Catena 119 (2014) 28–35

Contents lists available at ScienceDirect

Catena

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

The response of soil organic carbon and nitrogen 10 years after returning cultivated alpine steppe to grassland by abandonment or reseeding

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ARTICLE INFO

Article history:
Received 10 January 2014
Received in revised form 1 March 2014
Accepted 8 March 2014
Available online 1 April 2014

Keywords:
Alpine steppe
Returning of cropland back to grassland
Reseeding
Abandonment
Carbon and nitrogen
Restoration

ABSTRACT

The effects on the status of carbon and nitrogen in alpine steppe soils from returning cultivated land back to grassland is not well known. The present study reported on the effects on the soil carbon and nitrogen status of alpine steppe soils from two restoration methods, reseeding grasses and abandonment. The study based on four study sites selected within the same broad area on the north slope of Qilian Mountain: native alpine steppe, cropland of 40 years, former oat cropland reseeded with the grass (*Elymus sibiricus*) 10 years ago, and cropland abandoned 10 years ago. This experiment measured the soil physical, carbon and nitrogen properties of all selected plots. Ten years after restoration by reseeding or abandonment had resulted in the return of cropland to a perennial grass community through succession, with total soil carbon and nitrogen returning to more than 70% of the original grassland plots. The reseeding method benefited soil carbon and nitrogen more than abandonment after 10 years. The light fraction organic carbon, microbial biomass carbon and microbial biomass nitrogen recovered more quickly than soil organic carbon and total soil nitrogen. In conclusion, we recommend the two methods (reseeding and abandonment) as suitable methods to engineer the returning of cultivated land back to grassland in the alpine steppe.

1. Introduction

Land use is important in determining both carbon sink and carbon emissions in natural ecosystems (Contant et al., 2001; Hoffmann et al., 2008; Rees et al., 2005; Wang et al., 2011). Associated with land use change, the potential for carbon sequestration in soil has been a topic of intense study over the last 20 years (Don et al., 2011; Fornara et al., 2011; He et al., 2008; Smith et al., 2001). Over the last century, cultivation has released a large quantity of carbon and nitrogen from soil (Baker et al., 2007; Luo et al., 2010; West and Post, 2002). Reducing or ceasing tillage can improve carbon storage of soil (Hill et al., 2003; Post and Kwon, 2000; Smith et al., 1998; Wang et al., 2011).

In China over the last 60 years a large area of native grassland (about 8×10^6 ha) had been cultivated to grow grain (Li et al., 2012; Xu and Li, 2003). Although this had increased grain production, it had led to losses of soil water, carbon, biodiversity and other ecological functions (Li et al., 2012; Xu and Li, 2003). In response, from 2000 the central government adopted the policy of 'returning cultivated land back to grassland' (or returning cropland to grassland) to restore grassland to a former state of natural grassland (Li, 2001). However, the effects of conversion of cultivated land to grassland on carbon sequestration need to be more accurately assessed (Qiu et al., 2012; Shi et al., 2010; Su, 2007; Su et al., 2009), which requires more data.

There were two main approaches for engineering the returning of cultivated land back to grassland in rangeland areas of China: abandonment of cropland; and ceasing cropping and reseeding with local forage species (Han et al., 2005; Li et al., 2009). The two restoration mechanisms, abandonment and reseeding, have different effects on vegetation and soil. The outcomes from the former occur through natural succession, while from the latter, through designed community composition (Bakker and van Diggelen, 2006; Gibson, 2009; Nelson et al., 2008). The different approaches produce different restoration results and rates in different flora communities, climates, soil textures, nutrition and altitudes (Breuer et al., 2006; Su, 2007; Su et al., 2009; Wu et al., 2010; Zhang et al., 2007).

Many evaluations of the returning of cultivated land to grassland in China have focused on low altitude rangeland areas (He et al., 2008, 2009; Li et al., 2012; Wang et al., 2011, 2012), with few studies in the alpine steppe (Li et al., 2009). Alpine steppe is the main grassland vegetation type in China, especially in high mountain areas (Miehe et al., 2011), and over the last 50 years has suffered more cultivation than other grasslands in mountainous areas (Li et al., 2009; Squires and Yang, 2009). To better understand the effects of the project of 'returning cultivated land back to grassland' in the alpine steppe, this study

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http://dx.doi.org/10.1016/j.catena.2014.03.006
0341-8162/

investigated soil characteristics after 10 years of abandonment or reseeding of grasses, and compared these with data from natural alpine steppe and croplands. We collected data on: 1) basic vegetation and soil property changes, and 2) the variation of soil carbon and nitrogen.

2. Materials and methods

2.1. Study site description

The study site was situated in Hongwan village, Dahe township, Sunan County of Gansu province (N: 38°57′, E: 99°30′), on the north slope of Qilian Mountain at the headwaters of the Heihe river (Fig. 1). The study site has an altitude of 2722 m above sea level. The average annual temperature was 0–3 °C and average temperatures of the hottest and coldest months were 12 to 15 °C and −11 to −13 °C, respectively, average annual precipitation was 150–300 mm (from June to September), and annual evaporation range was 1500–1800 mm. The relative humidity was 65%, there were 2200 h of sunshine annually and the relatively frost-free period ranged from 80 to 110 days. Soils were classified as alpine steppe soils (Cold calcic soils) (National soil survey office, 1995) similar to the USDA classification of frigid Calcic Haploxerolls soil. Native vegetation was mainly alpine steppe with dominant species of *Stipa capillata*, *Elymus nutans*, *Aneurolepidium dasystachys* and *Potentilla acaulis* (Office of Gansu Soil Census, 1993).

For about 50 years, much of the grassland area has been ploughed for grain production. Farmers mainly planted spring wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), oats (*Avena sativa*), canola (*Brassica campestris*) and vegetable peas (*Pisum sativum*), without regular crop rotations (Shi et al., 2010). Grain yields varied from 3000 to 3750 kg ha^{-1} for wheat, oats and barley, from 1500 to 2250 kg ha^{-1} for vegetable peas, and from 750 to 2250 kg ha^{-1} for canola (Li et al., 2009). Most common fertilizers used were urea, ammonium sulfate and diammonium phosphate, and fertilizing quantity dependant on the rainfall and the farmers' financial state. The two methods used to return the cropland to grassland were reseeding of grasses (such as *Elymus* spp.) to establish perennial grassland quickly, or simply abandonment of cropping to allow gradual restoration of the grassland.

To assess recovery of soil carbon and nitrogen by the two restoration methods, one study area was selected which included the two methods (abandonment and reseeding) and for comparative analysis against the same background conditions (alpine steppe), cropland and native grassland. Four adjacent study sites were selected within the study area (Fig. 1) according to their flora, topography and soil type prior to cultivation (Table 1), with details obtained through interviews with local elder farmers. The four study sites were native alpine steppe (SL), cropland of 40 years duration (CL40), reseeded grasses (*Elymus* spp.) of 10 year duration on former oat cropland (RL10), and abandoned oat cropland of 10 years (AL10). Vegetation investigations of the four study sites involved listing dominant species composition (Table 1).

