Soil carbon and nitrogen stocks and their relationship with plant and soil dynamics of degraded and artificial restoration grasslands in an alpine region

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Abstract. Land disturbances and management approaches can significantly alter grassland soils. Therefore, understanding the carbon and nitrogen storage accompanying plant and soil physical and chemical properties due to anthropogenic disturbance and different management strategies is important. In our study, we investigated carbon and nitrogen storage in artificial grasslands with different durations of restoration and native grasslands with different levels of degradation. We found that total carbon and nitrogen were significantly higher five years after restoration than after seven and nine years, but decreased due to grassland degradation. Furthermore, soil carbon and nitrogen had a close relationship with plant and soil factors, as reflected by a correlation index. The above-mentioned results indicate that artificial grasslands can be used as an effective method to restore "black-beach" soil grassland. In the long term, however, human intervention should be implemented to prevent the degradation of artificial grasslands.

Keywords: Carbon, nitrogen, artificial grassland, degraded grassland.

Introduction

Qinghai-Tibetan Plateau (QTP), the headwater region of Asia and the earth's "third pole", represents a distinct cryospheric environment (Wang *et al.* 2007; Shi *et al.* 2010). However, the alpine grasslands on the QTP have faced degradation due to anthropogenic and natural factors in recent decades (Harris 2010). Therefore, it is essential to take actions such as fencing pastures, reducing the number of livestock and applying fertilizers to restore these degraded grasslands (Akiyama and Kawamura 2007). None of these interventions have proved to be significantly effective in restoring extremely degraded grasslands ("black-beach") on the QTP (Wu *et al.* 2010b). In order to solve the above problems, 2000 km^2 of degraded alpine meadow has been artificially established in Guoluo Prefecture of Qinhgai Province with financial support from central and provincial governments.

Some researchers have revealed that changes in plant composition can alter the abiotic and biotic properties of soil, including soil organic matter, soil nutrient availability, soil microbial composition and efficiency (Wu *et al.* 2011a). For the alpine grassland on the QTP, previous studies have broadly explored the species composition dynamics and nutrient changes under different grazing intensities. However, few studies have examined the effects of grassland degradation and artificial grassland establishment on carbon and nitrogen storage and their interactions with vegetation changes.

Materials and methods

Study sites

This study was conducted in Dawu village, Maqin County, of the Glog Tibetan Autonomous Prefecture of Qinghai Province, China (34°28′11″N; 100°12′39″E, 4200 m a.s.l.). Non-degraded grasslands (ND), moderately degraded grassland (MD), heavily degraded grassland (HD) and extremely degraded grassland (ED) were selected. The 5Y, 7Y and 9Y plots were artificially restored grasslands on areas of soil erosion and pasture degradation locally known as 'black-beach' with restoration starting in 2004, 2002, and 2000, respectively.

Field sampling and laboratory analysis

Field sampling was conducted in August 2010. We established six zonal sampling plots (5 m × 8 m) and three random quadrats (50 cm ×50 cm) per plot. Below-ground biomass was determined using a soil corer (diameter, 3.5 cm) at three sampling points for each plot. Similarly, the soil samples were collected for physical and chemical analysis.

All the data were presented as means of the replicates. One-way analysis of variance (ANOVA) and least significant difference (LSD) tests were applied to compare the carbon and nitrogen storage in the different types of grasslands. Significant differences were assessed at the level of P<0.05. A correlation analysis was used to determine the relationship between soil and vegetation

Table 1. Changes of carbon and nitrogen storage in the different grasslands.

Different experimental plots	TSC (kg/m^2)	TSN (kg/m^2)	TSOC/TSC	SMBC/TSC	SMBN/TSN	C:N
5Y	10.791±0.409a	0.864±0.056ac	0.615±0.007ac	0.011±0.0001ab	0.0265±0.0003a	12.484±0.262a
7Y	8.263±0.844b	0.763±0.067b	0.604±0.010ab	0.010±0.0003ac	0.0244±0.0011a	10.827±0.458b
9Y	7.809±0.667b	0.742±0.055ac	0.591±0.002b	0.012±0.0012ab	0.0287±0.0035a	10.531±0.278b
ND	13.725±1.078c	0.955±0.077a	0.620±0.010c	0.013±0.0008b	0.0295±0.0114a	14.367±0.574c
MD	10.721±0.352a	0.908±0.021a	0.607±0.006abc	0.010±0.0019ac	0.0275±0.0049a	11.806±0.461a
HD	8.486±0.392b	0.786±0.039bc	0.595±0.007ab	0.0096±0.0005c	0.02511±0.0055a	10.791±0.557b
ED	7.802±0.778b	0.769±0.043b	0.578±0.001bd	0.0073±0.0001d	0.0223±0.0015a	10.144±0.214b

properties. All statistical analyses were performed using SPSS16.0.

