Impact of land use/cover changes on carbon storage in a river valley in arid areas of Northwest China postprint

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Abstract

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Full Text

Preamble

Impact of Land Use/Cover Changes on Carbon Storage in a River Valley in Arid Areas of Northwest China

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Abstract: Soil carbon pools can become either a CO_2 source or sink depending on the direction of land use/cover changes. Even slight alterations in soil carbon inevitably affect atmospheric CO_2 concentrations and consequently influence climate. Based on data from 127 soil sample sites, 48 vegetation survey plots, and Landsat TM images, we analyzed land use/cover changes and estimated soil organic carbon (SOC) storage and vegetation carbon storage in grassland, discussing the impact of grassland changes on carbon storage from 2000 to 2013 in the Ili River Valley of Northwest China. Results indicate that the areal extents of forestland, shrubland, moderate-coverage grassland (MCG), and water bodies (including glaciers) decreased, while those of high-coverage grassland (HCG), low-coverage grassland (LCG), residential and industrial land,

and cultivated land increased. Grassland SOC density in the 0-100 cm depth varied with coverage in descending order: HCG > MCG > LCG. Regional grassland SOC storage in the 0-100 cm depth increased by 0.25×10^{11} kg in 2013 compared to 2000. Regional vegetation carbon storage (Srvc) of grassland was 5.27×10^{9} kg in 2013, representing a 15.7% decrease from 2000. Underground vegetation carbon reserves (Sruvb) in 2013 were 0.68×10^{9} kg, increasing by approximately 19.01% compared to 2000. This research improves our understanding of how land use/cover changes impact carbon storage in arid areas of Northwest China.

Keywords: land use/cover; organic carbon; grassland; global change; Ili River Valley

Introduction

Land use/cover change is widely recognized as a key driver of global carbon dynamics and plays a critical role in maintaining and building soil carbon. Soil contains the largest organic carbon pool, with approximately 2344, 1550, and 615 Pg C stored in 3.0, 1.0, and 0.2 m soil depths, respectively, in global terrestrial ecosystems. Moreover, the soil organic carbon (SOC) pool is 2.2 times larger than the atmospheric carbon pool and 2.8 times larger than the biomass carbon pool. SOC is relatively easy to change and inevitably affects atmospheric CO_2 concentration. Under the influence of land use/cover change, soil carbon pools can become either a source or sink of CO_2. Due to high spatial heterogeneity of soil, global SOC reserves vary regionally, ranging from 1220 to 2000 Pg C in the 0-100 cm soil layer. Conversion of farmland to grassland significantly increases soil carbon sequestration, while the opposite conversion results in SOC loss. Therefore, evaluating SOC pools and their response to land use/cover changes is crucial for precise assessment of the global carbon cycle.

The Ili River Valley, located in arid Northwest China, is a key region on the Silk Road Economic Belt that suffers from serious soil and water loss resulting from land use/cover changes. Land use/cover change represents a major driving force for soil carbon pool changes. Our previous work indicated that both SOC and SOC density (Dsoc) in the 0-50 cm soil horizon of meadows in the Ili River Valley were higher than those of temperate coniferous forest. During 2000-2013, grassland experienced major changes in the Ili River Valley. How have these changes affected the grassland carbon pool there?

The objectives of this study were: (1) to analyze land use/cover changes, (2) to estimate regional grassland carbon storage in the Ili River Valley, and (3) to discuss the influence of grassland changes on carbon storage during 2000-2013. This study will not only obtain specific information on the effects of grassland changes on SOC stocks in the Ili River Valley but also provide regional information on how regional policies impact land use/cover changes.

Methods

2.1 Study Area

The Ili River Valley is located in the western part of the Tianshan Mountains (42°14 16 -44°50 30 N, 80°09 42 -84°56 56 E), China. The valley is surrounded by high mountains on the north, east, and south, with terrain that generally tilts westward and narrows eastward. The climate is dominated by moderate temperate continental and alpine conditions, generally warm and humid with large diurnal temperature differences. Mean annual precipitation and annual mean air temperature range from 200 to 800 mm and 2.9°C to 9.1°C, respectively. Precipitation increases significantly with altitude, reaching 200–300 mm in low-elevation plain areas and exceeding 1000 mm in high-elevation mountains. At our study area, the Narat Grassland (above 1700 m a.s.l.), mean annual precipitation exceeds 800 mm, and mean annual evaporation is 1260–1900 mm. Annual frost-free days are 130–180 d, and mean annual sunshine hours are 2700–3000 h. Detailed descriptions of vegetation types in the valley can be found in Yang et al. (2010).

