A Summary of the Impact of Land Degradation on Soil Carbon Sequestration

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Abstract. Soil carbon pools have a great impact on global climate change, and land degradation caused by natural conditions or human activities is one of the important causes of soil carbon sequestration changes. In order to explore the impact of different types of land degradation on soil carbon sequestration and its mechanisms, this paper reviews the effects of different types of land degradation on soil carbon sequestration, such as desertification, soil erosion, soil salinization, nutrient loss and soil impoverishment. It is pointed out that various types of land degradation will increase the rate of CO2 release from soil to the atmosphere to varying degrees, which will increase the function of soil carbon source and weaken the function of carbon sink. However, the impact of land degradation on soil carbon stocks is likely to be reversed. In the future, the dynamic changes of soil carbon sequestration and deep soil carbon pools in different types of land degradation processes should be strengthened in order to further study the effects of soil carbon cycling in land degradation. And lay a foundation for enhancing the function of soil carbon sources.

1. Introduction
Soil is an important part of the global carbon pool and plays a crucial role in the global atmospheric carbon dioxide content change. The global soil organic carbon storage is about 1500-2000 Pg, which is 2-3 times that of the terrestrial vegetation carbon pool, which is more than twice the global atmospheric carbon pool, and the total inorganic carbon reserve is between 700-1000 Pg, the total carbon sequestration near 3000 Pg, the annual flux of soil contributing to atmospheric CO2 is 10 times that of fossil fuel combustion [1, 2]. Due to the large storage capacity of soil carbon stocks, its small-scale changes may affect the carbon-to-atmosphere emissions, affect the global climate change with the greenhouse effect, but also affect the nutrient supply of terrestrial vegetation, finally, it has a profound impact on the distribution, composition, structure and function of terrestrial ecosystems [3,4]. At present, under the background of global changes, the mechanism of soil carbon storage, distribution, transformation and decay is studied and its influencing factors and ecological effects are revealed, which will help to explore the scientific use and protection of limited soil resources, it is great...
significance to reduce greenhouse gas emissions, increase soil carbon sequestration, and improve soil quality, rational planning of the soil and environmental governance and protection.

Although terrestrial ecosystems occupy an important position in the global carbon cycle, natural conditions and a variety of human activities have resulted in the degradation of land in a wide range of degrees [5]. During the process of land degradation, the decrease of soil organic carbon content and the reduction of vegetation coverage may aggravate the greenhouse effect [6]. China is a country with low average soil carbon pool content in the world. The average soil carbon content in China is only 40.3t ha⁻¹, and the average organic carbon content is 10.53kg m⁻² [7]. The total area of degraded soil in China is 465 million hm², which accounts for 48.44% [8] of the total land area, which not only causes the decline of cultivated land productivity, but also seriously affects soil carbon sequestration because of the decrease of land function. In this paper, the related research in recent years to carry on the comprehensive review and analysis of different types of land degradation in soil carbon sequestration effect and its mechanism, not only help to the global ecological impact assessment of land degradation, also for the future land management decisions and to provide scientific reference.

2. Impact of desertification on soil carbon sequestration
Some studies suggest that land desertification caused by increased human disturbance intensity is the main reason for the accelerated release of soil organic carbon into the atmosphere. Particularly for fragile ecosystems in arid and semi-arid regions, non-sustainable land use patterns will accelerate carbon emissions from the soil. Release to the atmosphere [9]. At present, the area of land affected by desertification in the world is about 3.6 billion hm² [10]. About 27.2% of China’s land area is decertified land, which is one of the countries most seriously affected by desertification in the world [11]. In the grassland desertification process, the net productivity of the Maowusu Sandy Land ecosystem was reduced from +36.16 to -22.49 g·m⁻², carbon sink function was reduced, and eventually turned into a carbon source for atmospheric CO₂ [12]. From 1990-2000 years only ten years, the desert of the Yellow River source region leads to soil organic carbon loss amounted to 4.11×10⁶t, the average annual loss from soil organic carbon of 0.41×10⁶t [13], in the course of the expansion of non-decertified land into extremely heavy desertification land, the carbon density dropped by an average of 7.469 kg m⁻². It is estimated that the storage of carbon in the 0~50 cm depth of different types of decertified land in China is 855.45 Mt [14], and the total net emission of CO₂ from decertified land in China is equivalent to 90.9 Mt C in the past 40 years.

The direct cause of desertification leading to increased soil carbon emissions and reduced soil carbon pools is exacerbated by erosion of the topsoil layer, resulting in the exposure of carbonate materials or calcium deposits in the soil to the topsoil, and promotion of soil organic carbon (SOC) and inorganic carbon (SIC). Mineralization, in turn, led to acidification and CO₂ release [15]. The indirect reason is that the vegetation coverage is reduced, and the amount of plant debris returned to the soil is rapidly reduced, which leads to a decrease in soil respiration and a decrease in secondary carbonate formation in the soil [16].