2.2. Sampling and analysis methods

In the local plant peak growth season (August), at each study site, we selected a 1 ha area for soil sampling and for the three pseudo-replicated round plots (area of each was about 300 m^2). True replication was not possible in this study due to a lack of similar land use transitions in the study area. In order to avoid any edge effects all plots were located about 20 m from the boundary of each site (Fig. 1). We used the soil core method to take random soil samples in each plot i.e. 15–20 soil cores, diameter 3.5 cm, in three layers: 0–10 cm; 10–20 cm; and 20–30 cm. These depths were selected as root biomass is generally restricted to a 30 cm soil depth, with a consistent pattern of declining biomass from the top to the bottom layer and 10 cm is the common soil carbon field sampling depth in grasslands in the Qilian mountain area (Li et al., 2009). Before removing any soil cores the surface herbage was removed by cutting. Soil cores (fresh weight about 1 kg) from each soil layer in each plot were mixed, so that each study site had nine soil samples (3×3). All soil samples were stored in a refrigerator in the laboratory below 4 °C. Samples of soil bulk density were taken from each soil layer using the steel cutting ring method (volume 100 cm^3; inner diameter 5 cm). Bulk density samples were put into plastic bags and taken back to the laboratory.

In the laboratory, all soil samples were sieved through 2 mm mesh and roots and coarse plant debris (plant litter) were discarded. Each soil sample was then divided into two subsamples. One subsample was kept at field-moisture (4 °C) for the determination of microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) contents. The other subsample was used to measure pH, soil water content (SWC), electrical conductivity (EC), soil organic carbon (SOC), light fraction organic carbon (LFOC), total nitrogen (TN) and available nitrogen

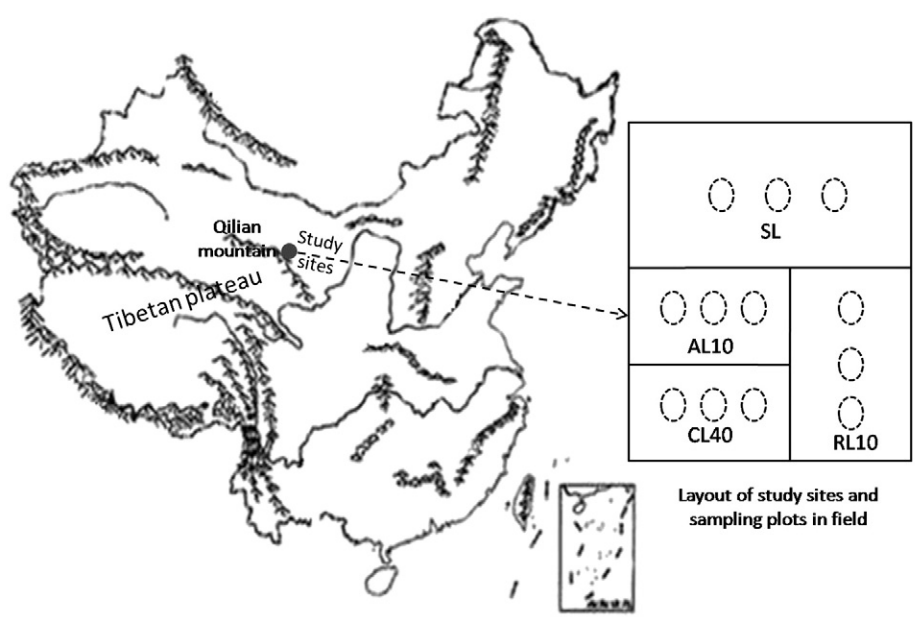

Fig. 1. Location of study sites in China with their layout displayed and that of the sampling plots (dotted circles). SL — native alpine steppe, CL40 — cropland of 40 years, RL10 — grassland reseeded with *Elymus sibiricus* 10 years ago on former oat cropland, and AL10 — abandoned cropland of 10 years.

Table 1
Basic description and community species composition at the four study sites.

Study sites name (Abb.)	Basic description	Dominant species
Native alpine steppe (SL)	Typical alpine steppe community Fenced in recent years, under grassland protection engineering, to exclude grazing. Vegetation cover was 92%. The site had a slope of 3–5° and the soil was typical alpine steppe soil.	*Stipa* spp., *Poa* spp., *Aneurolepidium dasystachys*, *Potentilla acaulis*, *Agropyron cristatum*, *Carex* spp., *Oxytropis kansuensis*, *Aster* spp., *Artemisia frigid*, *Stellera chamaejasme*.
Cropland of 40 years (CL40)	According to elder farmers, it was native steppe 40 years ago and ploughed for grain production every year since. Vegetation cover was 95%, mostly by oats at sampling time. The site was located in the south, adjacent to SL and on a flat area.	*Avena sativa*, *Elsholtzia* spp., *Pedicularis kansuensis*, *Daucus carota*.
Reseeding grasses of *Elymus sibiricus* of 10 years on former oat cropland (RL10)	Ten years ago the site which was cropped annually for oat or wheat production (as CL40), was reseeded with the perennial grass (*Elymus sibiricus*) to recover the native grassland. Vegetation cover was 97%. The site was located in a flat area adjacent to CL40.	*Stipa* spp., *Aneurolepidium dasystachys*, *Poa* spp., *Artemisia frigid*, *Aster* spp., *Daucus carota*, *Potentilla acaulis*, *Elymus* spp., *Pedicularis kansuensis*.
Abandoned cropland of 10 years (AL10)	Same as RL10, this site was cropland ten years ago and was abandoned to recover native grassland. Vegetation cover was 91% and, the site was located in flat are, adjacent to RL10.	*Stipa* spp., *Aneurolepidium dasystachys*, *Artemisia frigid*, *Daucus carota*, *Pedicularis kansuensis*, *Aster* spp.

Note: flora species were identified according to Liu (1996, 1997, 1999a, b).

(AN). Bulk density (Bd) was determined by the weight of the soil per unit volume (g cm^{-3}) using bulk density samples oven dried at 105 °C for 48 h (Bao, 2000). Soil water content (SWC), pH and EC were determined by the methods of Bao (2000). Soil MBC and MBN were measured using the fumigation extraction method (Roscoe and Buurman, 2003; Wu et al., 1990). Soil organic carbon (SOC) was measured by the Walkley and Black dichromate oxidation method (Nelson and Sommers, 1982), LFOC was determined according to Janzen et al. (1992) and Roscoe and Buurman (2003), total nitrogen (TN) and AN were measured by the Kjeldahl method (Bao, 2000). To measure plant cover, we used the methodology of Ren (1998) in five 0.25 m^2 (0.5 m × 0.5 m) quadrats with 5 cm × 5 cm mesh randomly distributed in each plot.