[Figure 1: see original paper] Location of the study area and sampling sites

2.2 Soil Sampling and Vegetation Survey

The sampling area (43°95 -44°20 N, 81°05 -81°55 E) was on the northern slope of the Ili River Valley, where human disturbances are rather severe. Sampling sites were selected across a gradient of human disturbance levels and a diversity of landscapes and vegetation. Specifically, more samples were collected in areas with higher levels of human disturbance and more diverse landforms and vegetation. Land use/cover types in the sampling area included high-coverage grassland (HCG), moderate-coverage grassland (MCG), low-coverage grassland (LCG), ecological forestland (EF), fruit forestland (FF), dry farmland (DF), and vineyards (VY).

Fieldwork was conducted from May to June 2015. A total of 127 soil sampling sites were established, with 11, 45, 28, 13, 17, 7, and 6 sites in HCG, MCG, LCG, EF, FF, DF, and VY, respectively. Each sampling site was positioned using a global positioning system (GPS). Soil samples were taken with a soil auger at 0–20 cm depth. Five soil samples were collected from different points at each site and mixed thoroughly to create a single representative sample. Soil samples were sorted for roots and gravels, air-dried at room temperature, and passed through a 2-mm sieve. Samples were subsequently analyzed in the laboratory for soil organic matter content using the K_2-Cr_2O_7-H_2SO_4 Walkley-Black oxidation method, and organic carbon content was obtained by multiplying soil organic matter content by a correction factor of 0.58.

Another set of 127 soil samples was collected in aluminum boxes at exactly the same sites and weighed in situ. These samples were later oven-dried at 105°C in the laboratory to measure soil moisture content. To calculate soil bulk density at 0-20 cm depth, three replicated undisturbed soil samples were collected at each site using soil cores.

We also dug four soil profiles in the grassland. Soil samples were collected from these profiles with a shovel at depths of 0-5, 5-10, 10-15, 15-20, 20-30, 30-50, 50-70, and 70-100 cm. At each layer, soil was sampled at five different points and mixed to create a single representative sample for that layer.

Vegetation was only sampled in grassland, where we established 48 quadrats (1 m × 1 m) to survey plant biomass according to coverage. Above-ground plant parts in each quadrat were mowed, placed in envelopes, and later oven-dried at 65°C to obtain above-ground biomass. To measure below-ground biomass, we first cleaned residues and impurities from the ground surface, then sampled soil in a 30 cm × 30 cm × 30 cm volume within each quadrat. Samples were sieved in situ to retain visible roots, which were later rinsed with clean water and oven-dried at 65°C in the laboratory to obtain below-ground vegetation biomass.

2.3 Other Data

Land use/cover changes during 2000-2013 were identified based on Landsat TM images from bands 5, 4, and 3 obtained on 8 August 2000 and 2013. Good-quality images were selected. Land use/cover in the Ili River Valley was classified into water bodies, forestland, shrubland, high-coverage grassland (HCG), moderate-coverage grassland (MCG), low-coverage grassland (LCG), cultivated land, residential and industrial land, and unused land according to the six-type classification system developed by the Resources and Environment Database of the Chinese Academy of Sciences. Classification was conducted using ENVI and ArcGIS, augmented by field trips with GPS. LCG, MCG, and HCG were defined as coverage >50%, 20%-50%, and 5%-20%, respectively.

2.4 Methods

We selected Dsoc, regional SOC storage (Ssoc), regional above-ground vegetation carbon storage (Srvc), and regional below-ground vegetation carbon storage (Sruvb) to analyze carbon storage under the impact of land use/cover changes in the Ili River Valley.

Dsoc refers to SOC reserve per unit area in a soil horizon with a specific depth, normally 1 m but potentially larger or smaller depending on soil conditions. If a soil profile comprises multiple horizons, Dsoc (kg/m^2) of each horizon can be calculated by Equation 1 (Wang and Zhou, 1999):

$$\mathrm{Dsoc} = \mathrm{SOC} \times \mathrm{H} \times \mathrm{D} \times (100 - \mathrm{Vcf})/100$$

where SOC is SOC concentration (g/kg), H is layer depth (cm), D is soil bulk density (g/cm^3) of the layer, and Vcf is volume (%) of coarse fragments (>2 cm). In this study, we calculated Dsoc at 0-100 cm depth (Dsoc_{100}) by summing Dsoc values for each soil layer within this depth.

