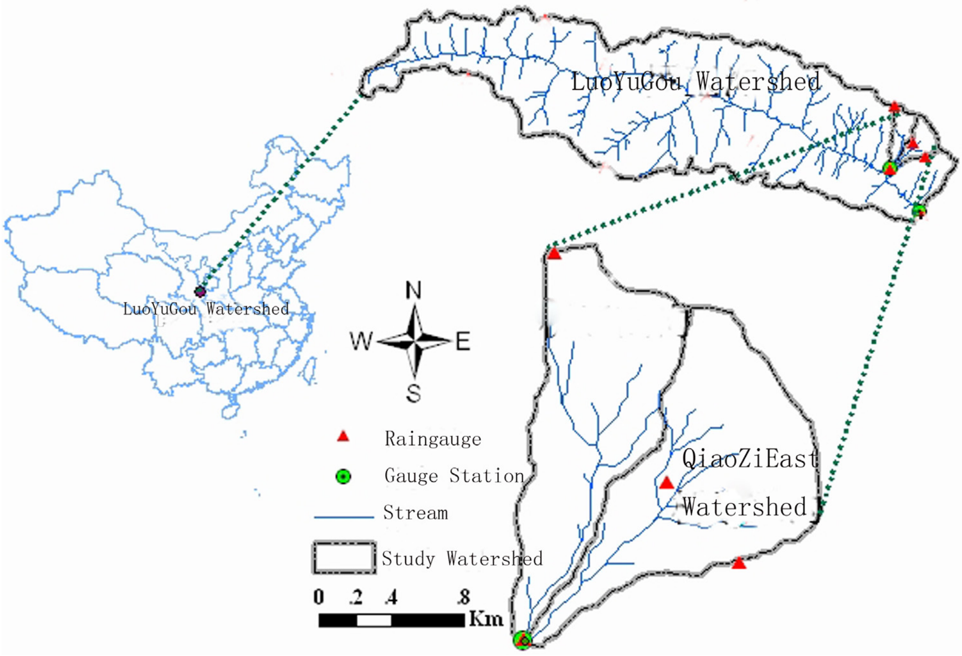

Fig 1. Location of the study catchment.

Table 1
The main geography character in the Qiaozi East watershed.

Watershed	Area (km^2)	Shape	Length (km)	Width (km)	Shape factor	Channel gradient (%)	Relative difference in elevation (m)	Gully density ($km\,km^{-2}$)
Qiaozi East	1.36	Half sallop	2.00	0.68	0.34	8.0	377	5.13

major branch of the Luoyugou watershed. The main geographical characters in the Qiaozi East watershed are shown in Table 1. The area is characterized by a semi-arid climate, with a mean annual temperature of 10.7 °C and an average annual precipitation of 542.5 mm. The rainfall is mainly concentrated from May to September, with large inter-annual and annual variations. According to the U.S. Soil Taxonomy, the most widely distributed soil type is black cinnamonic soil, which accounts for more than 82% of the whole basin area, followed by rhogosol, such as red loess black and brown soil (Zhou et al., 2012). Given the loess in the study areas, the soil has a weak resistance to erosion. The Qiaozi East watershed that is currently managed has a low erosion rate, with an average soil loss of 18.48 $Mg\,ha^{-1}$ in comparison to the Qiaozi West watershed (54.69 $Mg\,ha^{-1}$) (Zhou et al., 2012).

In the studied watershed, cropland was the main land use type prior to the 1950s. Several soil and water control practices were carried out since the 1970s. The control practices mainly included grazing exclusion, constructing check dams, terraces, and vegetation restoration. All croplands with slope greater than 15° were converted to forestland or grassland, whereas parts of gentle slopes were abandoned for vegetation restoration by the natural succession in 1999. At present, a long-term vegetation recovery process exists with only slight disturbances from people and animals in the Qiaozi East watershed. The vegetation coverage of the Qiaozi East watershed was 39.9% compared with that of the Qiaozi West, with only 21.8% vegetation by 2000 (Zhou et al., 2012). To control the loss of soil and soil nutrients efficiently in the loess hilly gully region of the Loess Plateau, three vegetation restoration types were chosen on the hillslope-gully slope in the Qiaozi East watershed, involving the conversion from farmland (*Maize*) to native grassland (*Roegneria kanoji, Pedicularis spp. and Elymusdahuricus*), artificial forestland (*Robinia pseudoacacia* and *Populus davidiana*), and artificial grassland (*Medicago sativa*).

2.2. Experimental design and sampling

Prior to sampling, the land-use history was investigated based on field interviews with local villagers and leaders. Cropland (i.e., planting maize, wheat, potatoes, and rape) was the main land use type before the vegetation restoration since 1985 (Zhou et al., 2012). Three transects with typical land use types in existence for over 15 years were selected from the hillslope of the Qiaozi East watershed, including AGL, AFL, and NGL. Three soil sampling sites were selected with 20 m intervals from the upper-slope position to the lower-slope position under each land use type. The aspects, gradients, and altitudes were recorded in situ at each quadrat using a global positioning system receiver (GPS), with an accuracy of approximately 1 m.

