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Spatial patterns of soil organic carbon fractions and their control in temperate grasslands of China

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ABSTRACT

Soil organic carbon (SOC) fractions (light fraction organic carbon, LFOC; heavy fraction organic carbon, HFOC), which have different sensitivities to environmental change, have been widely used as an effective way to assess the soil carbon pool. To explore the spatial patterns of SOC, its fractions (LFOC, HFOC), and their influential factors in temperate grasslands of China, 16 study sites were selected without significant human disturbance along temperature and precipitation gradients in Inner Mongolia, China. These study sites covered three community types: meadow steppe, typical steppe, and desert steppe. Soil samples were collected from five discrete depth intervals (0–10 cm, 10–20 cm, 20–40 cm, 40–60 cm, and 60–100 cm) for each study site in July 2013, the peak period for plant growth. The variations in SOC, LFOC, HFOC, and their major influential factors were analyzed in the three community types and at five soil depths. The effects of abiotic and biotic factors on SOC and its fractions were evaluated. The coefficient of variation for LFOC was lower than that for HFOC among the different grassland types and higher among the different vertical depths. The LFOC in the 0–10 cm soil layer was significantly higher than that in the substratum, whereas HFOC did not differ significantly among the different soil depths. LFOC/SOC in meadow steppe, typical steppe, and desert steppe (7.34%, 8.29%, and 9.41%, respectively) appeared to be lower when compared with previous studies (3%–48%). Both LFOC and HFOC were significantly positively correlated with mean annual precipitation (MAP), soil moisture, aboveground biomass, root biomass, soil microbial biomass carbon (MBC), clay content, soil total nitrogen content (STN), and soil total phosphorus content (STP), and negatively correlated with mean annual temperature (MAT), soil temperature, and soil pH. Among these factors, root biomass, MBC, STN, and STP were the most important influential factors for LFOC, whereas soil moisture, MAP, STN, and STP were the most important for HFOC. STN had a greater influence on LFOC than on HFOC, whereas STP had a greater influence on HFOC than on LFOC. In conclusion, labile C occurred in the surface soil and was closely correlated with biotic factors, whereas steady fraction C did not significantly change with soil depth and was more closely correlated with abiotic factors in temperate grasslands. Our results emphasize the importance of STN and STP in affecting the variation in SOC fractions, and could provide a theoretical basis for accurately predicting SOC stabilization and its response to global climate change.

1. Introduction

In the terrestrial ecosystem, the dynamic change in the soil organic carbon (SOC) pool is an important and difficult problem in global change [1]. The IPCC Fourth Assessment Report noted that climate warming has reduced global SOC by 2%, with these losses mainly occurring in grassland ecosystems; thus, it is very important to study the stability of SOC in grasslands. The SOC pool can be divided into functional fractions with different turnover rates according to their time of turnover, chemical properties and so on [2–5]; light fraction organic carbon (LFOC) characterizes the labile carbon (C) pool and heavy fraction organic carbon (HFOC) characterizes the stable C pool [6–7]. Because of the sensitive differences between the response of LFOC and HFOC to environmental changes, it is helpful to explore the response of SOC fractions to understand the stability of SOC in grassland.

Studies on grassland soil functional fractions often focus on the effects of degradation, natural restoration, grazing intensity, conversion of cropland to grassland, and changes along different altitudinal levels on LFOC and HFOC. Studies show that LFOC in grassland accounts for 3%–48% of total SOC [8–9], and the ratio decreases with increasing soil depth [10]. LFOC and HFOC were reduced by wetland degradation into meadow in the Zoigê Plateau [11]. LFOC in the surface layer was significantly higher than in other soil layers, whereas HFOC decreased with depth from 0 to 50 cm in an alpine meadow [12]. Natural restoration and reduced grazing intensity led to significant increases in LFOC and HFOC in the Qinghai–Tibet Plateau alpine grassland (0–10 cm) [13], Horqin Sandy Desertification Grassland (0–20 cm) [14] and Inner

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Table 1
Characteristics of the sampling sites.