Ssoc refers to total SOC reserves within a region, derived from the sum of Ssoc for each soil layer, obtained by multiplying region area by Dsoc of each layer. We calculated Ssoc (kg) of each soil layer using Equation 2:

$$\text{Ssoc} = S \times H \times \text{Dsoc}$$

where S is region area (m^2), H is layer depth (cm), and Dsoc is SOC density (kg/m^2) of the layer. We estimated grassland Ssoc at 0–100 cm depth (Ssoc_{100}) based on Dsoc_{100}.

Srvc refers to vegetation carbon reserves of above-ground plant parts, calculated by Equation 3:

$$\text{Srvc} = \text{Davb} \times A \times B$$

where Davb is above-ground vegetation biomass density of grassland (g/m^2), A is grassland area (m^2), and B is the coefficient for converting vegetation biomass to vegetation carbon. B equals 0.5 for forest land use and 0.45 for non-forest land use (Liu et al., 2010). In this study, we used $B = 0.45$ when calculating grassland Srvc.

Sruvb refers to vegetation carbon reserves of below-ground plant parts, calculated by Equation 4:

$$\text{Sruvb} = \text{Duvb} \times A \times B$$

where Duvb is below-ground vegetation biomass density of grassland (g/m^2), A is grassland area (m^2), and we also used $B = 0.45$. Based on Davb and Duvb values from 2015, combined with grassland areas from 2000 and 2013, we estimated Srvc and Sruvb for 2000 and 2013, respectively.

2.5 Statistical Analysis

We compared effects of land use/cover change on SOC among different land use types using one-way analysis of variance and least significant difference ($P < 0.05$).

Results

3.1 Land Use/Cover Change

Due to human activities, land use/cover experienced considerable changes in the Ili River Valley during 2000–2013. The areal extents of forestland, shrubland, MCG, and water bodies (including glaciers) decreased, while those of HCG, LCG, residential and industrial land, and cultivated land increased. In 2000, forestland and shrubland accounted for 10.08% and 0.67% of the total area, respectively, decreasing to 6.41% and 0.16% in 2013. However, total grassland area in 2013 was larger than in 2000. Specifically, HCG and LCG areas increased from 30.79% and 7.80% in 2000 to 42.53% and 8.44% in 2013, respectively, while MCG area decreased significantly. Water bodies (including glaciers) decreased from 5.65% to 2.57%, while cultivated land, unused land, and residential and industrial land increased from 12.20% to 14.83%, 10.59% to 11.99%, and 1.08% to 1.46%, respectively.

[Figure 2: see original paper] Land use/cover changes in the Ili River Valley during 2000-2013

3.2 Grassland Soil Organic Carbon

Grassland Dsoc$_{100}$ varied with vegetation coverage in descending order: HCG > MCG > LCG. Overall, grassland Ssoc$_{100}$ increased by 0.25$\times10^{11}$ kg from 2000 to 2013. Among the three grassland types, HCG Ssoc$_{100}$ increased by 1.25$\times10^{11}$ kg, MCG Ssoc$_{100}$ decreased by 0.87$\times10^{11}$ kg, and LCG Ssoc increased by 0.06$\times10^{11}$ kg.

Within soil profiles, SOC gradually decreased with depth, except in the 50-70 cm layer where SOC was higher than the overlying layer. To further compare Dsoc among different soil layers, we used 5 cm as the standard height to calculate Dsoc (Dsoc$_5$) for each layer. As shown in the analysis, Dsoc$_5$ decreased within the top 0-20 cm, then increased within 20-70 cm, and decreased below 70 cm. In the profile, the highest SOC appeared in the 0-5 cm soil layer, but the highest Dsoc$_5$ occurred in the 50-70 cm layer, demonstrating that SOC concentration cannot replace Dsoc to reflect Ssoc.

[Figure 3: see original paper] Soil organic carbon (SOC) in grassland under different coverage and soil depths. Values of 5, 10, 15, 20, 30, 50, 70, and 100 cm represent soil layers of 0-5, 5-10, 10-15, 15-20, 20-30, 30-50, 50-70, and 70-100 cm, respectively. DSOC100, SOC density at 0-100 cm depth; SSOC100, grassland regional SOC storage at 0-100 cm depth; DSOC5, SOC density with a standard height of 5 cm; HCG, high-coverage grassland; MCG, moderate-coverage grassland; LCG, low-coverage grassland. Bars indicate standard errors.