A total of 162 evenly distributed soil samples (6 depths, 3 land uses, and 3 replications) were collected using a 7.0 cm-diameter soil sampler. Soil samples in each land use were taken to determine soil the physico-chemical properties at depths of 0–5, 5–10, 10–20, 20–40, 40–60, and 60–100 cm. Furthermore, nine soil profiles (100 cm) were dug with picks and spades at identical soil layer intervals among land uses, and a total of 108 soil samples were obtained to estimate the soil bulk density using the soil cores (100 cm^3 volume stainless steel tubes), with three replicates in each sampling site. A total of 36 bulk samples were extruded from the core to a 30 cm depth for the determination of ^{137}Cs to the calculate erosion intensity in each sampling point using a 5-cm diameter soil auger with three replications. Among the samples, 18 were collected from each sampling site in three land use types. The remaining samples were obtained to determine the reference values from three flat and undisturbed sites adjacent to the soil sampling sites as close as possible with 5 cm increments to a depth of 30 cm. Weeds and litterfall were cleared before the sampling process.

2.3. Laboratory analysis

Soil samples were analyzed at the State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences. Prior to the laboratory analysis, visible root residues and stones in the soil samples were removed. The samples were air-dried at room temperature, gently ground and passed through a 2-mm sieve to determine soil texture and pH. The samples were then passed through a 0.25-mm mesh to determine SOC and TSN. The soil pH was determined with a soil–water ratio of 1:2.5 using HI 3221 pH meter (Hanna Instruments Inc., USA). The soil bulk density ($Mg\,m^{-3}$) was measured by the volumetric ring method (Carter, 1993). SOC and TSN concentrations were determined using the dichromate oxidation method (Nelson and Sommers, 1982) and the modified Kjeldahl method (Liu et al., 1996). The soil texture was analyzed using the Laser Particle Size Analyzer (Mastersizer 2000, Marlven, Ltd. UK). In addition, DOC was determined following Jones' procedure (Jones and Willett, 2006). Briefly, fresh soil was extracted with 0.5 M K_2SO_4 in the 150 cm^3 Erlenmeyer flasks on a reciprocating shaker at a speed of 250 rpm, with a shaking time of 1 h at a temperature of 20 °C and a soil-to-solution (0.5 M K_2SO_4

Table 2
General physico-chemical properties of different land use types.

Land use types	Bulk density ($Mg\,m^{-3}$)	Soil texture (%)			pH	Soil water content (%)
		Clay	Silt	Sand		
AGL	1.45 ± 0.04	22.71 ± 0.68	69.77 ± 0.62	7.52 ± 0.23	8.24 ± 0.02	17.26 ± 1.41
AFL	1.36 ± 0.04	28.56 ± 2.60	66.75 ± 2.25	4.69 ± 0.40	8.32 ± 0.03	18.95 ± 1.29
NGL	1.30 ± 0.02	22.54 ± 0.60	70.41 ± 0.56	7.04 ± 0.04	8.23 ± 0.16	19.37 ± 0.63

Notes: AGL: Artificial grassland slope; AFL: Artificial grassland slope; NGL: Natural grassland slope. Values are represented as mean ±Standard Deviation (n = 3).

solution) ratio of 1:5 (w/v). After shaking, the extracts were centrifuged at 2500 rpm for 20 min, and the supernatant was filtered through a 0.45 μm filter before the analysis (Ma et al., 2016). The DOC was determined by using a Shimadzu TOC-VCPH (Shimadzu Corp., Kyoto, Japan). The ^{137}Cs content was measured by low background gamma spectrometry using a hyper-pure coaxial germanium detector (GMX50, PerkinElmer) linked to a multi-channel digital analyzer system (Ma et al., 2016). The reference value for ^{137}Cs was presented, and the average of which was 1657.45 Bq m^{-2} in the selected study areas. The general physico-chemical properties under different land use types and slope positions are shown in Table 2.

The SOC and TSN stocks (Mg ha^{-1}) were calculated using the following equations as follows (Chen et al., 2007):

$$\mathrm{TSOC} = \Sigma \mathrm{SOC_i} \times \mathrm{B_i} \times \mathrm{D_i} \times 10^{-1} \tag{1}$$

$$\mathrm{TSN} = \Sigma \mathrm{TN_i} \times \mathrm{B_i} \times \mathrm{D_i} \times 10^{-1} \tag{2}$$

where $\mathrm{SOC_i}$ is the SOC content on the ith layer (g kg^{-1}), $\mathrm{TN_i}$ is the TN content on the ith layer (g kg^{-1}), $\mathrm{B_i}$ is the bulk density of the ith layer (Mg m^{-3}), and $\mathrm{D_i}$ represents the soil depth of the ith layer (m).

2.4. Statistical analyses

All statistical tests were conducted using SPSS version 18.0 (SPSS Inc., Chicago, IL, USA) and Origin 8.5 software for the figure drawings. The soil physico-chemical properties (BD; pH; sand, silt, and clay content; SWC, SOC and TSN contents; C/N ratio and DOC concentration) were treated with the mean ± standard deviation and the coefficient of variation in all of the soil samples. A linear regression analysis was conducted to test the Pearson correlation coefficient (r) between SOC and TSN stocks, soil physico-chemical properties, ^{137}Cs among different land-uses, and landscape positions. Significant differences were evaluated at the 0.05 levels using the least significant differences (LSD).