2.3. Data analysis

Carbon and nitrogen (%) levels in the plots were calculated as carbon or nitrogen storage (t ha^{-1}) in each layer, using the equation:

$$S\left(\mathrm{t\ ha}^{-1}\right) = C_i \times \mathrm{Bd} \times T$$

where S is the storage of carbon or nitrogen, C_i is the concentration (%) of SOC, LFOC, TN, AN, MBC and MBN, Bd is the bulk density (g cm^{-3}) of each soil layer and T is one soil layer thickness (10 cm). Soil organic carbon (SOC), LFOC, TN, MBC and MBN storage of the 0–30 cm soil layer were calculated as:

$$T_{(0\text{–}30\ \mathrm{cm})} = S_{(0\text{–}10\ \mathrm{cm})} + S_{(10\text{–}20\ \mathrm{cm})} + S_{(20\text{–}30\ \mathrm{cm})}.$$

The ratio of carbon and nitrogen (C:N), LFOC/SOC, MBC/SOC and MBN/TN were calculated to evaluate the effect of land use change on soil properties. The normality and homogeneity of variances of the data were verified by using Kolmogorov–Smirnov and Levene tests, respectively (He et al., 2011). We used one-way ANOVAs (with LSD method for multiple comparisons) in the DPS software (Tang and Feng, 2002) to evaluate significant differences of soil properties among the four land use types. Partial correlation coefficients were calculated to test correlation among all soil properties in this study.

3. Results

3.1. General soil property variation

After 10 years, restoration of former cropland through reseeding or abandonment has resulted in a herbaceous community (Table 1). At the sampling time, the soil water content of RL10 was significantly higher at all soil depths than at the other three sites ($p < 0.05$) (Table 2). Electrical conductivity (EC) of CL40 was higher than that at the other sites (SL, RL10 and AL 10) (Table 2). In the two top soil layers (0–10 cm and 10–20 cm), the pH of SL was significantly lower than that at the other sites, but in the 20–30 cm layer, the pH of CL10 was significantly lower ($p < 0.05$) (Table 2). Soil bulk density values of RL10 at all depths were significantly smaller at all sites ($p < 0.05$), and CL40 had the largest Bd values (Table 2). At all sites, deeper soil layers had less soil water and higher bulk density than top soil layers (Table 2). Long-term cultivation (CL40) of grassland increased the soil bulk density, and restoration approaches (RL10, AL10) decreased it significantly when compared with native grassland (SL) ($p < 0.05$) (Table 2).

3.2. Variation of soil carbon and nitrogen

For each soil layer, the soil organic carbon (SOC) of the four sites was significantly different ($p < 0.05$) (Fig. 2). The natural steppe site (SL) has the most SOC storage at each soil layer and across the aggregated soil layers (0–30 cm) (Fig. 2). The variation of LFOC (Fig. 3) storage among the four sites in different soil layers was similar to that of SOC (Fig. 2). MBC storage among the four sites in each soil layer was significantly different ($p < 0.05$) (Fig. 4). MBC was highest for SL and lowest for CL40, the difference being significant ($p < 0.05$) (Fig. 4). The variation of TN (Fig. 5) storage among the four sites in different soil layers was similar to SOC (Fig. 2). The AN of SL was greatest in each soil layer, significantly at 20–30 cm and 0–30 cm ($p < 0.05$) (Fig. 6). At 0–10 cm, there were no significant differences of AN in sites of CL40. There were no significant differences of AN between RL10 and AL10 (Fig. 6). The MBN of SL was highest of the four sites at each soil layer (Fig. 7), but was not significantly different from RL10 at 0–10 cm and 10–20 cm (Fig. 7). At 0–10 cm, there were no significant differences in MBN in CL40, SL10 and AL10 (Fig. 6). MBN of CL40 was lowest, the difference being significant at 10–20 cm and 0–30 cm ($p < 0.05$) (Fig. 7). MBN were not significantly different between SL10 and AL10 at all soil layers (Fig. 7).

3.3. Ecological stoichiometry of carbon and nitrogen

The value of C:N in the 0–10 cm soil layer in RL10 was significantly lower than that in the other three sites (SL, CL40 and AL10) ($p < 0.05$), but that of C:N in 10–20 cm and 20–30 cm in RL10 was higher than that at other sites (SL, CL40 and AL10) (Table 3). There were no significant differences of C:N among SL, CL40 and AL10 (Table 3), or among all four sites in the 20–30 cm soil layer (Table 3). The values of LFOC/SOC in CL40, RL10 and AL10 were significantly higher than those of the reference study site (SL) ($p < 0.05$) for the 0–10 cm soil layer (Table 3). However, for the 10–20 cm and 20–30 cm soil layers, LFOC/SOC of CL40 was lowest among the four sites (Table 3). The value of MBC/SOC in SL was lowest among the four sites for all three soil layers (Table 3). For the 0–10 cm soil layer, the lowest value of MBN/TN was

Table 2
Soil water content (SWC), electric conductivity (EC), pH and bulk density (Bd) values (mean ± standard deviation) of the different soil layers in the four study sites.

Soil layers	Study sites	SWC (%)		EC (dS/m)		pH		Bd (g cm^{-3})	
0–10 cm	SL	24.12^{a}	±0.43	0.30^{ab}	±0.01	8.16^{a}	±0.01	0.91^{a}	±0.01
	CL40	20.67^{b}	±0.19	0.32^{c}	±0.01	8.33^{b}	±0.01	0.96^{b}	±0.02
	RL10	30.51^{c}	±0.66	0.31^{bc}	±0.01	8.40^{c}	±0.02	0.57^{c}	±0.02
	AL10	24.72^{a}	±0.77	0.29^{a}	±0.01	8.32^{b}	±0.03	0.84^{d}	±0.04
10–20 cm	SL	21.14^{a}	±0.50	0.27^{a}	±0.02	8.25^{a}	±0.02	1.02^{a}	±0.01
	CL40	18.71^{b}	±0.58	0.56^{b}	±0.02	8.48^{b}	±0.02	1.05^{b}	±0.01
	RL10	29.53^{c}	±0.45	0.29^{a}	±0.01	8.44^{c}	±0.03	0.63^{c}	±0.01
	AL10	20.76^{a}	±0.19	0.27^{a}	±0.01	8.49^{b}	±0.02	0.92^{d}	±0.00
20–30 cm	SL	17.64^{a}	±0.03	0.28^{a}	±0.01	8.50^{a}	±0.02	1.06^{a}	±0.02
	CL40	18.84^{b}	±0.08	0.41^{b}	±0.04	8.44^{b}	±0.03	1.07^{a}	±0.00
	RL10	28.73^{c}	±0.50	0.28^{a}	±0.01	8.55^{c}	±0.02	0.80^{b}	±0.11
	AL10	16.28^{d}	±0.25	0.27^{a}	±0.00	8.54^{c}	±0.03	0.99^{a}	±0.01

Within each soil horizon, different superscripts within a column indicate that means differ significantly ($p < 0.05$). SL — native alpine steppe, CL40 — cropland of 40 years, RL10 — grassland reseeded with *Elymus sibiricus* 10 years ago on former oat cropland, and AL10 — abandoned cropland of 10 years.

found in RL10, but it was not significantly different to SL, but significantly different from the other two sites (CL40, AL10) ($p < 0.05$) (Table 3). For the 10–20 cm soil layer, MBN/TN of SL was significantly higher ($p < 0.05$), and for the 20–30 cm soil layer, RL10 had significantly higher MBN/TN values ($p < 0.05$) (Table 3).