3. Impact of soil erosion on soil carbon sequestration
The slow geological erosion promoted by wind erosion and rain erosion can promote the renewal of soil nutrients, but accelerated erosion under disturbance of human activities is a destructive process, which not only destroys soil structure reduces soil fertility, but also affects soil carbon cycle [17]. At present, the effect of soil erosion on the carbon cycle in terrestrial ecosystems is still controversial, and some studies suggest that soil erosion is more conducive to carbon accumulation. On the other hand, soil erosion can lead to soil organic carbon consumption, which is not conducive to carbon accumulation, which has a negative impact on terrestrial ecosystem carbon pool [18, 19].

The mechanism of wind erosion and rain erosion on soil carbon accumulation mainly comes from the separation effect on soil particles[17]: The results of research on soil erosion in the red soil in South China confirmed by artificial rainfall confirmed that rain erosion will cause organic carbon in forest land and abandoned farmland. With a large amount of loss, and the loss of forest land is higher
than abandoned farmland, the organic carbon loss rate ranges from 1.6%~18.9% [20]. The runoff erosion results on Lossiah soil in Ningxia show that the slope and erosion intensity have a significant impact on the carbon content of soil erosion and sediment, especially the effect on the content of active organic carbon is more significant [21]. Soil wind erosion, as the main process of desertification, results in a large amount of soil carbon erosion in the surface soil layer [22, 23], which is the main driving force of soil loss in arid and semi-arid areas. However, in view of the uncertainty of the amount of wind erosion and its fate, at present, the study of soil carbon dynamics under the influence of wind erosion is relatively scarce. The loss of soil carbon pool in the soil 0-20cm depth of farmland soil can reach 1.77% [24] every year. At present, more than 1 billion hectares of land area in the world are under water erosion, of which 7.51 hectares are serious water erosion, and about 550 million hectares are affected by wind erosion, of which nearly 300 million hectares are severe wind erosion [19]. Wind erosion and water erosion not only change the carbon mineralization rate and humification rate, affect the efficiency of water and nutrient utilization, but also directly strip surface carbon [25]. The study concluded that the greater the loss of soil carbon caused by soil erosion, the higher the value of carbon sequestration potential when remediation is restored [26-28]. Therefore, it is of great practical significance to explore the mechanism of carbon loss in soil erosion and the corresponding treatment measures.

Although soil erosion may cause loss of soil carbon on the slope (upstream), it may also contribute to the improvement of soil quality on the other hand. In Maryland, the average carbon content of soil in sloping field was 1%, but the carbon content in the edge of river ecosystem was 20%. The wetland ecosystem in the river became a local carbon sink [29]. Although the wetland system as a whole does not increase soil carbon, the soil erosion-migration-retention process has a greater impact than simple soil carbon migration [17]. First, the process of vegetation growth and decomposition in agricultural erosion areas in the basin provides a stable source of carbon for neighboring sedimentary areas, which promotes the formation of new carbon in the farmland erosion area, and the eroded carbon transports continuously through rivers to sedimentary area [30]; Second, organic carbon is stored in the soil of wetland ecosystem reduction environment longer than that in high slope oxidation environment of watershed. The average carbon sequestration rate of farmland soil was 0.2 tha-1yr-1, while that of soil in wetland soil was 1.6-2.2 tha-1yr-1 or higher. In addition, soil erosion is accompanied by the loss of nutrients, and excess N, P and other nutrients eroded by farmland are input into the wetland ecosystem, which increases the net primary productivity of river ecosystems and accelerates the carbon sequestration of river wetland ecosystems.

4. Impact of soil salinization on soil carbon sequestration
The salinization of the land caused by high groundwater level, arid climate and poor drainage will result in too high salt content in soil, too strong soil alkalinity, a decline in yield of large areas of good farmland, even abandonment of cultivation, and a decrease in grassland forage yield. Reduction of stocking capacity in pastureland and other hazards. The saline alkali soil in the carbon cycle in source and function also gradually attention: studies have suggested that high salt content could inhibit soil carbon emissions [31], but research has shown that exogenous carbon after saline soil carbon release was higher than that of saline 16%-31% [32], due to the impact of the salt alkalization the process of soil carbon sequestration is still controversial.