3. Results

3.1. Vertical distribution of SOC and TSN under different land use types

A large amount of SOC and TSN were centralized in the superficial layer (0–10 cm) over the entire soil profile (Fig. 2a and b). The SOC and TSN contents decreased with soil depth in all land uses, and no significant variation was found in the deeper layer

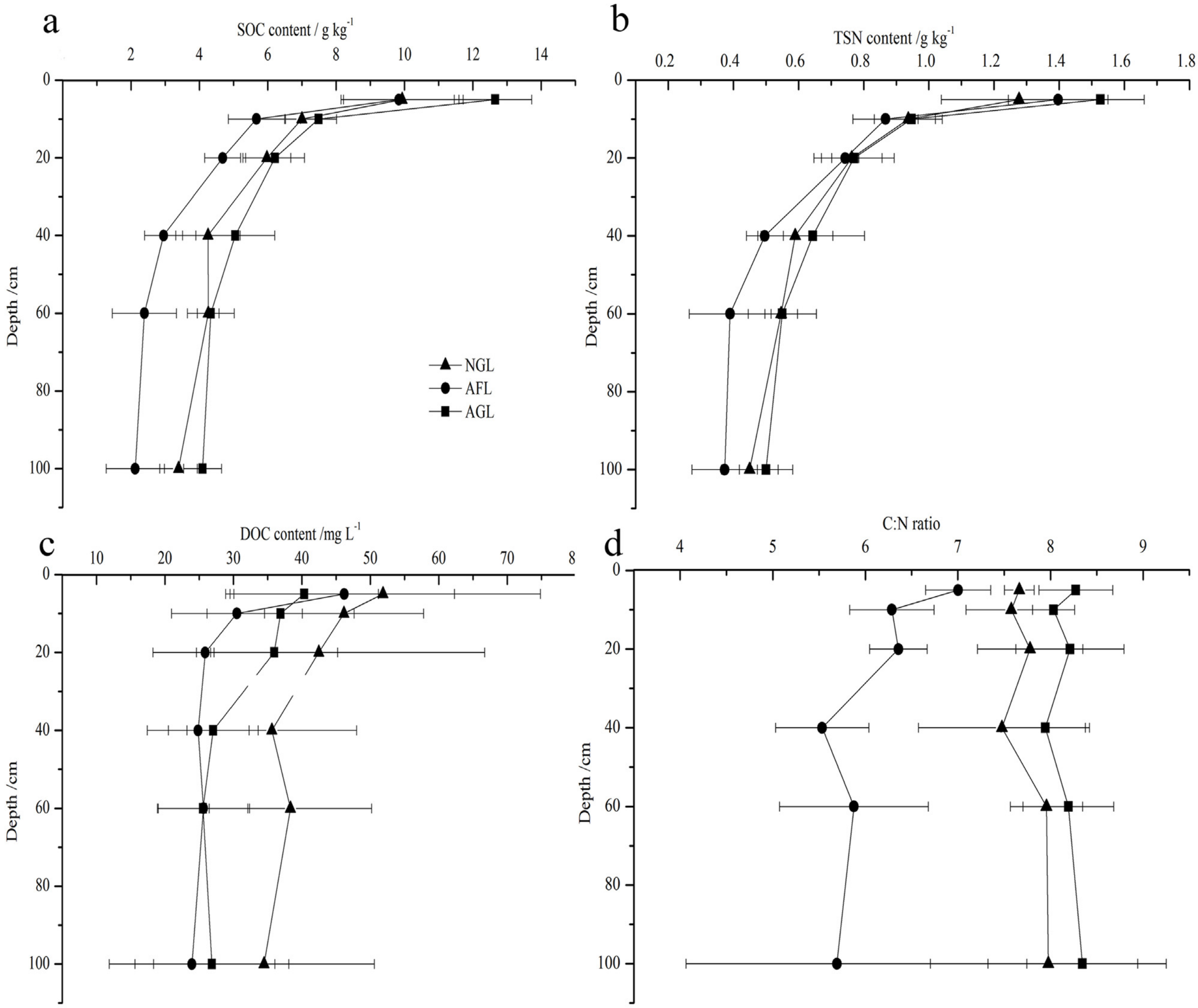

Fig. 2. SOC, TSN and DOC contents along with the C/N ratio at different soil depth intervals under various land use types. The error bars represent the standard deviation of the mean (n = 3).