3.4. Correlation among soil properties

In this study (Table 4), soil water content (SWC) showed a significant negative correlation with bulk density (Bd) ($p < 0.01$) and available nitrogen (AN) ($p < 0.05$) and a positive correlation with EC, TN, MBC and MBN, but not significant ($p > 0.05$). Electrical conductivity (EC) had a positive correlation with all properties except LFOC and MBC, and pH had a negative correlation with Bd, SOC, AN, and MBN. Soil bulk density (Bd) had a negative correlation with SOC, AN, and MBN (Table 4). Soil organic carbon had a positive correlation with TN and MBC, and a negative correlation with AN and LFOC (Table 4). Microbial biomass carbon and nitrogen had a positive correlation with SOC, TN and LFOC. However, MBN had a weak negative correlation with MBC (Table 4).

4. Discussion

4.1. Effect of land use change on storage of soil C and N

Estimates of soil carbon (C) and nitrogen (N) in grasslands after long-term disturbance and restoration are normally derived from chronosequence studies, or comparing disturbed and adjacent control areas, because direct observation in long term is often impractical (Knops and Tilman, 2000). A common result from studying the impact of land use on soil C and N is that cultivation greatly reduces their storage in grasslands especially in arid areas, and restoration approaches (enclosure, fallow, abandonment and reseed grasses, etc.) can enhance their recovery rate (Baker et al., 2007; Breuer et al., 2006; Li et al., 2009; Rees et al., 2005; Shang et al., 2012; Smith et al., 2001; Török et al., 2011). This study also showed that surface soil layers experienced significantly greater change than deeper layers (Figs. 2–7, $p < 0.05$) after 40 years of cultivation in alpine steppe. The 0–10 cm only had 40% of the total soil C and N of the original grassland, and while LFOC, AN, MBC and MBN levels were still reduced they were more than 40% of the original grassland values.

In contrast, long term (30 years) ploughing of some low land and high rainfall rangeland areas, such as in the savannas of the Brazilian cerrados (730 m altitude, 1340 mm precipitation) has not changed SOC (Roscoe and Buurman, 2003), but LFOC has decreased and soil bulk density increased. Although, at times mineral fertilizer was used on the cropland, mineral fertilizers have only small carbon sequestration rates, so large carbon losses from plant and microbial respiration are not prevented by cultivation (Jones et al., 2006; Rees et al., 2005).

Planting grasses can enhance SOC and TN, but not to the level of native grasslands (Guo et al., 2009; Su, 2007). The restoration of alpine steppe by reseeding former cropland has a faster recovery rate than the average for China (1.304 Mg C·ha^{-1}·yr^{-1}) (Wang et al., 2011). In some areas, long term fallow or abandonment is not practical so the

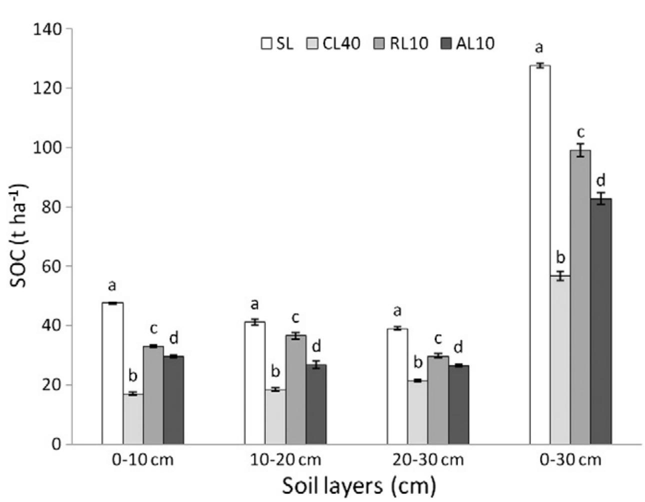

Fig. 2. Soil organic carbon levels (SOC t ha^{-1}) at the four study sites for the different soil layers. The letters above the error bars indicate significant difference ($p < 0.05$) among the four study sites within each soil layer.

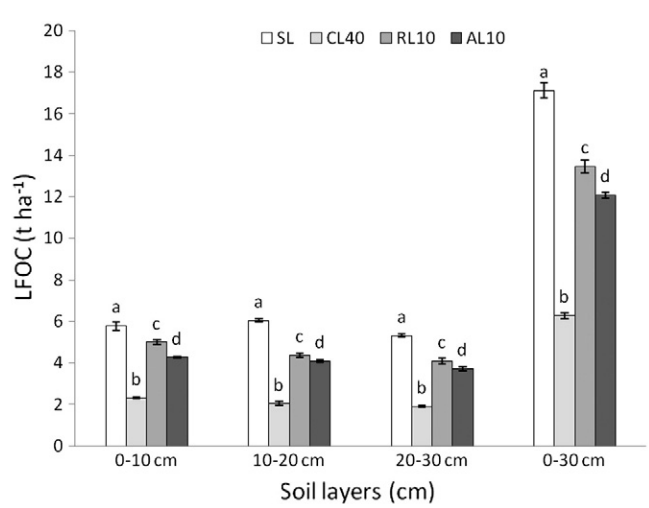

Fig. 3. Light fraction of soil organic carbon levels (LFOC t ha^{-1}) at the four study sites for the different soil layers. The letters above the error bars indicate significant difference ($p < 0.05$) among the four study sites within each soil layer.

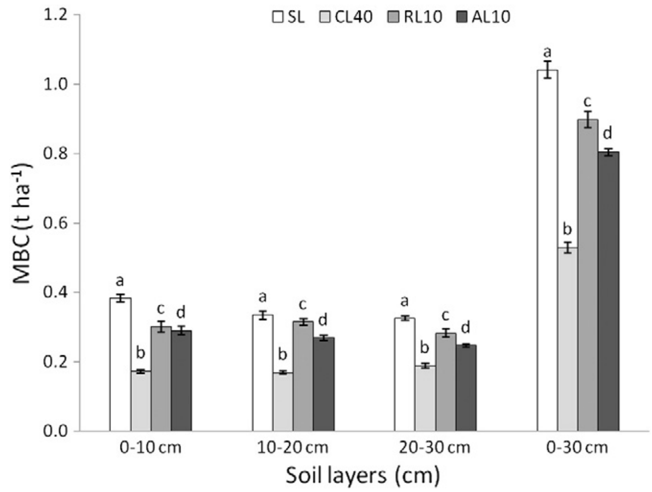

Fig. 4. Microbial biomass carbon levels (MBC t ha^{-1}) at the four study sites for the different soil layers. The letters above the error bars indicate significant difference ($p < 0.05$) among the four study sites within each soil layer.

