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Effects of a conversion from grassland to cropland on the different soil organic carbon fractions in Inner Mongolia, China

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Abstract: Cultivation is one of the most important human activities affecting the grassland ecosystem besides grazing, but its impacts on soil total organic carbon (C), especially on the liable organic C fractions have not been fully understood yet. In this paper, the role of cropping in soil organic C pool of different fractions was investigated in a meadow steppe region in Inner Mongolia of China, and the relationships between different C fractions were also discussed. The results indicated that the concentrations of different C fractions at steppe and cultivated land all decreased progressively with soil depth. After the conversion from steppe to spring wheat field for 36 years, total organic carbon (TOC) concentration at the 0 to 100 cm soil depth has decreased by 12.3% to 28.2%, and TOC of the surface soil horizon, especially those of 0–30 cm decreased more significantly ($p<0.01$). The dissolved organic carbon (DOC) and microbial biomass carbon (MBC) at the depth of 0–40 cm were found to have decreased by 66.7% to 77.1% and 36.5% to 42.4%, respectively. In the *S.baicalensis* steppe, the ratios of soil DOC to TOC varied between 0.52% and 0.60%, and those in the spring wheat field were only in the range of 0.18%–0.20%. The microbial quotients (qMBs) in the spring wheat field, varying from 1.11% to 1.40%, were also lower than those in the *S. baicalensis* steppe, which were in the range of 1.50%–1.63%. The change of DOC was much more sensitive to cultivation disturbance. Soil TOC, DOC, and MBC were significantly positive correlated with each other in the *S. baicalensis* steppe, but in the spring wheat field, the correlativity between DOC and TOC and that between DOC and MBC did not reach the significance level of 0.05.

Keywords: temperate grassland; cultivation; soil; total organic carbon, dissolved organic carbon; microbial biomass carbon

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1 Introduction

As one of the most important nutrient elements, soil organic carbon (SOC) is crucial indices of soil fertility and environmental quality (Liebig *et al*., 2006; Wang *et al*., 2011b). Soil also plays a vital role in controlling global climate change because it acts as the main source and sink for greenhouse gases and is the biggest C reservoir of terrestrial ecosystem (Post and Kwon, 2000; Prentice *et al*., 2001; Lal, 2004). Land use/cover change (LUCC) is widely recognized as one of the most important driving forces of soil C balance (Watson *et al*., 2000; Yang *et al*., 2009), and its effect on the soil C pool is also one of the links with great uncertainty in the current study on the carbon cycle (Gao *et al*., 2004). The results obtained by Houghton (2003) indicated that globally, the C loss amounted to about 156 PgC of the terrestrial ecosystem from 1850 to 2000 caused by the land use change, contributing about 33% of the increased atmospheric CO_2 concentration. Therefore, strengthening the study about the effect of LUCC on the soil C cycle not only can provide important data for the international environmental negotiations, but also is the need of Post-Kyoto era which aims to manage and control C cycle (Tian *et al*., 1998; Tans and Wallace, 1999).

Grassland, as one of the most dominant plant types worldwide, is the biggest terrestrial ecosystem in China, covering about 40% of the nation's total land area (Chen and Wang, 2000). Cultivation is one of the most important human activities affecting the grassland ecosystem besides grazing. The data reported by WBGU (1998) showed a global average value of 20%–30% losses in soil C stocks over 1 m reference depth due to the cultivation of grassland, roughly equivalent to the C loss of 25% to 30% for the same soil horizon when converting native forest into arable land (Houghton, 1995). The cultivation of grassland has the same important impact on global carbon cycle as the deforestation (Zhou *et al*., 2002). In China, the arable land originated from the reclamation of grassland since the 1950s has reached 1.93×10^7 hm^2, approximately accounting for 5% of the total area of the existing grassland (Su *et al*., 2005), and accordingly resulted in the great change in soil C stock.

In China, it has been extensively studied about the effect of the cultivation on the soil C pool, but most of the studies were mainly focused on the agricultural ecosystems (Zhang *et al*., 2007; Ma *et al*., 2007; Liang *et al*., 2009; Huang *et al*., 2010) and few on the grassland (Wu and Tiessen, 2002; Su *et al*., 2004; Wang *et al*., 2011a). Wang *et al*. (2011a) synthesized 133 papers published in the last 10 years on the effects on soil C of grassland management and related land use conversions in China, of these publications, only 19 reported about the conversion from grassland to cropland. Besides, the results obtained about the effects of cultivation on SOC were variable even contradictory across different grassland biomes (Su *et al*., 2002; Chen *et al*., 2004; Li *et al*., 2005; Jiao *et al*., 2009), and there still existed a big uncertainty in the response of soil C dynamics to the grassland cultivation. Furthermore, to date, there was still little knowledge about the effect of cultivation on the soil liable organic C fraction, which with a rapid turnover rate, in grassland ecosystem of China (Ma, 2006; Li *et al*., 2007a), and simultaneous observations of different soil C fractions were more rarely seen. Therefore, further research on soil organic C should be crucial for the accurate prediction of the change in grassland soil C pool and indispensable to the carbon cycle research of Chinese grassland.

