Effects of grassland conversion to croplands on soil organic carbon in the temperate Inner Mongolia

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Abstract

This study investigated the effects of grassland conversion to croplands on soil organic carbon (SOC) in a typical grassland-dominated basin of the Inner Mongolia using direct field samplings. The results indicated that SOC contents decreased usually with increasing soil depth, with significant differences between the upper horizons (0–30 cm) and the underlying horizons (30–100 cm). Also, SOC densities decreased with an increase in the depth of soils. Average SOC densities in the upper horizons were 2.6–3.7 and 6.0–8.3 kg C m⁻² for desert grassland–cropland sites (sites 1 and 2) and meadow–cropland sites (sites 3 and 4), respectively, with significant differences between grasslands and croplands (P < 0.05). However, the SOC densities in the underlying horizons did not significantly differ between the land uses. The SOC densities up to 100 cm depth were much higher in the meadow–cropland sites than in the desert grassland–cropland sites, reaching approximately 16 and 6 kg C m⁻², respectively. The SOC: total nitrogen (TN) ratios were approximately 10, with no significant difference among the soil horizons of grasslands and croplands. The conversion of grasslands to croplands induced a slight loss of SOC, with a range of from –4% to 22% for the 0–100 cm soil depth over about a 35-year period, in the temperate Inner Mongolia.

Keywords: Soil organic matter; Meadow; Farmland; Land use; Semi-arid region

1. Introduction

Atmospheric carbon dioxide (CO₂) concentrations have increased by 31% since 1750, and the current increase of approximately 1.5 μL L⁻¹ yr⁻¹ is predominantly due to fossil fuel combustion and land use changes (IPCC, 2001). Local and regional human-induced disturbances to carbon stocks are associated with increases in atmospheric CO₂ concentration, air temperature, and extreme climatic events at the global scale (Melillo et al., 1993). An important strategy for controlling the rise in the atmospheric CO₂ concentrations is to enhance carbon sequestration in the terrestrial ecosystems, which is cost-effective and environmentally beneficial.

Soils may act as a source or sink of CO₂ in exchange with the atmosphere; soils contain a large stock of soil organic carbon (SOC), and thus, even slight changes in SOC stock represent large CO₂ fluxes (Krogh et al., 2003). Land uses can induce the significant changes in SOC, although the involved processes in soils are incompletely understood. In the last two centuries, land uses have been a significant source of the atmospheric CO₂ through the conversion of natural vegetation to farming (Wu et al., 2003). Wherever the change in land uses decreased SOC, the reverse process usually increased SOC, and vice versa (Guo and Gifford, 2002). Using the SOC pool in current grassland as the baseline in comparison with that in cropland should be a good indicator of either the SOC source contribution to the greenhouse effect or the potential of SOC sequestration through the conversion between grassland and cropland (Tan and Lal, 2005). Hence, there is a considerable potential to enhance SOC sequestration through efficient land managements.

Grasslands are often a susceptible ecosystem to changes in land uses. Changes in grassland soil carbon can occur in response to a wide range of management and environmental factors (Tan and Lal, 2005). Chinese grasslands covered 41.7% of its territory, reaching 4 × 10⁶ km² in...
2001, and were distributed mainly in the Inner Mongolia and Tibet plateaus (National Statistics Bureau of China, 2002). Previous works have been conducted to estimate the SOC stocks in Chinese grasslands using national survey databases (e.g. Fang et al., 1996; Ni, 2001, 2002). However, the databases were insufficient, which affected the estimated accuracy of SOC stocks. Also, SOC densities for calculating the SOC stocks in the grasslands of China were common values derived from global ecosystems, whereas they were not perfectly suited to Chinese grasslands (Ni, 2002). On the other hand, Guo and Gifford (2002) reviewed the effects of land uses on SOC stocks using a meta analysis of the data from 74 publications, in which no report occurred in China. The Inner Mongolia steppes constitute an important component of the Eurasian temperate grasslands (Zhang et al., 1997; Wang et al., 2007). To our knowledge, there is a lack of information about changes in SOC induced by land uses in the temperate grasslands of the Inner Mongolia.

The Xilin River basin is one of the most representative geographic areas in the Inner Mongolia steppe region (Tong et al., 2004). In this study, we performed field samplings in the Xilin River basin to assess the effects of grassland conversion to croplands on SOC. We then suggested efficient land managements for protecting SOC loss from land uses in this region.

2. Materials and methods

2.1. Region and site descriptions

This work was undertaken in four grassland–cropland paired sites of the Xilin River basin. The detailed description for this region can be found in Tong et al. (2004) and Wang et al. (2005). In brief, this region belongs to the semi-arid temperate climatic zone. The mean annual temperature is approximately 0.6°C. The coldest monthly temperature is −21.4°C in January, and the warmest is 18.5°C in July. The region receives an average of 350 mm precipitation annually, approximately 10% of which falls as snow in winter. The plants usually grow from late April to early October. The soils are mainly luvis kastanozem (previously named as chestnut soils) with the texture of approximately 20% clay, 20% silt, and 60% sand.