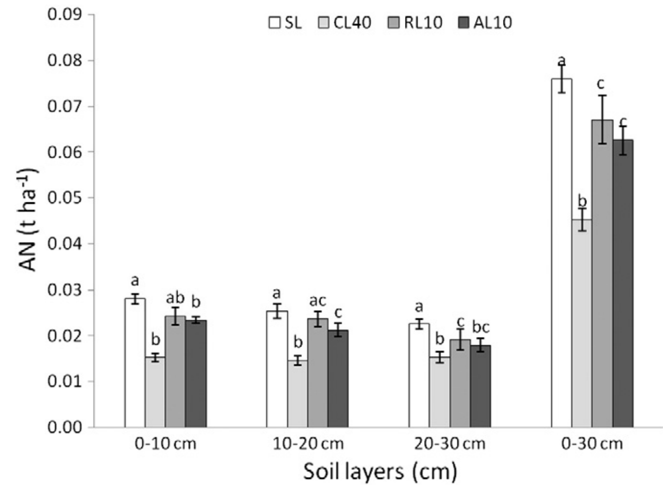

Fig. 6. Available soil nitrogen levels (AN t ha^{-1}) at the four study sites for the different soil layers. The letters above the error bars indicate significant difference ($p < 0.05$) among the four study sites within each soil layer.

reseeding or planting of legumes or grass mixtures is a better approach to enhance soil C and N contents (Barthès et al., 2004) and to provide forage to feed livestock. Local species are usually used as reseeding material to restore former cropland due to low cost and fitness for purpose (Török et al., 2011), especially when the reseeding aims to restore the target community (Kiehl et al., 2010; Lindborg, 2006).

For cropland, abandonment produces positive effects on the restoration of soil C and N, because when croplands were ploughed from grassland, soil C and N were reduced significantly. However, for grassland, abandonment sometimes has a negative effect on soil C and N (Li et al., 2009). During the abandonment of cultivated land, plant litter input to the soil is increased due to a greater quantity of plant litter left on the ground and accumulated each year (Zhang et al., 2007).

Soil microbial C and N biomass levels are readily restored by restoration of arid grasslands because the soil microbial community is very sensitive to plant litter and root increases with suitable soil moisture (Huang et al., 2011; Zhang et al., 2007). Soil microbial biomass of C and N have the same trend of variation with SOC, LFOC, and quantity of litter inputing. The reseeding method resulted in a large quantity of roots from perennial grasses, which may account for differences with abandonment. Abandonment has resulted in faster recovery rates of LFOC and MBC than SOC (Zhang et al., 2007), which is also found in this study.

In the long term cultivated cropland (CL40), soil C and N were reduced by more than 50% of the original alpine steppe, especially SOC, LFOC and TN values ($p < 0.05$). Ten years of the reseeding approach (RL10) has restored the soil C and N contents more than abandonment (AL10) ($p < 0.05$; Figs. 2–7). The complete recovery of soil C and N contents to the same levels as the original grassland plots is not usually seen. According to Knops and Tilman (2000) in North America, recovery to 95% of the original soil C and N grassland levels from former cropland could perhaps take 180 yrs and 230 yrs, respectively. The current study showed the soil C and N recovery rate is higher than the average global rate (0.54 Mg C$\cdot ha^{-1} \cdot yr^{-1}$) in restoration of grassland from former cropland (Contant et al., 2001). Other low cost options to quickly recover grassland from former croplands is abandonment and enclosure of the land (Wu et al., 2010).

4.2. Impact of land use change on stoichiometry of soil C and N

The varying stoichiometry of C and N contents of the soil by reseeding with grasses or legumes depends on the different compositions

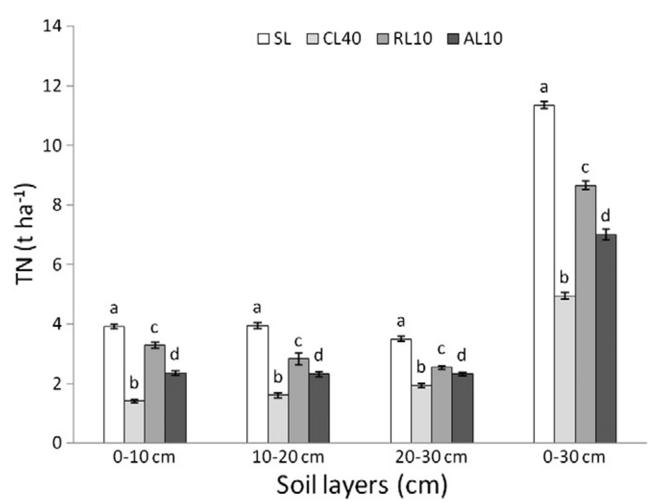

Fig. 5. Total soil nitrogen levels (TN t ha^{-1}) at the four study sites for the different soil layers. The letters above the error bars indicate significant difference ($p < 0.05$) among the four study sites within each soil layer.

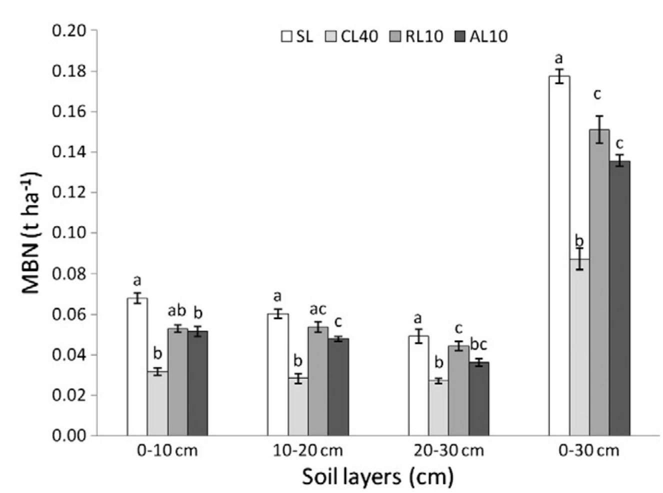

Fig. 7. Microbial biomass nitrogen levels (MBN t ha^{-1}) at the four study sites for the different soil layers. The letters above the error bars indicate significant difference ($p < 0.05$) among the four study sites within each soil layer.

Table 3
C:N, LFOC/SOC (%), MBC/SOC (%), and MBN/TN (%) in different study sites and soil layers (mean ± standard deviation).