In this study, the *Stipa baicalensis* (*S.baicalensis*) steppe and the spring wheat field that was reclaimed from the former in Inner Mongolia of China were chosen for investigation. The objectives of this study were as follows: (i) to evaluate the potential effects of grassland cultivation on the dynamics of different soil C fractions (total organic carbon, dissolved organic carbon and microbial biomass carbon) and their vertical distribution; (ii) to find the difference in the coupling relationships among different soil C fractions generated by land use change from temperate steppe to wheat agroecosystem and (iii) to determine the sensitivity index of grassland soil C stock to the cultivation disturbance.

2 Materials and methods

2.1 Site description

The experimental sites were chosen in the Xilin River Basin of Inner Mongolia, lying in the east of the Inner Mongolia Plateau, China (43°26′–44°39′ N, 115°32′–117°12′ E, Figure 1). The Xilin River Basin is not only the major base of livestock husbandry in China but also the core area of the Northeast China Transect (NECT) of the International Geosphere-Biosphere Program (IGBP) on global change studies. The original feature of the grassland in this transect possesses both typicality and representativeness amongst China’s temperate grassland, even the entire Eurasian grassland area (Zhang *et al*., 1997). Meanwhile, it is also seriously threatened by desertification and pasture degradation as a result of long-term over-grazing and irrational reclamation, becoming important sand sources for the sandstorm of Beijing (Lu *et al*., 2004). There was practically no human activity before the 1950s. Cultivation started in 1953 and the amount of arable land reached 3.32×10^4 ha in 2000 (Chen *et al*., 2003), all of which originated from the cultivation of grassland, particularly of the meadow steppe. Meadow steppe, distributed in the upper Xilin River, belongs to more humid grassland type with representative formations of *S.baicalensis* steppe and

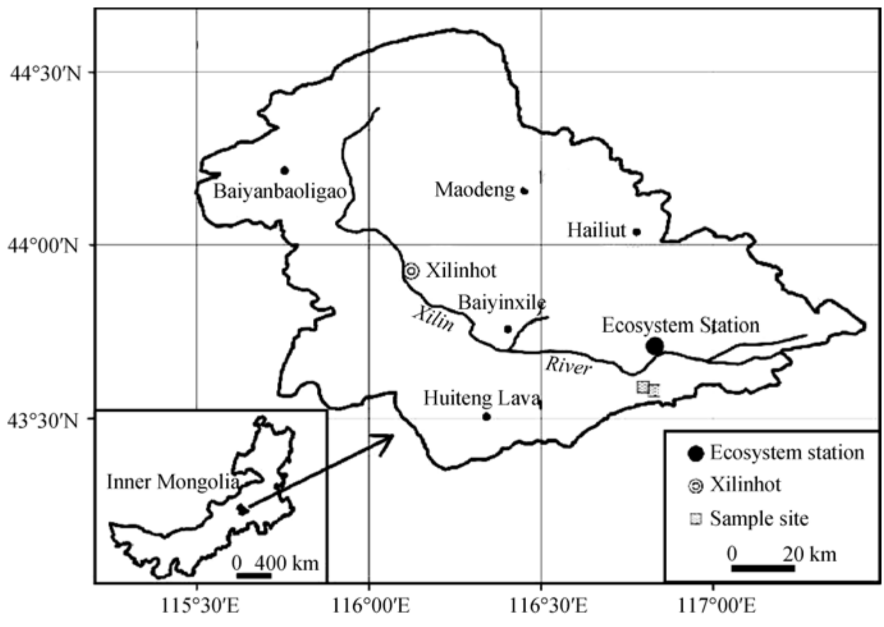

Figure 1 Map showing the sampling sites and the Xilin River Basin, Inner Mongolia

Filifolium sibiricum steppe. In our study, two experimental sites, a *S. baicalensis* steppe and a spring wheat field, were selected.

