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Changes in soil carbon storage due to over-grazing in *Leymus chinensis* steppe in the Xilin River Basin of Inner Mongolia

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Abstract—The long-term changes in soil carbon storage due to land-use change in *Leymus chinensis* steppe in the Xilin River Basin of Inner Mongolia since 1950's was examined. The results showed that over-grazing was the most serious and wide-spread non-sustainable land-use practice in the area, an average of about 12.4% of the total carbon initially stored in soils (0—20cm soil layer) for seven major *L. chinensis* communities in the Xilin River Basin has been lost due to over-grazing over the 40-year period. Most carbon loss due to over-grazing was from the active and slow soil carbon pools which had a residence time of 10's of years.

Keywords: over-grazing; soil carbon; *Leymus chinensis* steppe; Xilin River Basin.

Land-use change is one of the major contributions to increases in atmospheric CO_2 concentrations. It is estimated that land-use changes release 0.6 to 2.6 Pg C/a to the atmosphere currently(Dale, 1994).

The most important change in the amount of soil carbon in terrestrial ecosystems was produced by cultivation of grasslands to croplands, about one-third of the total loss of carbon from soils of the world since 1850 occurred in the grasslands of the temperate zone (Houghton, 1995). When grasslands are cultivated to croplands, about 20%—40% of the carbon initially held in soils will be released through enhanced soil respiration (Buyanovsky, 1995; Mann, 1986). In fact, besides cultivation, another non-sustainable land-use practice, namely, livestock over-grazing, has been proved to be the most powerful human influence on grasslands, which is far more serious and wide-spread than that of conversions of grasslands to croplands. In terms of both areas affected and the time pattern, over-grazing induced changes in soil carbon storage might be no less than that of cultivation (Graetz, 1994). Therefore, understanding the impact of over-grazing on soil carbon storage in grasslands, especially temperate grasslands, is of great significance in correctly evaluating effects of land-use change on atmospheric CO_2 concentrations.

1 Study area

The Xilin River Basin is located in the central part of Inner Mongolia at 43°26′—44°39′ N and 115°32′—117°12′ E, and covers a total area of about 10786km^2. The climate is continent middle

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temperate semi-arid. It is generally cold and dry in winter but warm and wet in summer. Annual mean temperature ranges between −1.4℃ to −0.4℃, and annual precipitation varies between 310—400 mm. Dominant soils are chestnut and chernozem. Vegetation is dominated by *Leymus chinensis* steppe, which covers about one-third of the total land area in the Xilin River Basin (Libo, 1988). *L. chinensis* steppe is widely distributed in the Euro-Asia steppe zone and representative of typical temperate grasslands in Inner Mongolia (Wu, 1980).

Historically, *L. chinensis* steppe in the Xilin River Basin had been used primarily as grazing lands. It is believed that *L. chinensis* steppe in the area had been in good conditions until the establishment of the Baiyinxile livestock farm in the early 1950s when large scale settlement of humans began to occur. Increased population in the area depended their living completely on livestock raising, therefore, the grazing pressure on grasslands has become intensified, and degradation of grasslands occurred since then(Libo, 1988).

2 Methods

Changes in soil carbon storage in *L. chinensis* steppe in the Xilin River Basin in recent 40 years due to land-use change could be estimated by Houghton' logic (Houghton, 1995). For this purpose, two types of data are needed: (1) Affected areas by land-use change over the interval of time (40 years); (2) changes in the carbon stored in soil per unit area in the ecosystem due to the land-use change.

The areal extent of *L. chinensis* steppe 40 years ago was derived from the vegetation map of the Xilin River Basin compiled in the early 1960s and other historical data available as early as possible (Libo, 1988). Estimates of early soil carbon contents were made by sampling well-protected plots along a succession degradation gradient in an even habitat for each *L. chinensis* community under the assumption that these plots had been in equilibrium levels of soil carbon at the time of our investigation. Current areas and soil carbon contents were investigated by transect line method. Soil sample were analyzed with $K_2Cr_2O_7$ oxidation method. The active, slow and passive carbon pools in soils were estimated by CENTURY model(Parton, 1987).

3 Results and discussion

L. chinensis steppe is mainly distributed in the central eastern part of the Xilin River Basin. The total area is about 3000 km^2, including twelve *L. chinensis* communities. In this study, seven major *L. chinensis* communities, with a total area of 2199.48 km^2, were investigated to examine the effect of land-use change on soil carbon storage in the ecosystem.

According to our investigation, there are mainly two types of land-use practices affecting *L. chinensis* steppe in the area, namely, cultivation of grasslands to croplands, and over-grazing by livestock. In the past 40 years, about 3% of the total area of *L. chinensis* steppe had been cultivated to croplands, and the rest (97%) been used as seasonal or all-year-round grazing lands. At present, almost all the *L. chinensis* steppe in the Xilin River Basin has become degraded to a certain extent, with about 30% of the total area having become seriously degraded. The most important cause for degradation of *L. chinensis* steppe in the area is over-grazing. Areas, total soil carbon storage and mean carbon contents (0—20 cm soil layer) for major *L. chinensis* communities in the Xilin River Basin, and change due to land-use change over the 40-year period are summarized in Table 1.