Locations of study sites	Longitude and latitude	Grassland type	Dominant and subdominant plant species	MAP/mm	MAT/°C
Ergun	119°22′53.04′′ E 50°10′22.35′′ N	Meadow steppe (MS)	*Stipa baicalensis*, *Leymus chinensis*, *Potentilla chinensis*	368	−1.7
Dongwuqi	118°24′45.10′′ E 45°47′56.74′′ N	Meadow steppe (MS)	*S. grandis*, *L. chinensis*, *Melilotoides ruthenica*	327	0.6
Old Barag Banner	119°12′45.75′′ E 49°59′51.24′′ N	Meadow steppe (MS)	*S. grandis*, *L. chinensis*, *P. chinensis*	368	−1.9
Duolun	116°40′47.76′′ E 42°27′59.04′′ N	Meadow steppe (MS)	*P. tanacetifolia*, *Sanguisorba officinalis*	390	0.6
Saihanba	117°8′45.56′′ E 42°33′54.43′′ N	meadow steppe (MS)	*L. chinensis*, *P. chinensis*, *Galium verum*	433	0.6
Abaga Banner	114°56′48.72′′ E 44°1′59.88′′ N	Typical steppe (TS)	*S. krylovii*, *Artemisia frigida*, *L. chinensis*	249	1.0
Xilinho	116°33′9.36′′ E 43°32′25.8′′ N	typical steppe (TS)	*L. chinensis*, *S. grandis*, *Agropyron cristatum*	329	1.6
Zhengxiangbai Banner	115°17′12.06′′ E 42°23′40.38′′ N	Typical steppe (TS)	*S. krylovii*, *Convolvulus ammannii*	326	2.7
Dongsheng District	109°48′9.9′′ E 39°50′48.24′′ N	Typical steppe (TS)	*S. krylovii*, *L. chinensis*, *A. frigida*	357	6.7
Ejin Horo Banner	109°24′49.38′′ E 39°31′49.92′′ N	Typical steppe (TS)	*L. chinensis*, *Lespedeza bicolor*	382	5.7
Sonid Left Banner A	113°6′55.38′′ E 44°35′25.68′′ N	Desert steppe (DS)	*S. breviflora*, *Agropyron cristatum*, *A. frigida*, *Allium polyrrhizum*	204	1.0
Sonid Left Banner B	114°4′13.8′′ E 43°53′22.5′′ N	Desert steppe (DS)	*Kochia prostrata*, *Cleistogenes songorica*, *S. breviflora*, *A. frigida*	223	2.1
Sonid Right Banner	112°21′35.58′′ E 42°32′55.56′′ N	Desert steppe (DS)	*S. breviflora*, *Caragana microphylla*, *A. frigida*	198	3.8
Siziwang Banner	111°53′55.86′′ E 41°46′37.14′′ N	Desert steppe (DS)	*S. breviflora*, *Cleistogenes songorica*, *Neopallasia pectinata*	227	3.5
Damao Banner	110°25′5.64′′ E 41°36′58.08′′ N	Desert steppe (DS)	*S. breviflora*, *L. chinensis*, *A. frigida*, *N. pectinata*	267	7.5
Etuoke Banner	107°57′40.38′′ E 38°58′19.2′′ N	Desert steppe (DS)	*Artemisia capillaris*, *N. pectinata*	267	7.5

MAP: Mean annual precipitation; MAT: Mean annual temperature.

Mongolia grassland (0–45 cm) [15]. Conversion of cropland to grassland significantly increased LFOC and HFOC [16–17]. The LFOC content in the Qinghai–Tibet Plateau increased with increasing altitude and decreased with soil depth from 0 to 100 cm [18]. However, there have been few studies on the spatial patterns of SOC fractions and their influential factors among different natural grassland types and depths.

The effects of abiotic and biotic factors on LFOC, HFOC and SOC in grassland is still unknown. Previous studies showed that the spatial variation of SOC in grassland is mainly related to soil moisture, temperature, soil clay content and other factors [19–22]. Soil moisture has different effects on LFOC and HFOC; changes during wetland restoration into meadow [11] and increased water content of cultivated land [23] make LFOC more susceptible to change. In farmland, soil clay content can affect the distribution of LFOC and HFOC [24–25] and a positive correlation between clay and HFOC content was reported [26]. Root biomass as a major source of organic matter affects the vertical distribution of C fractions [10]. Microorganisms can have complex impacts on both LFOC and HFOC; microbes decompose plant residues to LFOC, then some of the LFOC and recalcitrant compounds bind together with soil particles, fungal hyphae, bacterial cells, fine roots and polysaccharides from plants and microorganisms to form stable HFOC [27]. The movement of new active organic C down through the soil and the stimulation of microbial metabolism will also accelerate the decomposition of organic matter in deeper soil [28]. Studies have shown that the effect of nitrogen (N) addition on LFOC is controversial, but it is more likely to be positively correlated with LFOC [29]. In conclusion, there is a lack of systematic understanding of the factors determining SOC fractions.

Inner Mongolia is an important component of Eurasian grassland, which is the main distribution area of temperate grassland in China and is very sensitive to climate and environmental changes. To understand the stability of the soil C pool, our study was designed along a climatic transect of Inner Mongolian temperate grassland to explore: (1) the spatial patterns of SOC fractions in meadow steppe, typical steppe and desert grassland with soil depth, and (2) the relative contributions of abiotic and biotic factors on SOC fractions. We hypothesized that: (1) LFOC and HFOC content would follow the order of meadow steppe

Table 2
Characteristics of soil organic carbon fractions.

Soil organic carbon fractions	Typical steppe	n	Minimum	Maximum	Mean	Standard deviation	Variable coefficient (CV)/%	
							[a]CV %$^{(1)}$	[b]CV %$^{(2)}$
Light fraction organic carbon/(mmol/kg)	MS	75	16.07	630.52	126.02	137.42	109.05	31.59
	TS	75	1.56	414.26	86.97	85.67	98.51	
	DS	90	1.65	222.58	56.65	46.64	82.33	
Heavy fraction organic carbon/(mmol/kg)	MS	75	416.39	3997.19	1584.01	831.28	52.48	44.40
	TS	75	231.52	2449.12	962.40	474.78	49.33	
	DS	90	71.57	2367.99	545.62	429.87	78.79	

[a] CV%: Coefficient of variation based on vertical patterns.
[b] CV%: Coefficient of variation among community types.