The *S. baicalensis* steppe lies between 43°30′47.9″N and 116°49′28.2″E, with an elevation of 1340–1350 m above sea level. It is utilized as a mowing pasture and the frequency of mowing is once a year, always in mid- or late August. There are abundant species characterized by mesophytes, xeromesophytes and mesoxerophytes, including *S.baicalensis*, *Filifolium sibiricum*, *Carex pediformis*, *Festuca dahurica*, *Aneurolepidium chinense*, and *Achnatherum sibiricum*. The edificator of the steppe is *S.baicalensis*, the density of plant is 29–39 species m^{-2}, with coverage of about 50%–90%. Chernozem soil dominates the steppe, with a 50 cm humus layer. The calcic horizon of soil is insignificant or only with slight $CaCO_3$ pseudomycelium deposition. Annual precipitation is about 450 mm, annual mean temperature is –1.4℃ and the ≥10℃ accumulated temperatures are 1600–1800℃.

The sample plot of the spring wheat field was adjacent to the *S.baicalensis* steppe (43°30′54.1″N and 116°48′34.4″E) and had been established in part of the *S.baicalensis* steppe in 1972. It has the same topography, precipitation and temperature conditions as to the *S. baicalensis* steppe site. The tillage system was spring wheat-fallow rotation, and spring wheat is usually sown in early April and harvested in late August. Some 150 kg ha^{-1} diammonium phosphate, 60 kg ha^{-1} special compound fertilizer for wheat containing 18% N, 16% P_2O_5 and 6% K_2O, and 37.5 kg ha^{-1}urea were applied as the base fertilizer before sowing, and there was no irrigation applied during the duration of the study.

2.2 Sampling and analysis

Soil samples were collected in growing season (from April to October) of 2008 from the two experimental plots. After removal of the litter layer, nine soil cores per site were collected randomly at depths of 0 to 10, 10 to 20, 20 to 30, 30 to 40, 40 to 70 and 70 to 100 cm using a handheld auger, respectively, and mixed evenly for the samples from the same layer. The sampling frequency was twice per month in July and August, once per month in the other months. After removing all the visible extraneous materials (including roots, stone, and organic debris) by hand, the soil samples were sieved (<2 mm) and divided into two sub-samples. One sub-sample was air-dried at ambient temperature, ground, and sieved through a 0.15 mm mesh for the analysis of total organic carbon (TOC), and the other sub-samples were kept fresh in the dark at 4℃ for the assessment of dissolved organic carbon (DOC) and microbial biomass carbon (MBC). Gravimetric water moisture was determined by oven-drying method at 105℃ for 24 h. The concentrations of TOC were measured for all the six soil horizons, and DOC and MBC were only analyzed for the upper four soil horizons at 0 to 40 cm depth.

Sub-samples were analyzed for TOC using the $K_2Cr_2O_7$ oxidation method (Tiessen and Moir, 1993).

DOC extraction began within 48 h of field collection. The extraction of soil DOC was conducted using 10 g fresh soil with 50 ml of ultrapure water in a 100 ml centrifuge bottle. The soil/water suspensions were shaken for 30 min and centrifuged at 5000 rpm for 10 min, and then the supernatants were vacuum filtered through 0.45 μm polycarbonate filter membrane. DOC was quantified with a total organic carbon analyzer (Elementar High TOC Ⅱ).

Soil MBC was determined by the chloroform fumigation–extraction method. Three sub-samples of fresh soil (equivalent to 25 g dry soil) were fumigated in a 25℃ dark room with ethanol-free chloroform for 24 h and extracted with 100 ml 0.5 M K_2SO4, shaken for 30 min, filtered by quantitative filter paper, and the extract was vacuum filtered through 0.45μm polycarbonate filter membrane. While the unfumigated control soil was also extracted in the same manner. The K_2SO_4-extractable soil C was measured by Elementar High TOCⅡ total organic carbon analyzer. The MBC was calculated according to the equation: $MBC=E_c/0.45$, where E_c was organic C extracted from fumigated soil minus organic C extracted from unfumigated soil.

2.3 Data analysis

All the statistical analyses were conducted using a SPSS 13.0 software package (SPSS Inc., 2001). The Paired-samples T-test was used to test the differences in the TOC, DOC, and MBC between the two sample sites, and the one-way analysis of variance (ANOVA) was performed on the data of TOC, DOC, and MBC from different soil depths of the two sample sites, respectively. Correlativity among different soil C fractions was analyzed using a Pearson test. Graphs were prepared using Excel® 2003 (Microsoft Corporation, 2003).

3 Results

3.1 Effects of grassland cultivation on the concentration and vertical distribution of TOC

The TOC concentrations in surface soil, especially in the top 30 cm soil horizons, decreased significantly ($p<0.01$) after the grassland has been cultivated for nearly 40 years (Table 1). While the decreasing amplitude of TOC in the soil layer below 30 cm was relatively smaller and the difference in TOC between two sample sites did not reach the significance of 0.05. After the conversion from the *S. baicalensis* steppe to the spring wheat field, the concentrations of TOC in the soil layer of 0 to 100 cm in depth decreased by about 12.3%–28.2%, and the decreasing amplitude basically attenuated with the soil depth exception for that of 70–100 cm.