3.3 Above-Ground and Below-Ground Vegetation Carbon Storage in Grassland

Grassland Davb varied with vegetation coverage in descending order: MCG > HCG > LCG. Overall, grassland Srvc was 5.27$\times10^{9}$ kg in 2013, decreasing by 15.7% from 2000. HCG and LCG Srvc increased by 38.3% and 8.3% during 2000-2013, respectively, while MCG Srvc decreased by 54.1%. Vegetation coverage affected Duvb of grassland, with the highest Duvb in HCG and the lowest in LCG. Sruvb in 2013 was 0.68$\times10^{9}$ kg, increasing by approximately 19.01% from 2000.

A significant correlation existed between Duvb and Davb ($P = 0.031 < 0.05$, $n = 45$) in grassland, expressed as: $y = -9.95 + 0.099x - 7.1\times10^{-5}x^{2}$ ($P = 0.009 < 0.05$).

[Figure 4: see original paper] Vegetation carbon in grassland under different coverage. Davb, above-ground vegetation biomass density; Duvb, below-ground vegetation biomass density; Srvc, regional vegetation carbon storage; Sruvb, regional below-ground vegetation carbon storage. Bars indicate standard errors.

3.4 Influence of Land Use/Cover on Soil Organic Carbon

Land use/cover affected both SOC and Dsoc_{100}. Grassland SOC was higher than that of forestland and DF. The highest and lowest SOC and Dsoc_{100} appeared in HCG and VY, respectively. FF SOC was significantly different from other land use/cover types, though no significant difference existed among VY, EF, and DF or between DF and LCG. Dsoc_{100} ranked in descending order: HCG > MCG > LCG > EF > FF > DF > VY.

[Figure 5: see original paper] SOC and Dsoc_{100} in different land use types. Lowercase letters denote significant differences among land use/cover types at $P < 0.05$. FF, fruit forestland; VY, vineyard; EF, ecological forestland; DF, dry farmland. Bars indicate standard errors.

Discussion

4.1 Land Use/Cover and Soil Organic Carbon

SOC can reflect the dynamic status of an ecosystem under certain conditions. SOC accumulation varies greatly depending on climatic conditions and human disturbances. Vegetation coverage, grassland productivity, and rainfall are the main factors influencing surface SOC. Our research indicates that grassland SOC is intuitively highest in HCG, moderate in MCG, and lowest in LCG. Grassland Dsoc_{100} was higher than that of DF, showing that conversion of grassland to DF can decrease Dsoc in the Ili River Valley. Therefore, natural grassland represents the optimal choice for increasing soil carbon storage.

Dsoc values in the 0–20 cm soil layer varied with vegetation types, with values of 3.77, 4.70, and 2.56 $\mathrm{kg/m^2}$ under coniferous forest, broadleaved forest, and scrub, respectively. In the Ili River Valley, grassland Dsoc of the 0–20 cm soil layer estimated from SOC (2.02 $\mathrm{kg/m^2}$) was significantly lower than that under forestland, showing that Ssoc of grassland is significantly lower than that of forestland in the Ili River Valley.

4.2 Land Use/Cover and Vegetation Carbon Storage

SOC at 0–5 cm depth in DF and VY was lower than in MCG, showing that land use/cover change can affect surface SOC, supporting the research of Batjes and Dijkshoorn (1999) and Batjes and Sombroek (1997). Dsoc in MCG was lower than in HCG while Davb in MCG was higher than in HCG, possibly due to differences in plant species. Our field survey shows that gramineae herbs with rich fine roots dominate HCG, while non-gramineae herbs such as *Sophora alopecuroides* with greater above-ground biomass and fewer roots dominate MCG.

4.3 Changes of Grassland Types and Carbon Storage

Above-ground vegetation carbon densities for LCG, MCG, and HCG in our study were 8.77, 26.58, and 18.93 kg C/hm^2, respectively—far lower than those of grassland in the Tibet Plateau (44.542–1620.895 kg C/hm^2). Ma et al. (2014) reported that overall Davb values (4.3–731.3 g/m^2) were much lower than overall Duvb values (44.6–4899.5 g/m^2) in Chinese grasslands. Our research found Davb was approximately 10 times Duvb in Ili grasslands, contradicting Ma et al. (2014). This discrepancy may result from differences in sampling times. In spring, above-ground growth rate exceeds below-ground growth rate, and the root-shoot ratio decreases with rising temperatures in July and August, reaching its minimum ratio then. Our vegetation biomass survey in July may have led to an unusually small below-ground to above-ground biomass ratio. Mokany et al. (2006) reported that over 62% of published root:shoot ratio data are not acceptable for representing yearly ratios, with non-acceptability most likely due to sampling-depth differences. Because of difficulties in obtaining below-ground biomass data, other studies used root-shoot ratios to estimate below-ground biomass, potentially increasing estimation errors of grassland vegetation carbon stocks. Our study used measured data to estimate grassland vegetation carbon stocks, which should be more reliable.