Results

Soil carbon and nitrogen levels

Total soil carbon (TSC) was highest in areas without degradation (ND), levels were similar for 5Y and MD, while there was no difference between 7Y, 9Y, HD and ED (Table 1). The lack of difference between the restoration treatments seven years or older and the highly degraded sites indicates that TSC levels decrease over time. Total soil nitrogen (TSN), while closely related to TSC did not vary consistently with time after restoration, but decreased under HD and ED. The contribution of total soil organic carbon (TSOC) to TSC was higher in more recently renovated and in less degraded grasslands. The proportion of soil microbial biomass carbon (SMBC) to TSC decreased with increasing degradation, while soil microbial biomass nitrogen (SMBN) did not change in proportion to TSN under any treatment. The C:N was highest for ND, and decreased with increasing degradation, it also decreased in restoration treatments that were seven years or older.

Correlation of soil carbon and nitrogen storage with plant and soil features

Correlation analysis demonstrated that TSOC, TSC and TSN all had similar relationships with the soil and vegetation characteristics monitored. They were positively correlated with SMBC, SMBN, SWC and each other (Table 2; P<0.01), whereas the contribution of the remaining soil physical chemical variables to soil carbon and nitrogen were negatively correlated (P<0.01; Table 2). Compared with the soil factors, the vegetation factors had a relatively lower correlation to the soil carbon and nitrogen content. While aboveground plant biomass (AB) was not correlated, the belowground plant biomass (BB), plant diversity, richness and evenness indexes and the ratio of belowground biomass to aboveground biomass were all positively correlated with soil carbon and nitrogen (P<0.01; Table 2).

Table 2. Correlations of soil carbon and nitrogen storage with plant and soil features

Factors		TSOC	TSC	TSN
Soil	TSOC	1	0.944**	0.904**
	TSC	0.944**	1	0.903**
	TSN	0.904**	0.903**	1
	SMBC	0.880**	0.879**	0.804**
	SMBN	0.846**	0.843**	0.834**
	SWC	0.884**	0.885**	0.741**
	Soil pH	-0.622**	-0.628**	-0.591**
	SBD	-0.698**	-0.701**	-0.610**
	SC	-0.808**	-0.811**	-0.748**
	C：N	0.640**	0.642**	0.273
Vegetation	AB	0.18	0.186	0.065
	BB	0.946**	0.947**	0.822**
	Richness	0.726**	0.725**	0.576**
	Diversity	0.721**	0.718**	0.712**
	Evenness	0.654**	0.652**	0.653**
	B:A	0.766**	0.766**	0.686**

TSOC: soil organic carbon; TSC: total carbon; TSN: total nitrogen; SMBC: microbial biomass carbon; SMBN: microbial biomass nitrogen; SWC: soil water content; SBD: soil bulk density; SC: soil conductivity; AB: aboveground biomass; BB: belowground biomass; Richness: richness index; Diversity: Shannon-Winner diversity index; Evenness: evenness index; C:N: the ratio of carbon to nitrogen; B:A: the ratio of belowground biomass to aboveground biomass. *Correlation significant at the 0.05 level; ** Correlation significant at the 0.01 level.

Discussion

Grazing intensity significantly affected carbon and nitrogen storage negatively (P<0.05). There is a range of potential direct or indirect mechanisms through which carbon and nitrogen can be affected by increased degradation levels. First, grazing depresses carbon and nitrogen storage by altering the quantity and quality of resources returned to the soil (Sun *et al.* 2011). Increased aboveground biomass and litter production may increase the water holding capacity of the soil and promote nutrient cycling via litter decomposition (Wu *et al.* 2011b). Although there were considerable changes in carbon and nitrogen storage under the different land-use types, the changes in TSOC/TSC and SMBC/TSC under the different land-use types were relatively small. Soil microbial biomass is another important factor affecting soil carbon and nitrogen because it is sensitive to the changes in soil function (Li *et al.* 2009). We found that MBC and MBN decreased significantly along the degradation gradients, and the artificial grasslands had a relatively higher MBC and MBN than the degraded grasslands. We also found that MBN was significantly positively correlated with total N storage. The increase in microbial biomass demonstrates that soils can supply more readily available N and decomposable organic matter as nutrients for plants (Feng *et al*. 2010). There was a decline in the available N for plants with the increase of degradation. There was an enrichment of available N for plants with the establishment of artificial grasslands.

Conclusion

The results indicate that artificial grasslands can be used as an effective method to restore "black-beach" soil grassland on the QTP. In the long term, however, human intervention should be implemented to prevent the degradation of artificial grasslands, as soil nutrients and soil carbon substantially decreased with increasing restoration years.

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