A paired-site design was taken to compare the changes in SOC between grasslands and croplands. Grasslands are the most important land cover in the Xilin River basin, while croplands have been derived from the reclamation of grasslands in the 1960–1970s. We determined major grasslands of from desert pasture to meadow. They are representative in the basin. Hence, four paired sites with different soil and vegetation characteristics are selected (Fig. 1).

Site 1 is located roughly in 1 km south of Xilin River. Cropland was reclaimed from a desert grassland around 1970. The cropland has been planted with spring wheats and highland barleys in a fallow rotation system. Desert pasture was covered mainly by Leymus chinensis, Stipa grandis, Stipa krylovii, Agropyron cristatum and Artemisia frigida with about 20–50% cover. The site has exhibited sandy chestnut soils with two distinct soil horizons, the upper horizon and the underlying horizon. The distance of sampling points between the grassland and the cropland was about 50 m.

Site 2 is located in approximately 2 km southeast of Xier. Cropland has been planted intermittently with maizes and rapes for about 20 years. Grassland was an abandoned land covered dominantly with Stipa grandis, Stipa krylovii, Agropyron cristatum, Artemisia frigida and Bupleurum bicaule with 10–30% cover. The site has existed barren brown calcic soils with gravel horizon below 60 cm of profile. The distance of sampling points between the grassland and the cropland was about 1 km.

Site 3 is located in about 4 km north of Hailiut. Cropland was derived from the reclamation of a meadow in 1972. The cropland has been planted with spring wheats in a fallow rotation system but occasionally planted with rapes. Meadow steppe was mainly composed of Stipa grandis, Stipa baicalensis, Leymus chinensis, Bupleurum scorzonerafileum, Fillifolium sibiricum and Festuca with the cover of 60–90% and the plant height of 40–60 cm. The meadow has been harvested in autumns. The site has been fertile chernozem soils with the upper humic horizon of about 50 cm. The distance of sampling points between the grassland and the cropland was about 100 m.
2.2. Soil samplings and analysis

Field samplings were undertaken during July–August 2005. In order to decrease soil heterogeneity in each site, soils were sampled randomly in the cropland and grassland on a flat area.

Soils were sampled in four horizons of 0–10, 10–30, 30–60 and 60–100 cm using a stainless steel corer (3.5 cm in diameter). Each site was designed with three replicates for the cropland or the grassland. The distance was about 50 m between the replicates. For each replicate, soils were sampled minimally in field and then taken to laboratory. Each soil sample was air-dried and sieved through 2 mm sieve, and then ground to a fine powder (mesh number 100) using a pestle and mortar.

Soil bulk density (BD) was determined using a stainless steel cylinder of 98.18 cm³ (5 cm in diameter, 5 cm in height). The soils did not contain the gravels with more than 2 mm in diameter, which accounted for a small height). The soils did not contain the gravels with more than 2 mm in diameter, which accounted for a small

2.3. Calculation of SOC density and statistical analysis

Since SOC content varies along soil profile, SOC density is calculated as follows:

\[
\text{SOC Density} = \sum_{i=1}^{n} D_i \times B_i \times O_i,
\]

where \( n \) is the number of soil horizons, \( D_i \) is the depth interval (cm) of the horizon \( i \) from the top soil and down on, \( B_i \) is the BD (g cm\(^{-3}\)) in the horizon \( i \) and \( O_i \) is the mean SOC content (%) in the horizon \( i \).

Statistical analysis was performed using the SAS program (SAS Institute, 1999). Duncan’s multiple comparison test was used to determine significant differences in mean BD (g cm\(^{-3}\)), SOC (%), SOC density (kg C m\(^{-2}\)) and TN (g kg\(^{-1}\)) among the depth intervals and between the land uses in each site at P < 0.05.

3. Results

3.1. Distributions of bulk density, soil organic carbon and total nitrogen

Table 1 lists the characteristics of BD, SOC and TN in four paired sites. The bulk densities were approximately 1.5–1.6, 1.6–1.7, 1.2–1.3 and 1.1–1.2 g cm\(^{-3}\) in the sites 1, 2, 3 and 4, respectively. They did not significantly differ between the same soil horizons of the cropland and grassland (\( P > 0.05 \)), with the exception of the 0–10 cm horizon in the site 2 and the 30–100 cm horizon in the site 4. As a result, there was a similar soil compaction between the land uses in each site. The SOC contents decreased generally with increasing soil depth, with significant differences between the upper horizons and the underlying horizons (\( P < 0.05 \)). The SOC contents in the sites 3 and 4 were higher than those in the sites 1 and 2, reaching approximately 1.5% and 0.5%, respectively. On a dry soil mass basis, the average ratios of SOC: TN in four paired sites were approximately 10. The SOC: TN ratios were slightly higher in the sites 3 and 4 with fertile soils than in the sites 1 and 2 with barren soils, whereas they usually lacked significant difference among the soil horizons of the land uses (\( P > 0.05 \)). Hence, the SOC and TN contents had existed a synchronous change in soils.