Table 1 The comparison of soil TOC concentrations at different soil depths between the *S. baicalensis* steppe and the spring wheat field

Soil depth (cm)	*S. baicalensis* steppe (g/kg)	Spring wheat field (g/kg)	Decreased amount (g/kg)	Decreased percentage (%)
0–10	23.81±1.21 a	17.10±1.40 c	6.71	28.2
10–20	22.82±1.61 a	16.70±0.69 c	6.12	26.8
20–30	17.50±1.52 b	13.92±1.97 d	3.58	20.5
30–40	14.62±3.96 d	12.44±1.33 d	2.18	14.9
40–70	9.64±3.35 f	8.45±2.60 f	1.19	12.3
70–100	6.47±3.95 g	5.10±1.12 g	1.37	21.2

* Values followed by the same letter in the same column are not significantly different at $P<0.05$.

Similar with those of native *S.baicalensis* steppe, the concentrations of soil TOC in the spring wheat field also decreased with soil depth. The cultivation of meadow steppe has not changed the vertical distribution pattern of soil TOC, but reduced the vertical variation of TOC in the plough horizon. In the *S. baicalensis* steppe, significant differences (p<0.05) in TOC were found among different soil layers except for that between 0–10 cm and 10–20 cm, whereas, the difference in soil TOC in the spring wheat field between 0–10 cm and 10–20 cm or that between 20–30 cm and 30–40 cm were all insignificant (Table 1). This may be explained by the consideration that the experimental plots were situated in tableland with higher elevation and affected seriously by the wind erosion, and there was a thin sand layer all the year round which decreased the TOC concentration of 0–10 cm soil layer evidently. In addition, the soil of plough horizon was mixed evenly due to the tillage activity was also one of the important reasons for the insignificant vertical variation in soil TOC in the spring wheat field besides the effect of wind erosion.

3.2 Effects of grassland cultivation on DOC and its variation dynamics

The term DOC is defined as comprising any organic C passing through a 0.45 μm filter and the entire pool of water soluble organic C either absorbed on soil or sediment particles or dissolved in soil interstitial water (Xi *et al*., 2007). DOC contributes significantly to soil nutrient cycling, and also plays an important role in the transport, geochemical reactivity and bioavailability of metals and organic compounds, etc (Buckingham *et al*., 2008).

Figure 2 shows the differences in the soil DOC concentration and its vertical distribution between the *S. baicalensis* steppe and the spring wheat field. From the figure one can find that after land use change from *S. baicalensis* steppe to spring wheat field, DOC concentrations of different soil layers especially those of 0–20 cm depth decreased significantly ($P_{0\text{-}10}$, $P_{10\text{-}20}$=0.01, $P_{20\text{-}30}$, $P_{30\text{-}40}$=0.05), and the DOC in the spring wheat field decreased by 77.1% (0–10 cm), 75.5% (10–20 cm), 67.3% (20–30 cm) and 66.7% (30–40 cm) respectively, as compared with those in steppe plot.

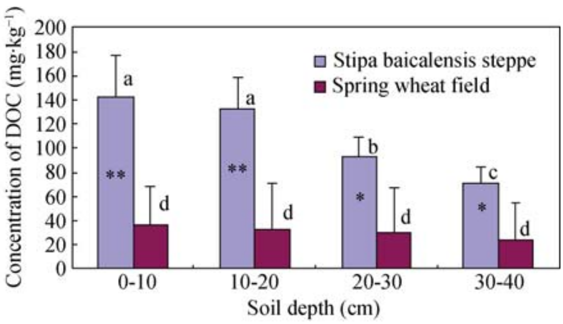

Figure 2 The amounts and distributions of soil DOC concentration in the *S. baicalensis* steppe and the spring wheat field. Values are mean± SE (n=9). Means with different letters indentify significant difference (p<0.05) between different horizons of each site. * denotes the same soil horizon of two sample sites differ significantly at p<0.05 and ** at p<0.01.