Table 1 Areas, total soil carbon storage and mean carbon contents for major *L. chinensis* communities in the Xilin River Basin, and change due to land-use change over the 40-year period

Community	Area, km^2			Soil carbon storage, $10^{10}g \cdot C$				Mean soil carbon content, g/m^2		
types[1]	1956	1996[2]	1996[3]	1956	1996	Change	Prop., %	1956	1996	Change
V_{15}	82.84	82.84		70.455	64.739	5.716	8.1	8505±806(3)	7815±899(3)	690
V_{20}	467.96	403.31	64.65	333.749	299.916	33.833	10.1	7132±680(3)	6409±834(7)	723
V_{21}	301.04	301.04		187.698	168.071	19.627	10.5	6235±705(3)	5583±860(6)	652
V_{33}	244.88	244.88		136.937	123.640	13.297	9.7	5592±257(3)	5049±670(6)	543
V_{37}	149.12	149.12		96.138	82.732	13.406	13.9	6447±656(3)	5548±905(3)	899
V_{38}	551.28	551.28		357.340	304.748	52.592	14.7	6482±374(3)	5528±1333(5)	954
V_{39}	402.36	402.36		245.198	206.491	38.707	15.8	6094±547(3)	5132±468(3)	962
Total	2199.48	2134.83	64.65	1427.515	1250.377	177.178	12.4			

Notes: 1. V_{15}: *L. chinensis*, mesophilous forbs and Carex pediformis meadow steppe; V_{20}: *L. chinensis*, *Bromus inermis* and *Carex pediformis* meadow steppe; V_{21}: *L. chinensis*, *Carex korshinskyi* and forbs meadow steppe; V_{33}: *L. chinensis*, *Artemisia frigida* and *Carex durivscula* steppe; V_{37}: *L. chinensis*, *Artemisia frigida* and *Cleistogenes kitagawae* steppe; V_{38}: *L. chinensis*, *Stipa grandis* and *Carex kershinskyi* steppe; V_{39}: *L. chinensis*, thicket grass and mesophytic-xerophilous forbs steppe. 2. Area affected by over-grazing. 3. Area cultivated for croplands.

Table 1 shows that mean soil carbon contents for seven major *L. chinensis* communities in 1956 varied between 5592—8505 $g \cdot C/m^2$, and decreases in soil carbon contents during 1956—1996 ranged between 543—962 $g \cdot C/m^2$. On average, about 12.4% of the total carbon initially stored in soils (0—20 cm soil layer) for seven major *L. chinensis* communities in the Xilin River Basin has been lost due to over-grazing over the 40-year period. Besides, the meadow types of *L. chinenesis* steppe (including the former three communities in Table 1), being relatively far away from residential areas and lacking in drinking water for livestock, was mainly used as seasonal grazing lands or as moving lands, therefore, the proportion of soil carbon loss was relatively low (ranging between 8%—11%). On the contrary, the typical *L. chinensis* steppe (the latter four communities) was distributed around livestock-farming spots and used mainly as permanent grazing lands, the soil carbon loss thus occurred more severely, with the proportion of the loss ranging between 10%—16%.

Soil carbon loss due to over-grazing from grassland ecosystems has been reported by other researchers (Ma, 1994). It is believed that the following two processes might be responsible for soil carbon loss through over-grazing: (1) Input of litter from both above-ground and below-ground plant materials to soil is greatly reduced by over-grazing; (2) Soil respiration can be enhanced by over-grazing (Risser, 1981). We had observed that changes in soil carbon storage in *L. chinensis* steppe were not as sensitive to livestock grazing as were the primary production, vegetation features and soil physical properties. Besides, the "time-lag" phenominum might exist in the soil carbon storage due to over-grazing, but the temporal pattern of over-grazing impacts has not been decided yet.

Soil organic carbon in grasslands is often divided into three pools, including the active, slow and passive pools. The active pool consists of live soil microbes and microbial products with a short turnover time (residence time <1 year), the slow pool includes plant and microbial products that are biologically resistant to decomposition (residence time of 10's of years), while the passive pool can be chemically recalcitrant(residence times of 100's—1000's of year). Table 2 shows soil carbon storage in the three pools in soils from both inside and outside a permanent fenced site of *L. chinensis* steppe in the Xilin River Basin, and changes over-20-year period due to over-grazing.

Table 2 Soil carbon storage in the active, slow and passive pools in soils from both inside and outside a permanent fenced site of *L. chinensis* steppe ($g \cdot C/m^2$)*

Carbon pool	Inside		Outside		Change	
	Carbon	Prop., %	Carbon	Prop., %	Carbon	Prop., %
Active	240	3.4	110	1.8	130	18.8
Slow	2540	36.6	2060	32.9	480	69.6
Passive	4160	60.0	4080	65.3	80	11.6
Total	6940	100.0	6250	100.0	690	100.0

* Results were estimated by CENTURY model

It can be noticed from Table 2 that the active, slow and passive pools account for 3.4, 36.6, and 60.0% respectively in the total SOM pool inside the fenced site, and 1.8%, 32.9% and 65.3% respectively outside the fenced site. A total amount of 690 $g \cdot C/m^2$ had been lost over the 20-year period due to over-grazing, of which 18.8% was from the active pool, and 69.6% from the slow pool, and only 11.6% from the passive pool. Considering the turnover time in each pool, our results were quite reasonable.

Grasslands may be among the earliest systems to exhibit the effects of global change. A number of studies have showed that the overall impacts of non-sustainable land-use practices are potentially greater than that of climate change or increased atmospheric CO_2 concentrations. Therefore, great importance should be attached to researches concerning the impact of land-use on soil carbon storage in grasslands, especially temperate grasslands in the future.

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