(40–100 cm). AGL showed a drastic decrease in the 0–10 cm layer, followed by AFL and NGL, whereas the coefficient of variation (CV) of SOC showed the following order in the whole soil profile (0–100 cm): NGL (41.6%) < AGL (48.3%) < AFL (63.1%). The CV of TSN in the soils was similar to SOC under different land uses. The SOC content showed a significant difference among land uses, whereas the TSN content showed a smaller variation compared with SOC. The highest SOC content was observed in AGL (4.13–12.67 g kg^{-1}), followed by NGL (3.37–9.93 g kg^{-1}) and then AFL (2.13–9.83 g kg^{-1}) in the entire soil layer. The variation of the content of TSN followed a trend similar to that of SOC in all land uses except for the topsoil (0–5 cm), which showed a descending order of AGL (1.53 g kg^{-1}) > AFL (1.40 g kg^{-1}) > NGL (1.30 g kg^{-1}). The DOC concentration also showed a decreasing trend as the depths increased in all land uses (Fig. 2**c**). The concentration of DOC in NGL was the highest among the soil profiles (100 cm), followed by AGL and then AFL except for the 0–5 cm layer. The CV yielded for SOC and TSN in the order of NGL (16.1%) < AGL (18.8%) < AFL (26.4%). The C/N ratio in the soils significantly varied with land use types in the soil profile (Fig. 2d). The highest C/N ratio was observed in AGL (8.0–8.4), followed by AFL (7.5–8.0) and then NGL (5.5–7.0). This finding was consistent with the variation of SOC. In the soil profile (0–100 cm), the C/N ratio of AGL and AFL showed an increasing trend with soil depth, whereas NGL showed a reverse change in trend. The smallest significant difference was found for the C/N ratio in AGL, followed by NGL and AFL in the entire soil depth. This distribution pattern indicated that soil C and N were predominantly concentrated in the topsoil layers, and the effect of afforestation and grassing on TSN and SOC primarily occurred at the superficial soil layers rather than at deep depths in the study areas.

3.2. Horizontal distribution of SOC and TSN under different land uses

The distribution patterns of ^{137}Cs, total SOC, TSN, DOC and C/N ratio were analyzed in the 0–20 cm deep soil layer at different slope positions (upper-slope, mid-slope, and lower-slope). The results indicated that SOC and TSN contents significantly varied at different landscape positions and showed a different distribution trends at all slope positions. The lowest SOC and TSN contents were mostly observed in mid-slope positions under different land uses. The higher contents of SOC and TSN were found on the upper-slope position compared with the lower- slope position in AGL and in AFL, whereas its values were higher on the lower-slope position relative to the upper-slope position in NGL (Fig. 3a and b). The DOC concentration also demonstrated different distribution trends from the upper-slope to the lower-slope in all land use types. The trend was in the order of mid-slope > upper-slope > lower-slope in NGL, whereas a reduction trend was exhibited down the slope in AGL and in AFL (Fig. 3c). The C/N ratio showed significantly different values under different slope positions in each of these land uses. A higher C/N ratio was found in the mid-slope position in NGL and AGL, whereas a lower value occurred in the mid-slope