In addition, the soil DOC in the two sites both decreased markedly with soil depth. In the *S. baicalensis* steppe, the soil DOC concentrations of 10–20 cm, 20–30 cm and 30–40 cm decreased by 6.9%, 34.2% and 49.8% respectively, compared with that of 0–10 cm. Furthermore, similar with that of the soil TOC, significant differences (p<0.01or p<0.05) in DOC among different soil layers of the *S. baicalensis* steppe were also found except for that between 0–10 cm and 10–20 cm. While in the spring wheat field, compared with that of 0–10 cm, the DOC concentrations of corresponding three soil layers at the 10 to 40 cm depth only decreased by 0.5%, 6.2% and 27.0%, respectively, and what's more, the differences in DOC between any two soil layers did not reach the significance level of 0.05. The cultivation of steppe reduced the vertical differentiation of soil DOC. Analyzing the reasons, it was probably that the conversion of steppe to arable land often induced a looser soil structure due to the long-term cultivation practices such as plowing, harrowing, fertilization, etc. (Jiao *et al.*, 2009), which facilitated the leaching and infiltration of DOC from the upper to deeper soil horizon in the rainy season and accordingly reduced the difference of DOC among different soil horizons.

The ratio of soil DOC to TOC (DOC/TOC) is called as the DOC allocation ratio (Garten *et al.*, 1999). The index of DOC allocation ratio could eliminate the effect, caused by the difference of TOC in different sample sites, on DOC to a certain degree and reflect the status of soil C pool as well as the difference in soil quality among different sites more truly. From Table 2, one can see that the DOC allocation ratio in the *S.baicalensis* steppe varied between 0.52% and 0.60% and basically attenuated with the soil depth, while those in the spring wheat field only varied from 0.18% to 0.20% with insignificant difference among different soil layers. The results of previous researches showed that the higher the DOC allocation ratio was, the more active and unstable the SOC would be (Zhu *et al.*, 2006). In this study, the ratios of soil DOC/TOC for different soil layers in the *S. baicalensis* steppe were all significantly higher than that at the same soil depth in the spring wheat field, as illustrated that the quality of soil organic C in the *S.baicalensis* steppe was much better, but at the same time, the organic C of the steppe plot was also more liable to be decomposed by microorganism. The soil C pool in the *S. baicalensis* steppe was more sensitive to the natural or anthropogenic perturbations than that in the spring wheat field. This was probably because that the spring wheat field has been cultivated for nearly 40 years with spring wheat-fallow rotation tillage system in recent years, and the organic C of soil has tended to be stable after a great amount of C loss at the initial stage of cultivation (Purakayastha *et al.*, 2009).

Table 2 DOC allocation ratio in the *S. baicalensis* steppe and the spring wheat field (%)

Sample site \ Soil depth	0–10 cm	10–20 cm	20–30 cm	30–40 cm
S. baicalensis steppe	0.60	0.58	0.54	0.52
Spring wheat field	0.18	0.19	0.20	0.19

3.3 Effect of grassland cultivation on variation of MBC and microbial quotient

Microbial biomass C (MBC) is one of the important fractions of soil organic matter and the general indices to soil microbial activities (Wick *et al.*, 1998; Li *et al.*, 2004). As an agent of labile nutrients, it is critically important for soil quality establishment and plays an essential role in the short-term turnover of nutrients (Jiang *et al.*, 2006).

Table 3 shows the concentrations of MBC at different soil depths in the *S.baicalensis* steppe and the spring wheat field. One can find from Table 3 that the MBC concentrations at the 0 to 40 cm soil depth were 372.75, 372.17, 268.96 and 218.72 mg/kg, respectively in the *S.baicalensis* steppe and 219.95, 233.60, 154.87 and 138.87 mg/kg, respectively in the spring wheat field. The MBC concentrations of the four soil horizons in the *S.baicalensis* steppe were 41.0%, 37.2%, 42.4% and 36.5% higher than those in the spring wheat field, and the difference in soil MBC concentrations of the same layer between the *S.baicalensis* steppe and the spring wheat field all reached the significance level of 0.05.

Table 3 The effect of grassland cultivation on the MBC concentrations and microbial quotient (qMB)

Soil depth (cm)	*S. baicalensis* steppe			Spring wheat field		
	MBC (mg/kg)	TOC (g/kg)	qMB %	MBC (mg/kg)	TOC (g/kg)	qMB (%)
0–10	372.75 a	23.81	1.57	219.95 c	17.10	1.29
10–20	372.17 a	22.82	1.63	233.60 c	16.70	1.40
20–30	268.96 a	17.50	1.54	154.87 d	13.92	1.11
30–40	218.72 b	14.62	1.50	138.87 d	12.44	1.11

* Values followed by the same letter in the same column are not significantly different at $p<0.05$.