Soil layers	Study sites	C:N		LFOC/SOC		MBC/SOC		MBN/TN	
0–10 cm	SL	12.14^{a}	±0.22	12.15^{a}	±0.43	0.80^{a}	±0.03	1.74^{a}	±0.06
	CL40	12.03^{a}	±0.65	13.68^{b}	±0.39	1.02^{b}	±0.06	2.26^{b}	±0.16
	RL10	10.04^{b}	±0.16	15.19^{c}	±0.58	0.92^{c}	±0.06	1.62^{a}	±0.10
	AL10	12.53^{a}	±0.27	14.47^{bc}	±0.29	0.98^{bc}	±0.03	2.19^{b}	±0.11
10–20 cm	SL	10.48^{a}	±0.50	14.65^{a}	±0.49	0.81^{a}	±0.05	1.53^{a}	±0.03
	CL40	11.47^{a}	±0.89	11.07^{b}	±0.62	0.92^{bc}	±0.05	1.76^{b}	±0.19
	RL10	13.02^{b}	±1.12	11.90^{b}	±0.31	0.86^{ab}	±0.01	1.90^{bc}	±0.04
	AL10	11.55^{a}	±0.16	15.24^{a}	±0.47	1.00^{c}	±0.06	2.06^{c}	±0.12
20–30 cm	SL	11.14	±0.20	13.66^{a}	±0.29	0.83^{a}	±0.02	1.41^{a}	±0.12
	CL40	11.18	±0.63	8.89^{b}	±0.32	0.88^{ab}	±0.05	1.41^{a}	±0.10
	RL10	11.57	±0.55	13.88^{a}	±0.98	0.96^{b}	±0.07	1.74^{b}	±0.08
	AL10	11.38	±0.17	14.08^{a}	±0.28	0.93^{b}	±0.03	1.56^{a}	±0.06

Within each soil horizon, different superscripts within a column indicate that means differ significantly ($p < 0.05$). SL—native alpine steppe, CL40—cropland of 40 years, RL10—grassland reseeded with *Elymus sibiricus* 10 years ago on former oat cropland, and AL10—abandoned cropland of 10 years. C—carbon, N—nitrogen, SOC—soil organic carbon, TN—total nitrogen, LFOC—light fraction organic carbon, MBC—microbial biomass carbon, MBN—microbial biomass nitrogen.

of introduced plant materials. The composition of introduced plants can be defined by C_3, C_4 and C:N ratios and other biological measures and these can affect the stability of C and N and their decomposition rates. In native steppe, soil organic carbon inputs come mainly from senescing plant tops and exudation of organic compounds from roots (He et al., 2008, 2009). In the current study, in the top layer (0–10 cm), LFOC/SOC, MBC/SOC and MBN/TN were higher in CL40 than in native steppe (SL) (Table 3).

With plant biomass being harvested, nitrogen has greatly declined, and a high ratio of C:N in surface soil layers (0–10 cm) is seen (Table 3). A high C:N ratio can limit the decomposition process, which is important in deciding the ratio of C:N of any additional materials such as manures (Jones et al., 2006). The development of reseeding method for restoration of former cropland in grassland areas needs more study. At present, reseeding grasses just play a role as a primary community in initiating vegetation succession. However, the priority effects need more investigation (Fukami et al., 2005). Knops and Tilman (2000) showed that abandonment increased the ratio of C:N from former cropland. However, soil C and N have not benefited significantly from very long term abandonment within enclosures (>20 years) (He et al., 2009). Plant residues from former land uses are very important to the accumulation of N (Willams and Haynes, 1997), so it is recommended that the farmers' land use regime should maintain a proportion of plant litter be left on the soil.

4.3. Relationship among soil properties

In low temperature areas, under cultivation, carbon and nitrogen are easily lost through soil losses, especally with higher precipitation (Miller et al., 2004). Alpine steppe on the Tibetan plateau is in highland areas with low temperature and sometimes relatively high rainfall, so it is common for carbon and nitrogen to be lost by continous cultivation. This study showed a large loss of soil C and N by cultivation, but lower than for the grasslands of North America (98% of C, 75% of N in the 0–10 cm soil layer) (Knops and Tilman, 2000). Soil texture is a key factor influencing C loss by disturbance (Dalal and Mayer, 1986). Long term cultivation will increase pH, bulk density (Table 2) and change soil texture (Shi et al., 2010). In general, the decline of carbon in the soil is associated with increasing bulk density (Breuer et al., 2006). Therefore, the common results of long-term continuous cultivation are increases of soil bulk density and decrease of carbon and nitrogen.

Soil water content is important in increasing soil C and N decomposition, especially in arid regions (Lu et al., 2011). However, our results showed a negative correlation between soil water and SOC although not significant ($p > 0.05$) (Table 4). Of the indicators shown in Table 2 (SWC, EC, pH and bulk density), pH and bulk density are assumed to be labile soil properties in the surface layers (0–10 cm and 10–20 cm). The average pH of the four sites was more than 8, and the three disturbed sites (CL40, RL10, AL10) had higher pH values than the reference site (SL) ($p < 0.05$). Long term cultivation resulted in a higher soil bulk density and restoration methods reduced bulk density significantly (Table 2). Other studies have shown that the conversion of cropland to grassland has not necessarily influenced soil pH, SW and, EC (Breuer et al., 2006; Guo et al., 2009; Wang et al., 2011). However, bulk density should be altered significantly as much as plant litter is added to the soil, significantly reducing bulk density.

5. Conclusion

Long term cultivation in alpine steppe increased pH, bulk density and changed soil texture, resulting in reduced storage levels of soil carbon and nitrogen. The two restoration methods studied (planting grasses and abandonment of cropping) enhanced soil carbon and nitrogen levels above those of cropland, but did not restore them to levels in native grasslands. Ten years after reseeding soil C and N contents increased more than with simple abandonment. Abandonment resulted

Table 4
The partial correlation coefficients among soil profiles (SWC (%), EC (dS m^{-1}), pH, Bd (g cm^{-3}), SOC (t ha^{-1}), TN (t ha^{-1}), AN (t ha^{-1}), LFOC (t ha^{-1}), MBC (t ha^{-1}) of our study.

	SWC	EC	pH	Bd	SOC	TN	AN	LFOC	MBC
EC	0.36								
pH	−0.4	0.54							
Bd	−0.93**	0.41	−0.53						
SOC	−0.56	0.37	−0.46	−0.44					
TN	0.55	0.05	0.08	0.4	0.79**				
AN	−0.75*	0.4	−0.51	−0.76**	−0.59*	0.53			
LFOC	−0.49	−0.21	0.11	−0.3	−0.63*	0.88**	−0.39		
MBC	0.57	−0.57	0.73**	0.54	0.87**	−0.5	0.64*	0.38	
MBN	0.54	0.11	−0.28	0.39	0.34	−0.64	0.61*	0.69*	−0.07

* and ** means that the correlation coefficients were significantly different at $p < 0.05$ and $p < 0.01$ respectively. SWC—soil water content, EC—electrical conductivity, Bd—bulk density, LFOC—light fraction organic carbon, SOC—soil organic carbon, TN—total nitrogen, AN—available nitrogen, MBC—microbial biomass carbon, MBN—microbial biomass nitrogen.

in faster recovery rates of LFOC and MBC than SOC. The restoration of alpine steppe through reseeding of former cropland displayed faster recovery rates than average rates for China or globally. Thus, the two restoration methods could both be recommended for returning cultivated land back to grassland.