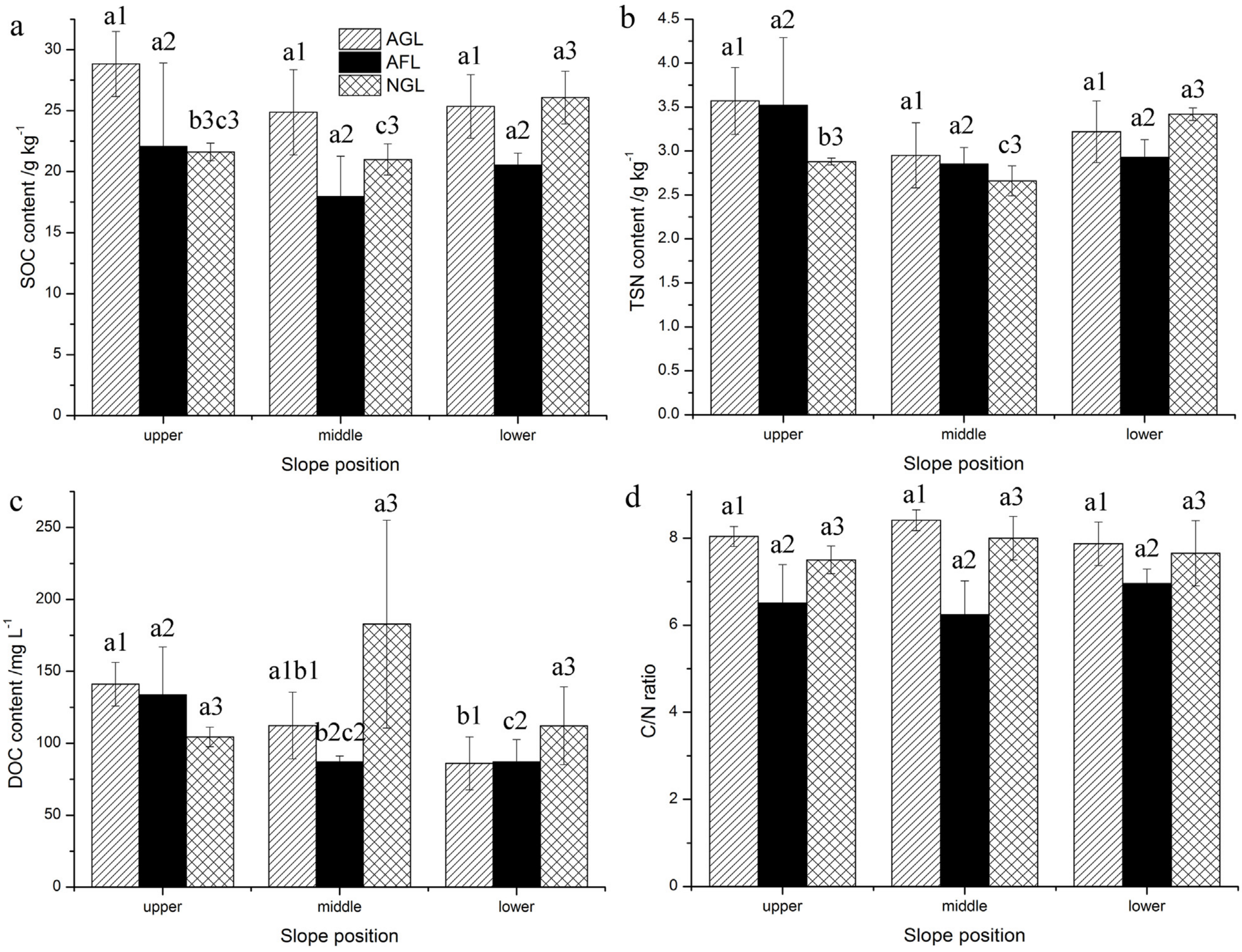

Fig. 3. The SOC, TSN and DOC contents along with C/N ratio at different slope positions under various land use types. The error bars represent the standard deviation of the mean ($n = 3$). Different letters (a, b, and c) indicate significant differences among various slope positions at $P < 0.05$. Different numbers (1, 2, and 3) indicate Artificial grassland, Artificial forestland, and Natural grassland in the watershed, respectively.

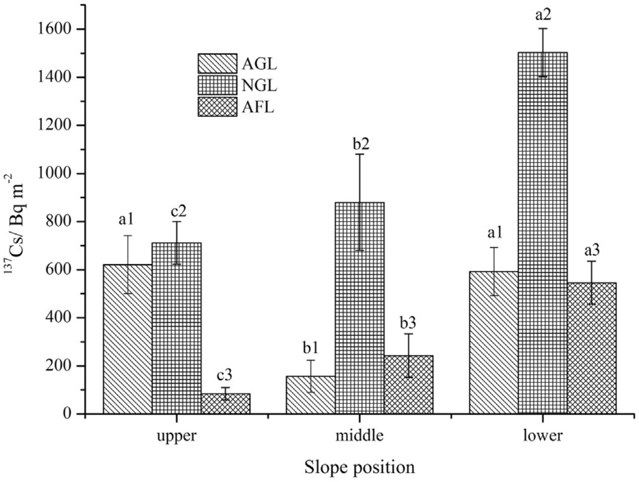

Fig. 4. Characteristics of Cesium-137 concentration at different slope position for the different land use types and at the reference site. The error bars represent the standard deviation of the mean ($n = 3$). Different letters (a, b, c) indicate significant differences among various slope positions at $P < 0.05$. Different numbers (1, 2, 3) indicate Artificial grassland, Artificial forestland, and Natural grassland in the watershed, respectively.

position in AFL (Fig. 3d). The amount of ^{137}Cs of all soil sampling sites was lower than the reference values. It increased in the following order: mid-slope < lower-slope < upper-slope in soils in AGL. This ascending trend was found down the slope in NGL and AFL (Fig. 4). The results indicated that all land uses experienced considerable net erosion since the mid-1950s. The contents of SOC and TSN varied distinctly under each land use at the landscape scale, and landscape positions and soil erosion might be the major influencing factors for the distribution patterns of SOC and TSN.

3.3. SOC and TSN stocks under different land uses and landscape positions

The SOC stocks in identical depth intervals decreased with soil depth under different land uses. The average SOC stocks varied from 13.4 to 24.7 Mg C ha^{-1} in the 20 cm layers and 37.0 to 82.5 Mg C ha^{-1} in the entire layers (100 cm) with respect to land uses (Table 3). The SOC stocks in AGL were significantly highest in all soil layers, followed by those in NGL and AFL. The stocks of SOC in AFL and NGL were 72.3% and 26.2% lower, respectively, than that in AGL in the 0–100 cm soil layer. The result showed that compared with other land-use types, AGL had a greater SOC sequestration capacity when the conversion from farming land to grassland or forestland took place. Slope positions also had a significant effect on the SOC stocks. In the 0–5 cm soil layer, a higher value of SOC stocks was found in the upper-slope relative to that in the mid-slope and lower-slope in AGL and AFL, whereas a lower value in the upper-slope position was seen compared with that on the mid- and lower-slope positions in NGL. The SOC stocks of mid-slope had lower values below the 5 cm soil layer in NGL and AGL. In AFL, the SOC stocks increased from the upper-slope to the lower-slope below the 10 cm soil layer. The average amount of TSN stocks varied from 2.0 to 3.1 Mg N ha^{-1} in the topsoil (0–20 cm) and 6.4 to 10.2 Mg N ha^{-1} in the 100 cm layer with respect to land use types (Table 4). The distribution of TSN stocks had a similar trend to that of SOC stocks along the slope in all land uses. Moreover, a significant positive correlation between SOC and TN stocks in each layer in the soil profile was observed. The result indicated that reestablishing farmland to forest or grassland not only contributed to water and soil conservation but also changed the soil quality and nutrient reserves. AGL was the optimal strategy to improve the soil carbon sequestration capacity in comparison with natural recovery and planted forest (*R. pseudoacacia*) in the slope landscape of this region.