In addition, the concentrations of soil MBC in the two sample sites were all basically attenuated with the depth except for that of 10–20 cm soil horizon in the wheat field. In the wheat plot, the crop residues and litter, which were the important source for soil MBC, were removed to the lower horizon through the plough activity after harvest (Franzluebbers, 2005). This was perhaps one of the important reasons for the higher MBC contents at 10–20 cm than at 0–10 cm soil depth. In addition, the change of soil structure after cultivation also intensified the wind erosion which carried more fine soil particles containing organic carbon out of the ecosystem from surface soil than from subsoil horizon (Lal, 2000; Li *et al.*, 2007b). But at the same time, the results of statistical analysis also indicated that in the spring wheat field, significant differences only existed between the upper two (0–10 cm, 10–20 cm) and the deeper two layers (20–30 cm, 30–40 cm). And in the *S.baicalensis* steppe, except the upper three soil layers (0–10 cm, 10–20 cm, 20–30 cm) differing from 30–40 cm soil layer at the 0.05 probability level, the differences in MBC concentrations between any other two soil horizons were also all insignificant. That is, whether in the *S. baicalensis* steppe or in the spring wheat field, the soil MBC concentrations of 0–10 cm or 0–20 cm were all relatively higher and the microorganism was fairly active and more sensitive to the change of soil C pool in this soil horizon, as can also be detected from the evident inflection point at the 20 cm soil depth in the vertical variation curve of MBC concentration (Figure 3).

The microbial quotient (qMB) was the ratio of soil MBC to TOC, and the change of which reflected the conversion efficiency of soil organic matter input to soil MBC (Sparling, 1992). From Table 3 we can see that the variation range of qMB in different layers in the *S.baicalensis* steppe was from 1.50% to 1.63%, all higher than that of the same layer in the spring wheat field which varied between 1.11% and 1.40%, as illustrated that the concentrations of MBC decreased more than those of TOC during the cultivation of the steppe. The cultivation not only resulted in numerous C loss, but also led to the decline in the availability of soil organic C. In addition, similar with the absolute value of MBC, the subsoil horizon (10–20 cm) had the highest qMB among different soil layers in both sample sites.

3.4 The coupling change of different soil organic carbon fractions (TOC, DOC and MBC)

The concentrations of different soil C fractions at four soil depths for the *S.baicalensis*

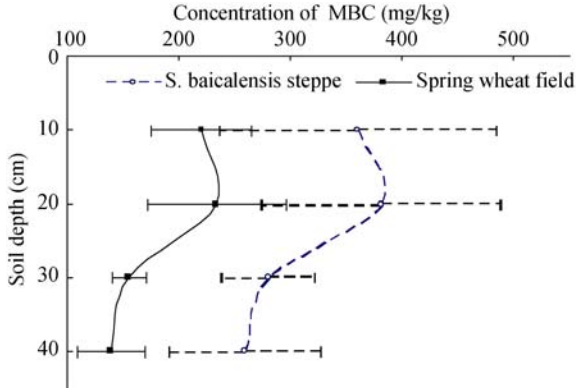

Figure 3 Soil MBC profiles of 0–40 cm in the two sample sites. Error bars indicate the standard error of the mean (n=9)

steppe and the spring wheat field were listed in Table 4. Different C fractions (TOC, DOC and MBC) in both sites expressed the similar vertical variation. Furthermore, the difference between the two sample sites in the three organic C fractions were also higher in the upper soil horizon than those in the deeper horizon with the exception of that in MBC at 20 to 30 cm soil depth, and in descending order, the decreasing amplitudes of three fractions were DOC > MBC> TOC. In general, the soil liable C, especially soil DOC, was more sensitive to the land use change than TOC, and can be used as the important sensitivity index of soil C pool to the grassland cultivation disturbance.

Table 4 Effects of grassland cultivation on different C fractions

Soil depth (cm)	*S. baicalensis* steppe (mg/kg)			Spring wheat field (mg/kg)			Decreasing amplitude (%)		
	TOC	DOC	MBC	TOC	DOC	MBC	TOC	DOC	MBC
0–10	2380.51	142.03	372.75	1709.59	32.51	219.95	28.2	77.1	41.0
10–20	2281.83	132.17	372.17	1670.10	32.35	233.60	26.8	75.5	37.2
20–30	1750.19	93.42	268.96	1391.86	30.50	154.87	20.5	67.3	42.4
30–40	1462.08	71.25	218.72	1243.68	23.75	138.87	14.9	66.7	36.5

The correlation matrix revealed that soil TOC, DOC, and MBC were significantly positive correlated with each other in the *S.baicalensis* steppe (Table 5), as on one hand showed that total C storage was a major determinant of the amount of labile organic C present, and on the other hand, it also indicated that there existed a closed relationship among different liable organic C fractions. DOC was both the product of metabolism and the main energy source of soil microorganism, and determined the activity and quantity of soil microorganism (Kalbitz *et al*., 2003). Whereas, the activity of soil microorganism was also the important factor influencing the generation and release of DOC, and contributed greatly to the change of soil water-soluble C pool (Haynes, 2000). But in the spring wheat field, the correlation was not significant between any two fractions except that between TOC and MBC. This was probably due to the much more loss in DOC during the process of cultivation, which resulted in the change of DOC was out of step with those of the other fractions. The cultivation disturbance has changed the inherent relationship of different organic C fractions in natural ecosystem. This was quite similar to the results obtained by Shrestha and Stahl

(2008) in their study on the semi-arid sagebrush steppe of Wyoming, USA. The research results indicated that the long-term grazing promoted the loss of the labile soil C and weakened the correlation between TOC and the other labile soil C fractions.