Acknowledgments

This work was supported by the World Bank/Global Environment Fund project (052456CHA-GS-Y-4), the National Natural Science Foundation of China (No. 41171417), and the Program for New Century Excellent Talents in University (NCET-13-0261). We thank Prof. Peter Smith (University of Aberdeen, UK) and Dr. Andrew White (The University of Adelaide, Australia) for their considerable editing of the manuscript and suggestions.

References

Baker, J.M., Ochsner, T.E., Venterea, R.T., Griffis, T.J., 2007. Tillage and soil carbon sequestration—what do we really know? Agric. Ecosyst. Environ. 118, 1–5.

Bakker, J.P., Van Diggelen, R., 2006. Restoration of dry grasslands and heathlands. In: Van Andel, J., Aronson, J. (Eds.), Restoration Ecology The New Frontier. Blackwell Publishing, UK, pp. 95–100.

Bao, S., 2000. Agricultural Chemical Analysis of Soil. China Agriculture Press, Beijing, China 14–16 (70–89).

Barthès, B., Azontonde, A., Blanchart, E., Girardin, C., Villenave, C., Lesaint, S., Oliver, R., Feller, C., 2004. Effect of a legume cover crop (Mucuna pruriens var. Utilis) on soil carbon in an Ultisol under maize cultivation in southern Benin. Soil Use Manage 20, 231–239.

Breuer, L., Huisman, J.A., Keller, T., Frede, H.-G., 2006. Impact of a conversion from cropland to grassland on C and N storage and related soil properties: analysis of a 60-year chronosequence. Geoderma 133, 6–18.

Contant, R.T., Paustian, K., Elliott, E.T., 2001. Grassland management and conversion into grassland: effects on soil carbon. Ecol. Appl. 11 (2), 343–355.

Dalal, R.C., Mayer, R.J., 1986. Long-term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II total organic carbon and its rate of loss from the soil profile. Aust. J. Soil Res. 24, 281–292.

Don, A., Schumacher, J., Freibauer, A., 2011. Impact of tropical land-use change on soil organic carbon stocks—a meta-analysis. Glob. Chang. Biol. 17, 1658–1670.

Fornara, D.A., Steinbeiss, S., McNamara, N.P., Gleixner, G., Oakley, S., Poulton, P.R., Macdonald, A.J., Bardgett, R.D., 2011. Increases in soil organic carbon sequestration can reduce the global warming potential of long-term liming to permanent grassland. Glob. Chang. Biol. 17, 1925–1934.

Fukami, T., Bezemer, T.M., Mortimer, S.R., van der Putten, W.H., 2005. Species divergence and trait convergence in experimental plant community assembly. Ecol. Lett. 8, 1283–1290.

Gibson, D.J., 2009. Grasses and Grassland Ecology. Oxford University Press, Oxford 211–242.

Guo, Y.J., Ni, Y., Han, J.G., 2009. The influence of land use change on the chemical and biological properties of steppe soils in Northern China. Arid Land Res. Manag. 23, 197–212.

Han, Y.W., Han, J.G., Zhang, Y.W., Wang, K., 2005. Discussion on ecological and economic benefit, technology of returning grassland from cropland in the agro-pastoral transitional zone. J. Agro-Environ. Sci. 24, 389–392 (Supplement issue).

He, N.P., Yu, Q., Wu, L., Wang, Y.S., Han, X.G., 2008. Carbon and nitrogen store and storage potential as affected by land-use in a *Leymus chinensis* grassland of northern China. Soil Biol. Biochem. 40, 2952–2959.

He, N.P., Wu, L., Wang, Y.S., Han, X.G., 2009. Changes in carbon and nitrogen in soil particle-size fractions along a grassland restoration chronosequence in northern China. Geoderma 150, 302–308.

He, N.P., Zhang, Y.H., Yu, Q., Chen, Q.S., Pan, Q.M., Zhang, G.M., Han, X.G., 2011. Grazing intensity impacts soil carbon and nitrogen storage of continental steppe. Ecosphere 2 (1). http://dx.doi.org/10.1890/ES10-00017.1 (art8).

Hill, M.J., Braaten, R., McKeon, G.M., 2003. A scenario calculator for effect of grazing land management on carbon stocks in Australian rangelands. Environ. Model. Softw. 18, 627–644.

Hoffmann, C., Funk, R., Li, Y., Sommer, M., 2008. Effect of grazing on wind driven carbon and nitrogen ratios in the grasslands of Inner Mongolia. Catena 75, 182–190.

Huang, Y.M., Michel, K., An, S.S., Zechmeister-Boltenstern, S., 2011. Changes in microbial-community structure with depth and time in a chronosequence of restored grassland soil on the Loess plateau in northwest China. J. Plant Nutr. Soil Sci. 174, 765–774.

Janzen, H.H., Campbell, C.A., Brandt, G.P., Lafond, G.P., Townley-Smith, L., 1992. Lightfraction organic matter in soils from long-term crop rotations. Soil Sci. Soc. Am. J. 56, 1799–1806.

Jones, S.K., Rees, R.M., Kosmas, D., Ball, B.C., Skiba, U.M., 2006. Carbon sequestration in a temperate grassland; management and climatic controls. Soil Use Manag. 22, 132–142.

Kiehl, K., Kirmer, A., Donath, T.W., Rasran, L., Hölzel, N., 2010. Species introduction in restoration projects-evaluation of different techniques for the establishment of semi-natural grasslands in central and Northwestern Europe. Basic Appl. Ecol. 11, 285–299.

Knops, J.M.H., Tilman, D., 2000. Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. Ecology 81 (1), 88–98.

Li, Y.C., 2001. Implementing the testing of 'conversion of cultivated land back to grassland' to improve the ecological and environmental building. People's Tribune 4, 27–29.

Li, X.G., Zhang, L.P., Yin, P., Li, Y.K., Ma, Q.F., Long, R.J., Li, F.M., 2009. Soil organic carbon and nitrogen fractions and water-stable aggregation as affected by cropping and grassland reclamation in an arid sub-alpine soil. Land Degrad. Dev. 20, 176–186.

Li, B.Y., Tang, H.P., Wu, L.H., Li, Q.H., Zhou, C.R., 2012. Relationships between the soil organic carbon density of surface soils and the influencing factors in differing land uses in Inner Mongolia. Environ. Earth Sci. 65, 195–202.