4. Discussion

4.1. Effects of land use types and soil depth on soil organic carbon and total nitrogen stocks

In the present study, the contents of SOC and TSN, as well as their stocks were significantly affected by land use types, which showed significant variation under different land use types. The SOC and TSN contents and stocks in soils under AGL were the highest, followed by NGL and then AFL, in the entire soil profile (0–100 cm). The results were consistent with previous studies (Chen et al., 2007; Fang et al., 2012; Zhang et al., 2013a). The different responses of SOC and TSN stocks to different land use types may be attributed to the difference in the amount and forms of organic material added to soils in different vegetation types, as well as the higher loess of SOC and soil nutrients, when the conversion from farming land to forestland and abandoned land took place (Wei et al., 2009). Additionally, different soil properties of different land use types in surface soil may affect SOC and TSN (Table 2; Jafarian and Kavian, 2013). Moreover, fine root systems might play an important role in the accumulation and distribution of SOC in different depths (Chang et al., 2012; Wang et al., 2015), and the fine root biomass showed a significantly positive relationship with SOC in deeper soil. A greater fine root system in soils under pasture was found than those under plantation forest during the sampling process in the present study. Thus, the input of root biomass may be considered as the major contributor to organic matter and nutrients in grassland (Guo et al., 2007; Guo and Gifford, 2002).

A significant negative relationship was found between the decomposition rate of organic matter and the C/N ratio (Vivanco

Table 3
Soil organic carbon stocks (Mg C ha^{-1}) at different soil depths and hillslope positions for the different land use types.

Depth (cm)	AGL			AFL			NGL		
	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower
0–5	9.78 ± 1.46	7.94 ± 1.70	7.85 ± 1.81	7.00 ± 2.32	5.20 ± 1.40	5.41 ± 0.42	4.83 ± 0.29	5.10 ± 0.43	6.10 ± 0.93
5–10	5.60 ± 0.42	4.77 ± 0.18	4.94 ± 0.39	3.42 ± 1.10	2.81 ± 0.73	3.73 ± 0.17	4.26 ± 0.18	3.75 ± 0.14	4.57 ± 0.16
10–20	9.32 ± 0.04	7.56 ± 0.96	9.31 ± 0.54	5.01 ± 1.21	5.44 ± 0.35	6.53 ± 0.46	7.65 ± 0.45	6.37 ± 0.42	9.22 ± 1.05
20–40	16.52 ± 1.14	11.53 ± 0.12	15.62 ± 0.96	7.93 ± 3.34	8.39 ± 0.75	9.03 ± 0.60	11.85 ± 0.68	9.57 ± 2.17	13.59 ± 0.28
40–60	14.61 ± 0.86	11.41 ± 0.20	13.21 ± 0.33	5.12 ± 1.25	6.82 ± 1.02	9.82 ± 0.75	12.23 ± 0.46	11.90 ± 4.52	12.28 ± 0.46
60–100	26.66 ± 0.72	23.59 ± 2.52	27.80 ± 1.28	8.59 ± 1.45	13.78 ± 2.11	18.56 ± 0.65	21.77 ± 0.05	16.71 ± 1.33	18.79 ± 1.80
Total	82.48 ± 2.63	66.80 ± 3.25	17.82 ± 2.02	37.07 ± 7.01	42.44 ± 4.14	53.07 ± 1.01	62.59 ± 0.13	53.40 ± 8.80	64.57 ± 1.39
Mean	13.75 ± 7.44	11.13 ± 6.61	13.12 ± 8.14	6.18 ± 1.98	7.07 ± 3.77	8.84 ± 5.27	10.43 ± 6.50	8.90 ± 4.86	10.76 ± 5.24

Notes: AGL: Artificial grassland slope; AFL: Artificial grassland slope; NGL: Natural grassland slope. Values are represented as mean ± Standard Deviation ($n = 3$).

Table 4
Total nitrogen stocks (Mg N ha^{-1}) at different soil depths and hillslope positions for the different land use types.