Table 5 Correlativity among different C fractions in the *S. baicalensis* steppe and spring wheat field

	S. baicalensis steppe			Spring wheat field		
	TOC	DOC	MBC	TOC	DOC	MBC
TOC	1	0.999**	0.965*	1	0.895	0.973*
DOC		1	0.957*		1	0.821
MBC			1			1

* Significance level of correlation is 0.05; ** significance level of correlation is 0.01.

4 Discussion

4.1 Grassland cultivation and the change of TOC in different soil depths and its age effect

The changes of different fractions of SOC were mainly decided by the balance between the decomposition of SOC and the input of organic C to the soil from the plant residues or litter. In this study, the concentrations of TOC in the uppermost 30 cm soil layer decreased significantly after the conversion from steppe to the spring wheat field, which was probably due to the combined effects of rapid decomposition of soil organic matter coupling with a significant reduction in C additions by the plant roots and debris in the plough horizon under cultivation. This was in good agreement with some other studies. Result obtained by Wang *et al*. (1999) indicated that agricultural practices in the grassland soil have resulted in a significant decrease in total soil C concentration (26% reduction), and most of the C loss occurred in the uppermost 30 cm soil horizon, and below 30 cm depth, both natural and disturbed soils have about the same C content. The experiment conducted by Wang *et al*. (1998) also indicated that after having been cultivated for 24 years, soil TOC at the depth of 0–35 cm in the meadow steppe was seriously affected by the tillage, but the decreased amplitude was about 35%–38%, slightly higher than 20.5%–28.2% obtained in our study which was measured after having been reclaimed for 36 years in the same area. The reason for this difference was probably due to the age effect. This was further proved by results obtained by Jiao *et al*. (2009). The experiment conducted in the Taipusi county of Inner Mongolia in China suggested that reclamation of cropland for 10 years, 15 years and 20 years lost TOC in 0–30 cm soil horizons, by 34%, 14% and 18%, respectively, compared with that of grassland, and with an increased age of cropland, the SOC density increased. Stable carbon may play some role in this age effect. The relatively stable part of soil carbon such as the mineral-associated organic carbon from previous land uses (grassland) should be mineralized and released gradually, but the part from current land use (cropland) may be also accumulated and converted from the particulate organic carbon at the same time (Yin, 2008; Jiao *et al*., 2009). Therefore, the change in TOC in the new land use was decided by the equilibrium of the two above-mentioned processes. In addition, the human inputs of organic matter through fertilization and spring wheat-fallow management in the recent years may also contribute to the age effect to a certain extent.

4.2 The uncertainty in the effect of cultivation on the TOC in different grassland regions

Marked difference was found across different Chinese grassland biomes in the previous researches (Table 6). Most of experimental results showed that the cultivation of grassland would reduce the organic carbon sequestration by soil. Results obtained by Jiao *et al.*(2009) indicated that cultivation of typical steppe worsened soil erosion, and after 20 years cultivation, soil organic carbon decreased by 18%. The results obtained by Yin (2008) in sub-alpine meadow and by our present study in temperate meadow steppe also found a significant decrease in TOC by 20.1% and 20.5%–28.2% after being cultivated for 33 years or 36 years, respectively. This range was consistent with previous report by WBGU (1998), who estimated a SOC loss of 20%–30% in the cultivated soils relative to their non-cultivated counterparts at a global scale and was slightly lower than that of 36.0 % synthesized by Wang *et al*. (2011a) at a national scale of China. But some other studies have also demonstrated that the cultivation of grassland had increased soil TOC. For example, Li *et al*. (2005) found that SOC at the 0 to 40 cm soil depth increased from 94.38 tC hm^{-2} to 95.89 tC hm^{-2} after 20 years cultivation of alpine meadow. The research results of Horqin Sandy Land reported by Chen *et al*. (2004) showed that the TOC concentration of the 0–20 cm has increased by about 5.96% after grassland conversion to arable land for 8 years. That means if we adopted proper land use intensity and management in different grassland regions according to their special climate and soil conditions, the cultivation of grassland would not certainly lead to the depletion of soil C pool, and the C depletion can also be re-sequestered through adoption of recommended soil and crop management practices, such as conversion from plow tillage to no tillage, frequent use of winter cover crops in the rotation cycle, or giving up cultivation in the extremely degraded land (Lal, 2002). However, what needed to be pointed out particularly here was that if the farmland, which being given up cultivation, was under a harsh climate condition, the wind erosion of abandoned soil would be more active, and the soil quality of them perhaps became much worse. Therefore, only reducing the conversion of grassland with poor soil quality or under extremely adverse environmental condition to cropland initially as much as possible was the most effective measure to maintain or increase the C sequestration by soil.