Lindborg, R., 2006. Recreating grasslands in Swedish rural landscapes-effects of seed sowing and management history. Biodivers. Conserv. 15, 957–969.

Liu, S.W., 1996, 1997, 1999a, bb. Flora of Qinghai Province. Qinghai People Press, Xining (Volume 1(1997), Volume 2(1999), Volume 3(1996), Volume (1999)).

Lu, F.M., Lu, X.T., Liu, W., Han, X., Zhang, G.M., Kong, D.L., Han, X.G., 2011. Carbon and nitrogen storage in plant and soil as related to nitrogen and water amendment in a temperate steppe of northern China. Biol. Fertil. Soils 47, 187–196.

Luo, Z.K., Wang, E.L., Sun, O.J., 2010. Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. Agric. Ecosyst. Environ. 139, 224–231.

Miehe, G., Bach, K., Miehe, S., Kluge, J., Yang, Y.P., La, D., Co, S., Wesche, K., 2011. Alpine steppe plant communities of the Tibetan highlands. Appl. Veg. Sci. 14, 547–560.

Miller, A.J., Amundson, R., Burke, I.C., Yonker, C., 2004. The effect of climate and cultivation on soil organic C and N. Biogeochemistry 67, 57–72.

National soil survey office, 1995. Chinese Soil Genus Records, vol. 5. China Agriculture Press, Beijing.

Nelson, D.W., Sommers, L.E., 1982. Total carbon, organic carbon and organic matter, In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of soil analysis. Part 2. Chemical and microbiological properties, second ed. Agronomy Monograph No. 9. American Society of Agronomy Inc., Madison, WI, pp. 539–577.

Nelson, J.D.J., Schoenau, J., Malhi, S.S., 2008. Soil organic carbon changes and distribution in cultivated and restored grassland soils in Saskatchewan. Nutr. Cycl. Agroecosyst. 82 (2), 137–148.

Office of Gansu Soil Census, 1993. Gansu Soil. Agricultural Press, Beijing.

Post, W.M., Kwon, K.C., 2000. Soil carbon sequestration and land-use change: processes and potential. Glob. Chang. Biol. 6, 317–327.

Qiu, L.P., Wei, X.R., Zhang, X.C., Cheng, J.C., Gale, W., Guo, C., Long, T., 2012. Soil organic carbon losses due to land use change in a semiarid grassland. Plant Soil 355, 299–309.

Rees, R.M., Bingham, I.J., Baddeley, J.A., Watson, C.A., 2005. The role of plants and land management in sequestering soil carbon in temperate arable and grassland ecosystems. Geoderma 128, 130–154.

Ren, J.Z., 1998. The Scientific Methods of Grassland Research. China Agriculture Press, Beijing.

Roscoe, R., Buurman, P., 2003. Tillage effect s on soil organic matter in density fractions of a Cerrado Oxisol. Soil Tillage Res. 70, 107–119.

Shang, Z.H., Cao, J.J., Guo, R.Y., Long, R.J., 2012. Effect of cultivation and abandonment on soil carbon content of sub-alpine meadows northwest China. J. Soils Sediments 12 (6), 826–834.

Shi, X.M., Li, X.G., Long, R.J., Singh, B.P., Li, Z.T., Li, F.M., 2010. Dynamics of soil organic carbon and nitrogen associated with physically separated fractions in a grassland-cultivation sequence in the Qinghai-Tibetan plateau. Biol. Fertil. Soils 46, 103–111.

Smith, P., Powlson, D.S., Glendining, M.J., Smith, J., 1998. Preliminary estimates of the potential for carbon mitigation in European soils through no-till farming. Glob. Chang. Biol. 4, 679–685.

Smith, P., Goulding, K.W., Smith, K.A., Powlson, D.S., Smith, Jo.U., Falloon, P., Coleman, K., 2001. Enhancing the carbon sink in European agricultural soils: including trace gas fluxes in estimates of carbon mitigation potential. Nutr. Cycl. Agroecosyst. 60, 237–252.

Squires, V., Yang, Y.L., 2009. Historical degradation episodes in China: socio-economic forces and their interaction with rangeland grazing systems since the 1950s. In: Squires, V., Lu, X.S., Lu, Q., Wang, T., Yang, Y.L. (Eds.), Rangeland Degradation and Recovery in China's Pastoral Lands. CABI, pp. 15–30.

Su, Y.Z., 2007. Soil carbon and nitrogen sequestration following the conversion of cropland to alfalfa forage in northwest China. Soil Tillage Res. 92, 181–189.

Su, Y.Z., Liu, W.J., Yang, R., Chang, X.X., 2009. Changes in soil aggregate, carbon, and nitrogen storages following the conversion of cropland to alfalfa forage land in the marginal Oasis of Northwest China. Environ. Manag. 43, 1061–1070.

Tang, Q.Y., Feng, M.G., 2002. DPS Data Processing System for Practical Statistics. Beijing Science Press.

Török, P., Vida, E., Deak, B., Lengyel, S., Tothmeresz, B., 2011. Grassland restoration on former croplands in Europe: an assessment of applicability of techniques and costs. Biodivers. Conserv. 20, 2133–2332.

Wang, S.P., Wilkes, A., Zhang, Z.C., Chang, X.F., Lang, R., Wang, Y.F., Niu, H.S., 2011. Management and land use change effects on soil carbon in northern China's grasslands: a synthesis. Agric. Ecosyst. Environ. 142, 329–340.

Wang, Z., Liu, G.B., Xu, M.X., Zhang, J., Wang, Y., Tang, L., 2012. Temporal and spatial variations in soil organic carbon sequestration following revegetation in the hilly Loess Plateau, China. Catena 99, 26–33.

West, T.O., Post, W.M., 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. Soil Sci. Soc. Am. J. 66, 1930–1946.

Willams, P.H., Haynes, R.J., 1997. Recovery of N derived from ^{15}N-labelled grass/clover residues, recently immobilised urine ^{15}N or native soil organic N by a wheat crop following cultivation of a pasture soil. Agric. Ecosyst. Environ. 63, 67–72.

Wu, J., Joergensen, R.G., Pommerening, B., Chaussod, R., Brookes, P.C., 1990. Measurement of soil microbial biomass C by fumigation extraction an automated procedure. Soil Biol. Biochem. 20, 1167–1169.
Wu, G.L., Liu, Z.H., Zhang, L., Cheng, J.M., Hu, T.M., 2010. Long-term fencing improved soil properties and soil organic carbon storage in an alpine swamp meadow of western China. Plant Soil 332, 331–337.
Xu, Z.X., Li, Y.Q., 2003. Effects of grassland degradation on soil and water loss. J. Arid Land Res. Manag. 17 (1), 65–68.
Zhang, J.B., Song, C.C., Wang, S.M., 2007. Dynamics of soil organic carbon and its fractions after abandonment of cultivated wetlands in northeast China. Soil Tillage Res. 96, 350–360.