3.2. Changes in soil organic carbon density

The SOC densities were approximately 2.8–3.7, 2.6–2.8, 6.7–8.3, and 6.0–7.8 kg C m\(^{-2}\) in the upper horizons of the sites 1, 2, 3 and 4, respectively (Fig. 2). There were significant differences between the upper horizons of the croplands and grasslands at \( P < 0.05 \), with the exception of those in the site 2. However, the SOC densities in the underlying horizons lacked significant difference between the land uses (\( P > 0.05 \)). The SOC densities up to 100 cm depth were approximately 16 kg C m\(^{-2}\) in the sites 3 and 4 and 6 kg C m\(^{-2}\) in the sites 1 and 2, whereas they lacked significant difference between the land uses (\( P > 0.05 \)).

4. Discussion

Cultivations readily induce soils compacted. For example, the 0–20 cm soil BD in cultivated lands was significantly higher than those in pasture and forest soils (Evrendilek et al., 2004; Celik, 2005). In this study, however, the bulk densities showed a similar change
Table 1

<table>
<thead>
<tr>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
<th>Site 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizons (cm)</td>
<td>BD (g cm(^{-3}))</td>
<td>SOC (%)</td>
<td>TN (g kg(^{-1}))</td>
</tr>
<tr>
<td>0-10</td>
<td>1.5 ± 0.0</td>
<td>0.61 ± 0.01</td>
<td>0.19 ± 0.01</td>
</tr>
<tr>
<td>10-30</td>
<td>1.6 ± 0.0</td>
<td>0.62 ± 0.01</td>
<td>0.18 ± 0.01</td>
</tr>
<tr>
<td>30-60</td>
<td>1.6 ± 0.0</td>
<td>0.63 ± 0.01</td>
<td>0.18 ± 0.01</td>
</tr>
<tr>
<td>60-100</td>
<td>1.6 ± 0.0</td>
<td>0.64 ± 0.01</td>
<td>0.18 ± 0.01</td>
</tr>
</tbody>
</table>

Mean value ± SE is shown for each determination. \( n = 3 \). Means with different letters identify significant differences (\( P < 0.05 \)) between horizons of the land uses for each variable using Duncan’s multiple range tests. Abbreviations: BD, bulk density; SOC, soil organic carbon; TN, total nitrogen.
use changes from pasture to crop. Evrendilek et al. (2004) and Celik (2005) also found that the conversion of the pasture into the cultivated land decreased soil organic matter pool for the 0–20 cm soil depth by 49% in a Mediterranean plateau. Cultivation of alpine grassland soils in China for 8, 16, and 41 yr decreased SOC by 25%, 39%, and 55%, respectively (Wu and Tiessen, 2002). The discrepancy in above SOC losses is due to the various edaphic conditions and land uses.

In this study, the SOC losses up to 100 cm depth ranged from $-0.25$ to $3.69 \text{ kg C m}^{-2}$ in the croplands relative to the grasslands, with an average of $1.36 \text{ kg C m}^{-2}$ over about a 35-year period. The range was mainly consistent with previous estimation in the grassland-dominated region of Inner Mongolia by Wang et al. (2003), who found a decrease in SOC density of from 2.15–5 to 0–2.15 kg C m$^{-2}$ due to desert expansion and soil degradation. Wind erosion can result in a considerable amount of soil loss and deposition. Potential soil carbon losses and gains from wind erosion depend on the carbon content of erodible particles and aggregates (Eynard et al., 2005). In recent decades, vegetation degradation (Tong et al., 2004), soil desertification (Feng et al., 2001) and wind erosion (Li et al., 2005) were severe in the semiarid Inner Mongolia. All these variables would disturb the assessment for SOC in this region.

Agricultural and grassland soils have substantial potential to sequester carbon (Lal et al., 1998). Improved land management during the next 20–50 years would provide a considerable potential to increase the SOC stock in China (Wu et al., 2003). However, the effects of grazing management on SOC sequestration have not been sufficiently evaluated in the grasslands of the Inner Mongolia. The evaluation requires further works to test.

5. Conclusions

Soils play an important role in carbon cycling in terrestrial ecosystems. Land uses affect both SOC storage and CO$_2$ exchange between soils and the atmosphere. This study investigated the effects of grassland conversion to croplands on SOC in a typical grassland-dominated basin of Inner Mongolia. On an average, the conversion of grasslands to croplands induced a slight loss of SOC in the 0–100 cm soil depth over about a 35-year period in the temperate Inner Mongolia.

The croplands were reclaimed from grasslands around 1970. During such a long period, the sites were not disturbed severely. Potential frequent cultivations should be strictly avoided. It could be proposed that fallow system, adequate fertilization and conservation tillage are expected to significantly prevent SOC loss and enhance SOC sequestration in the croplands, while moderate grazing is used to increase SOC stock in the grasslands of Inner Mongolia.

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References


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