Depth (cm)	AGL			AFL			NGL		
	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower
0–5	1.19 ± 0.20	0.93 ± 0.17	0.97 ± 0.19	0.94 ± 0.27	0.81 ± 0.07	0.75 ± 0.07	0.62 ± 0.01	0.65 ± 0.01	0.77 ± 0.06
5–10	0.71 ± 0.06	0.57 ± 0.02	0.65 ± 0.12	0.53 ± 0.10	0.46 ± 0.07	0.53 ± 0.03	0.58 ± 0.02	0.48 ± 0.05	0.60 ± 0.00
10–20	1.16 ± 0.03	0.90 ± 0.12	1.18 ± 0.11	0.85 ± 0.17	0.86 ± 0.03	0.99 ± 0.08	1.03 ± 0.02	0.78 ± 0.09	1.17 ± 0.15
20–40	2.12 ± 0.14	1.42 ± 0.03	2.00 ± 0.11	1.50 ± 0.43	1.38 ± 0.11	1.42 ± 0.10	1.56 ± 0.13	1.43 ± 0.47	1.87 ± 0.32
40–60	1.92 ± 0.12	1.37 ± 0.02	1.68 ± 0.08	0.88 ± 0.03	1.19 ± 0.19	1.50 ± 0.04	1.56 ± 0.21	1.51 ± 0.63	1.60 ± 0.20
60–100	3.14 ± 0.18	2.87 ± 0.35	3.52 ± 0.34	1.74 ± 0.33	2.70 ± 0.18	2.79 ± 0.25	2.86 ± 0.18	2.05 ± 0.07	2.70 ± 0.50
Total	10.24 ± 0.33	8.07 ± 0.45	10.01 ± 0.54	6.44 ± 0.60	7.40 ± 0.33	7.97 ± 0.43	8.22 ± 0.50	6.91 ± 1.12	8.70 ± 1.08
Mean	1.71 ± 0.88	1.34 ± 0.81	1.67 ± 1.03	1.07 ± 0.45	1.23 ± 0.79	1.33 ± 0.81	1.37 ± 0.86	1.15 ± 0.61	1.45 ± 0.78

Notes: AGL: Artificial grassland slope; AFL: Artificial grassland slope; NGL: Natural grassland slope. Values are represented as mean ±Standard Deviation (n = 3).

and Austin, 2006). A higher C/N ratio in artificial grass showed a lower decomposition rate of organic matter in the present region, making it an additional factor for maintaining more SOC and TSN in artificial grass. The results were in agreement with previous studies conducted either in the loess plateau or in other regions of the world (Jackson et al., 2002; Farley et al., 2004; Wei et al., 2009), indicating the conversion of native grass to forests would result in significant reductions of SOC and TSN in the surface soil layer in the studied regions. However, the results were inconsistent with many previous studies that demonstrated that afforestation and natural grassland contributed to increases of SOC and TSN in loess hilly regions (Guo and Gifford, 2002; Chang et al., 2012; Zhang et al., 2013a; Wang et al., 2015). The discrepancy of the results in the present study may be attributed to the combinations of low temperatures, little precipitation and large soil degradation in the study areas, where the climate and soil conditions go against the growth of forests, resulting in the reduction of litterfall or residue inputted into the soil (Wei et al., 2009).

The vertical distribution patterns of SOC and TSN stocks showed a similar trend in all land uses, which showed an exponential decline with respect to soil depth. It was in agreement with results by Fu et al. (2010) who observed a diminishing trend in SOC and TSN contents across depths in the loess plateau. Recently, Wang et al. (2016b) also reported a negative correlation between SOC and TSN stocks and soil depth in a hilly ecological restoration area of North China. However, the change of SOC and TSN stocks with depth was unusual in agro-forestry and some complex agricultural areas. For instance, Gelaw et al. (2014) observed a different trend in SOC and TSN concentrations with depth in the dry cropland in a semi-arid watershed in Tigray, Northern Ethiopia, Africa. This difference may be attributed to the mixing effects of tillage.

The amount of SOC and TSN was mainly concentrated in the superficial soil layer (0–10 cm) in all types of land uses, indicating that the risks of large amounts of SOC and TSN may be mineralized and transported from the surface soil by water erosion process, thereby increasing atmospheric CO_2. It was estimated that approximately 28 Pg of topsoil laterally redistributes per year due to water erosion, leading to approximately 0.5 Pg yr^{-1} of soil carbon being mobilized globally (Zhang et al., 2013b; Ma et al., 2016). This result was comparable to the results of other mountainous regions of the Loess Plateau (Chen et al., 2007; Wei et al., 2009; Fu et al., 2010). The high litterfall and residue inputs in the surface soil may contribute to the increased SOC and TSN contents (Wu et al., 2004; Zhang et al., 2013b). Plant residue inputs decreased and nutrients were absorbed by the root system from the soil for photosynthesis at increasing depths (Zhang et al., 2013a). The fine root systems were mainly centralized in the 0–20 cm soil layer, and none were found in deeper soil layers among land uses. The distribution pattern of fine root mass may be an additional factor to the vertical distributions of SOC and TSN.