This study shows that the relationship between grassland Davb and Duvb can be expressed by a quadratic model, while relationships between above-ground and below-ground biomass in other ecosystems (e.g., alpine meadow, warm desert grassland, alpine grassland) can be expressed by power models. However, Ma et al. (2014) found no obvious relationship between above-ground and below-ground biomass in mountain meadows. These differing results indicate that the relationship between above-ground and below-ground biomass requires further investigation.

Grassland Srvc in 2013 was less than in 2000, likely caused by changes in grassland areas and associated changes in Davb. In MCG, Davb was highest among the three grassland types, but MCG areal extent declined most dramatically. The combined effects of increased Davb and decreased areal extent made MCG Srvc in 2013 smaller than in 2000.

Areal extents of HCG and LCG increased while MCG decreased during 2000–2013. The increase in HCG and LCG may be directly related to government policies protecting grasslands from overgrazing. However, fencing (protection) and overgrazing coexisted on MCG. Coverage change directly affects not only grassland vegetation carbon storage but also the terrestrial ecosystem carbon cycle. Conversion from low-coverage to high-coverage grassland can increase Dsoc, while conversion from high-coverage to moderate-coverage, low-coverage, or other land use/cover types may lead to declining grassland Dsoc, thus reducing Ssoc in grassland.

Conclusion

Land use/cover plays an important role in carbon storage in terrestrial ecosystems. From 2000 to 2013, areal extents of forestland, shrubland, MCG, and water bodies (including glaciers) decreased, while those of HCG, LCG, residential and industrial land, unused land, and cultivated land increased. Land use/cover change strongly impacted both Srvc and Ssoc in the region. Overall grassland Srvc decreased during 2000-2013 while overall grassland Ssoc increased during the same period. The overall Ssoc increase resulted from expanded areal extents of HCG and LCG, but not MCG, which experienced a decline in areal extent.

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References

Batjes N H, Sombroek W G. 1997. Possibilities for carbon sequestration in tropical and subtropical soils. Global Change Biology, 3(2): 161-173.

Batjes N H, Dijkshoorn J A. 1999. Carbon and nitrogen stocks in the soils of the Amazon Region. Geoderma, 89(3-4): 273-286.

Chai X, Liang C Z, Liang M W, et al. 2014. Seasonal dynamics of belowground biomass and productivity and potential of carbon sequestration in meadow steppe and typical steppe, in Inner Mongolia, China. Acta Ecologica Sinica, 34(19): 5530-5540. (in Chinese)

Chen Z S, Chen Y N, Li W H, et al. 2010. Evaluating effect of land use change on environment in Ili Valley based on ecosystem service value analysis. Journal of Desert Research, 30(4): 870-877. (in Chinese)

Cheng S L, Ouyang H, Niu H S, et al. 2004. Temporal-spatial dynamic analysis of soil organic carbon in inversed desertification area: A case study in Yulin County, Shaanxi Province. Acta Geographica Sinica, 59(4): 505-513. (in Chinese)

Deng L, Shangguan Z P, Sweeney S. 2014. "Grain for Green" driven land use change and carbon sequestration on the Loess Plateau, China. Scientific Reports, 4: 7039.

Don A, Schumacher J, Scherer-Lorenzen M, et al. 2007. Spatial and vertical variation of soil carbon at two grassland sites—implications for measuring soil carbon stocks. Geoderma, 141(3-4): 272-282.

Fang J Y, Guo Z D, Piao S L, et al. 2007. Terrestrial vegetation carbon sinks in China, 1981-2000. Science in China Series D: Earth Sciences, 50(9): 1341-

1350.

Fu H, Chen Y N, Wang Y R, et al. 2004. Organic carbon content in major grassland types in Alex, Inner Mongolia. Acta Ecologica Sinica, 24(3): 469-476. (in Chinese)

Jia X H, Zhou H Y, Li X R. 2004. Primary conclusion of soil organic carbon and total nitrogen variation in planted sand regions without irrigation. Journal of Desert Research, 24(4): 437-441. (in Chinese)

Jobbágy E G, Jackson R B. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological Applications, 10(2): 423-436.