Table 6 The effect of grassland cultivation on the TOC in different grassland regions of China

Grassland type	Location	Change after cultivation	References
Alpine meadow	37°29′–37°45′N,101°12′–101°23′E	+1.6% (0–40 cm)	Li *et al*., 2005
Sub-alpine meadow	38°20′N,101°30′E	–20.1% (0–15 cm)	Yin, 2008
Typical steppe	41°49′–41°50′N, 115°13′–115°15′E	–18.0% (0–30 cm)	Jiao Y *et al*., 2009
Sandy grassland	42°58′N,122°21′E	+5.96%(0–20 cm)	Chen *et al*., 2004
Meadow steppe	43°30′–43°31′N, 116°48′–116°50′ E	–20.5% to –28.2% (0–30 cm)	Present study
Temperate grassland	China average	–36.0% (0–20 cm)	Wang *et al*., 2011
Temperate grassland	Global average	– 20% to –30% (0–100 cm)	WBGU, 1998

* Plus (+) means the cultivation increases the TOC, and minus (–) means the effect is decreasing TOC contents.

4.3 Grassland cultivation and the dynamics of the liable organic C

Most of the existing research found that the conversion from the natural ecosystem to cropland would lead to the reduction of liable organic C fractions. Cookson *et al*. (2007) found that the concentration of DOC in the forest was about three times as that of arable land. Results obtained by Zhang *et al*. (2005) in Sanjiang Plain of China indicated that wetland cultivated for one year resulted in 55% decline in soil DOC concentrations. The experiment conducted in the Jianou city of Fujian Province in China suggested that the concentrations of soil DOC and MBC in 0–10 cm declined respectively by 64.60% and 54.78% while woodland conversed into orchard land (Mao *et al*., 2008). Moreover, results reported by Delprat (1997) showed that there existed difference between the long-term and short-term effect of cultivation on the soil liable organic C, and during the first stage of three years, cultivation intensified mineralization of the initial organic matter, which led to an increase of 2- to 5-fold in the quantity of DOC, then DOC concentrations began to decrease with time of cultivation and tended to stable gradually. After nearly 30 years of cultivation, mean DOC concentrations were 4- to 6-fold less than those of the first stage. The research results illustrated that the cultivation of natural ecosystem would reduce the soil DOC concentration from the long-term point of view, but the DOC concentrations may have opposite changes of increasing or decreasing under the influence of short-term cultivation. Regarding their adverse influence on the global C balance and soil quality, and to ensure more accurate evaluation about the effect of cultivation on soil liable organic C, long-term dynamic monitoring on it should be strengthened in future study.

5 Conclusions

(1) The concentrations of TOC, DOC and MBC decreased by 12.3%–28.2%, 66.7%–77.1%, 36.5%–42.4%, respectively after the conversion of *S. baicalensis* steppe to spring wheat field for 36 years. DOC concentration decreased the most significantly among the three C fractions and was the important sensitive indicator for predicting and evaluating the response of soil C pool to grassland cultivation.

(2) In the *S. baicalensis* steppe, the concentrations of soil DOC accounted for about 0.52% to 0.60% of TOC, but in spring wheat field, the ratio of DOC/TOC only varied from 0.18% to 0.20%. The qMBs in the spring wheat field (1.11%–1.40%) were also lower than those in the steppe plot (1.50%–1.63%). The cultivation of grassland not only resulted in the numerous C loss of soil, but also led to the decline in the availability of SOC and the soil quality.

(3) Soil TOC, DOC, and MBC were significantly positive correlated with each other in the *S. baicalensis* steppe, but the cultivation of steppe weakened the correlation and resulted in the response of liable organic C fractions to the cultivation was out of step with that of TOC. Considering the importance of soil liable organic C in the C cycle process of grassland, it is not favorable to only study on the effect of cultivation on the TOC for accurately evaluating the effect of grassland cultivation on the soil C balance and its contribution to the greenhouse effect.

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