4.2. Effect of soil erosion and landscape position on soil organic carbon and total nitrogen stocks

The use of the ^{137}Cs technique at all soil sampling sites suggested that all land uses experienced substantial net erosion since the mid-1950s. The maximum erosion intensity was observed at AFL, with an average loss depth of 2.05 cm, whereas the minimum erosion rate was found at NGL, with an average loss depth of 0.54 cm. The highest and lowest SOC and TSN contents as well as their stocks were found in AGL and AFL. These results were in agreement with results by Ma et al. (2016) who found that the afforestation systems experienced appreciable net erosion, while different tree species had distinct influences on the water erosion intensity and SOC and TSN stocks in a planted forest catchment. The observed difference in the erosion intensity in all land uses may be attributed to the canopy density, floor covers, and easily fragmented leaves (Teramage et al., 2013; Ma et al., 2016). The erosion intensity mainly depends on the energy, size and velocity of raindrops, and the raindrops being intercepted by the canopy and floor covers would reduce the erosive power to splash the surface soils through changing the size of raindrops (Hartanto et al., 2003). The AFL had a lower canopy density and floor covers than those of AGL and NGL, which led to more bare soil surface, causing greater discharge and soil loss. Sediment-associated SOC, rather than runoff, played a major role in determining the total amount of SOC loss by water erosion (Zhang et al., 2013b). In this study, our results also indicated that the losses of SOC and TSN were due to soil loss by soil erosion in all land uses at the slope scale. Consequently, the forest floor covers were bare and the forest canopy density was low compared with grasses so that accelerated intensive soil erosion reduced the SOC and TSN stocks in AFL in the studied region.

Moreover, mechanical site preparation, as an important procedure before afforestation to favor the survival and growth of planted trees, may also be another possible reason for soil C stocks reduction (Wang et al., 2016a). Given that mechanical disturbance could disrupt the soil structure, modify the microclimate and enhance aeration (La Scala et al., 2005; Mataix-Solera et al., 2011), it would also accelerate soil erosion and soil C loss in widespread steep slopes (Black and Harden, 1995; Guo et al., 2010).

Landscape position showed a strong relation to SOC and TSN in mountainous topographies (Li et al., 2015). In the current study, the distributions of SOC and TSN contents and stocks from AFL and AGL were relatively uniform along the hillslope compared with the accumulation trend at the lower position for NGL. The lowest SOC and TSN contents were mostly observed in the mid-slope position under different land uses. It was comparable to the results of Li et al. (2015) who concluded that upper-slope > lower-slope > mid-slope in artificial vegetation on steep slopes in the red hilly region. Polyakov and Lal (2004) found that SOC followed the order lower-slope > upper-slope > mid-slope at forestland stands. However, the results in the current study were inconsistent with those of Wei and Wang (2008), who reported that the amount of SOC and ^{137}Cs increases along the down-slope transect and showed a significantly linear correlation on the control plot and on the treatment plot. The discrepancies in the studied results might be attributed to the multi-influencing factors, except for soil erosion, such as landscape position, micro-topographical climate, soil conditions, plants types on the slope land, tillage and human activities (Mabit et al., 2008).

Soil loss was greatest in lowest levels of labile fractions of organic matter at the mid-slope position and soil deposition occurred with the highest levels of SOC at the lowest slope position (Gregorich et al., 1998; Cambardella et al., 2004). The accumulation of SOC at the lower position in NGL was likely caused by soil erosion and sediment deposition because erosion led to the redistribution of labile organic carbon in the surface soil over the landscape (Lal, 2003). In our studies, a higher concentration of DOC was also found in the lower-slope under each land use type (Fig. 3c). 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; $n = 3$). Soil redistribution caused by soil erosion might be responsible for the differences (Zhang et al., 2013b; Li et al., 2015). Consequently, the effects of soil erosion and landscape position on SOC and TSN still need further research to better assess the SOC and soil nutrient loss during the vegetation restoration process in the hill and gully regions of Loess Plateau.

5. Conclusions

The comparison of the amount of ^{137}Cs of all soil sampling sites indicated that the studied land use types experienced considerable net erosion over the period since the commencement of ^{137}Cs fallout in the mid-1950s. The maximum erosion intensity was observed in AFL compared with that in AGL and NGL. The magnitude of SOC and TSN generally decreased with an increase in depth, and most of the SOC and TSN contents were centralized in the superficial layer (0–10 cm) in AGL, AFL, and NGL, indicating the risks of large amounts of SOC and TSN to be mineralized and transported from the surface soil by erosion process. The SOC and TSN stocks in AGL were significantly highest in all soil layers, followed by those in AFL and NGL, indicating that compared with other land-use types, AGL had a greater SOC sequestration capacity when the conversion from farming land to grassland or forestland took place. Furthermore, soils in the mid-slope had the lower average values of SOC and TSN stocks over the entire soil layer than those in the upper- and lower-slope in all land uses. Nevertheless, the amount of ^{137}Cs increased in the following order: mid-slope < lower-slope < upper-slope in soils in AGL and upper-slope < mid-slope < lower-slope in NGL and AFL. The results indicated that land-use types and landscape positions had great effects on SOC and TSN stocks and AGL is the optimal choice to increase carbon and nutrients sequestration and mitigate soil carbon and nitrogen loss in the Loess hilly–gully region. Moreover, the net effect of erosion on SOC and nutrients dynamics in deep soils remains an open scientific problem, and further studies should be made by long-term monitoring and field sampling at the hillslope scale.

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