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

Zhan-Huan Shang [a,*], Jing-Juan Cao [a], Rui-Ying Guo [b], Rui-Jun Long [a], Bo Deng [c]

[a] State Key Laboratory of Grassland Agro-ecosystems, College of Pastoral Agriculture Science and Technology, Lanzhou University, Lanzhou 730020, China
[b] Institute of Arid Agroecology, School of Life Sciences, Lanzhou University, Lanzhou 730000, China
[c] The Institute of Grassland Science, College of Animal Science & Technology, China Agricultural University, Beijing 100094, China

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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

* Corresponding author at: No. 768, Jiayuguan west road, Lanzhou City, Gansu province, 730020, China. Tel./fax: +0086 931 8914107.
E-mail address: shangzhh@lzu.edu.cn (Z.-H. Shang).

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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

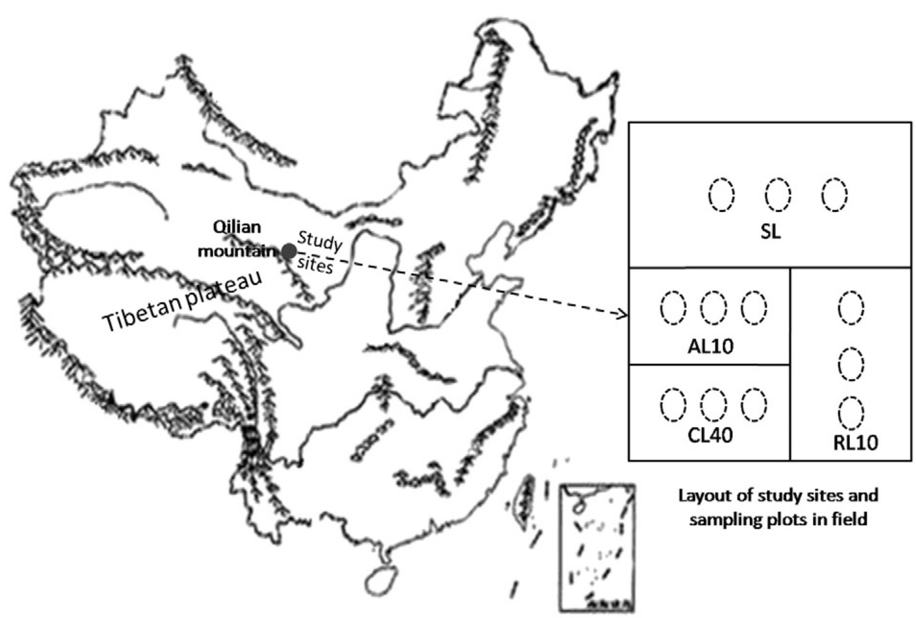

Fig. 1. Location of study sites in China with their layout displayed and that of the sampling plots (dotted circles). SL — native alpine steppe, CL40 — cropland of 40 years, RL10 — grassland reseeded with *Elymus sibiricus* 10 years ago on former oat cropland, and AL10 — abandoned cropland of 10 years.