Kang L, Zhang H Q. 2012. Assessment of the land desertification sensitivity of newly reclaimed area in Yili, Xinjiang. Resources Science, 34(5): 896-902. (in Chinese)

Laboratory of Soil Physics, Institute of Soil Science, Chinese Academy of Sciences. 1978. Methods of Soil Physic Measurement. Beijing: Science Press. (in Chinese)

Lal R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science, 304(5677): 1623-1627.

Lal R. 2009. Sequestering carbon in soils of arid ecosystems. Land Degradation & Development, 20(4): 441-454.

Liu M Y, Bao A M, Chen X, et al. 2010. Impact of land use/cover change on the vegetation carbon storage in the Manas River Basin between 1976 and 2007. Journal of Natural Resources, 25(6): 926-938. (in Chinese)

Ma A N, Yu G R, He N P, et al. 2014. Above- and below-ground biomass relationships in China' s grassland vegetation. Quaternary Sciences, 34(4): 769-776. (in Chinese)

Ma W H, Fang J Y, Yang Y H, et al. 2010. Biomass carbon stocks and their changes in northern China' s grasslands during 1982-2006. Science China Life Sciences, 53(7): 841-850.

McLauchlan K K, Hobbie S E, Post W M. 2006. Conversion from agriculture to grassland builds soil organic matter on decadal timescales. Ecological Applications, 16(1): 143-153.

Mokany K, Raison R J, Prokushkin A S. 2006. Critical analysis of root:shoot ratios in terrestrial biomes. Global Change Biology, 12(1): 84-96.

Post W M, Kwon K C. 2000. Soil carbon sequestration and land-use change: processes and potential. Global Change Biology, 6(3): 317-327.

Song X H, Peng C H, Zhou G M, et al. 2014. Chinese Grain for Green Program led to highly increased soil organic carbon levels: A meta-analysis. Scientific Reports, 4: 4460.

Stockmann U, Adams M A, Crawford J W, et al. 2013. The knowns, known unknowns and unknowns of sequestration of soil organic carbon. Agriculture, Ecosystems & Environment, 164: 80-99.

Sun C L, Xue S, Chai Z Z, et al. 2016. Effects of land-use types on the vertical distribution of fractions of oxidizable organic carbon on the Loess Plateau, China. Journal of Arid Land, 8(2): 221-231.

Tarnocai C, Canadell J G, Schuur E A G, et al. 2009. Soil organic carbon pools in the northern circumpolar permafrost region. Global Biogeochemical Cycles, 23(2): 2607-2617.

Wang J L, Chang T J, Li P, et al. 2009. The vegetation carbon reserve and its spatial distribution configuration of grassland ecosystem in Tibet. Acta Ecologica Sinica, 29(2): 931-938. (in Chinese)

Wang Q, Zhang L, Li L, et al. 2009. Changes in carbon and nitrogen of Chernozem soil along a cultivation chronosequence in a semi-arid grassland. European Journal of Soil Science, 60(6): 916-923.

Wang S Q, Zhou C H. 1999. Estimating soil carbon reservoir of terrestrial ecosystem in China. Geographical Research, 18(4): 349-356. (in Chinese)

Were K, Singh B R, Dick Ø B. 2016. Spatially distributed modelling and mapping of soil organic carbon and total nitrogen stocks in the Eastern Mau Forest Reserve, Kenya. Journal of Geographical Sciences, 26(1): 102-124.

Xie X L, Sun B, Zhou H Z, et al. 2004. Soil carbon stocks and their influencing factors under native vegetation in China. Acta Pedologica Sinica, 41(5): 687-699. (in Chinese)

Yang Y H, Chen Y N, Li W H, et al. 2010. Distribution of soil organic carbon under different vegetation zones in the Ili River Valley, Xinjiang. Journal of Geographical Sciences, 20(5): 729-740.

Yao M K, Angui P K T, Konaté S, et al. 2010. Effects of land use types on soil organic carbon and nitrogen dynamics in Mid-West Côte d' Ivoire. European Journal of Scientific Research, 40: 211-222.

Zhou L, Li B G, Zhou G S. 2005. Advances in controlling factors of soil organic carbon. Advances in Earth Science, 20(1): 99-105. (in Chinese)

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