Xie found that saline-alkali soils can absorb carbon from the atmosphere [33], but Li Ling believe that under the condition of no carbon input, Increasing soil salt content can significantly reduce soil CO2 release [34], which means that a certain degree of soil salinization may promote the enhancement of soil carbon sink function. On the other hand, through the statistical analysis of the carbon storage of 13 soil types in the Northeast Plain, it was found that the total storage of organic and inorganic carbon in the saline and alkaline land was about 4 kg·m⁻². In all soil types at a lower level [35], that is, salinization may reduce soil carbon sequestration and weaken its carbon sink function. Therefore, the impact of salinization on soil carbon sequestration needs to be further studied in order to find out the
influence mechanism of salinization content on soil carbon source and carbon sink function transformation.

5. Impact of nutrient loss and soil degradation on soil carbon sequestration

In the dual role of human activities and natural factors, soil may lose nutrients, land degradation and other degraded forms, these types of land degradation will affect the soil carbon cycle in different degrees and in different aspects. Sustainable agricultural production activities and the use of acid fertilizer may strengthen the acidification of soil, and then affect plant root exudates, resulting in the exposure of carbonate substances and carbon release. In addition, during this process, the deterioration of soil structure and the increase of soil bulk density, which are accompanied by nutrient loss and soil inferiority, lead to the increase of soil instability index, the decrease of the amount of organic matter, the weakening of stability, and the adverse impact on plant growth. The decrease of biodiversity and the return of plant residues to soil could significantly affect soil carbon sequestration [36]. Generally speaking, scholars believe that soil carbon content, especially organic carbon content, is positively correlated with soil fertility [37]. That is, soil depletion will cause a decrease in soil carbon content [38], and various fertilization measures will increase soil carbon content to varying degrees.

Taken together, various types of land degradation will increase the rate of CO2 release from the soil to the atmosphere to varying degrees, making the function of soil carbon sources increase and the function of carbon sinks weakened. This has negative significance for the regional and global carbon cycle. Many studies have confirmed that the process of land degradation affecting soil carbon stocks is reversible [40-43]. Therefore, strengthening the treatment of degraded land and promoting the restoration of soil function and vegetation reconstruction of degraded land can not only improve the local ecological environment, but also play an important role in the restoration of soil carbon pool and the stable development of carbon sequestration in different regional scales.

The study of carbon sequestration in the process of land degradation in China is still in its infancy. In the future, we propose to strengthen research in the following areas: First, in view of the great impact of land degradation on the carbon cycle of ecosystems, the study of dynamic changes in soil carbon sequestration in different types of land degradation processes has been strengthened to systematically explore the mechanism of land degradation impacts on soil carbon stocks. Second, considering that deep soil carbon pool may play an important role in promoting carbon sequestration in ecosystems and slowing down the rate of carbon regeneration in the surface system of the earth, the carbon pool characteristics of deep soil profile can be measured and calculated under different forms of land degradation. To achieve a more accurate assessment of soil carbon sequestration.

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References
[1] Schimel D S. Terrestrial ecosystems and the carbon cycle[J].Global Change Biology, 1995, 1: 77 - 91.
[2] Deng L, Liu G, Shangguan Z. Land-use conversion and changing soil carbon stocks in China's 'Grain-for-Green' Program: a synthesis [J]. Global Change Biology, 2014, 20: 3544 - 3556.
[3] Tan Z X, Lal R, Smeck N E, Calhoun F G. Relationships between surface soil organic carbon pool and site variables [J]. Geoderma, 2004, 121: 187 - 195.
[4] Houghton R A. The annual net flux of carbon to the atmosphere from changes in land use 1850-1990 [J].Tellus,1999, 51 (2): 299 - 313.
[5] Lal R. Carbon sequestration in drylands [J].Annals of Arid Zone, 2000, 39 (1): 1 - 10.
[6] Schlesinger W H, Reynolds J F, Cuningham G L, et al. Biological feedbacks in global desertification [J].Science, 1990, 247: 1043 - 1028.
[7] Han B, Wang X H, Ouyang Z Y. Saturation levels and carbon sequestration potentials of soil carbon pools in farmland ecosystems of China [J]. Rural Eco-Environment, 2005, 21 (4): 6 - 11. (In Chinese with English abstract).

[8] Li G C, Yin C B, Qiu J J. Controlling strategies of the land degradation and economic analysis[J]. Chinese Agricultural Science Bulletin, 2007, 23 (1): 128 - 131. (In Chinese with English abstract).

[9] Li L H. Effects of land-use change on soil carbon storage in grass land ecosystems[J]. Acta Phytoecologica Sinica, 1998, 22 (4): 300 - 302. (In Chinese with English abstract).

[10] Lal R. Carbon sequestration in dryland ecosystems[J]. Environmental Management, 2004, 33 (4): 528 - 544.

[11] Zhu Z D, Wu H Z, Cui S H. Combating Desertification/Land Degradation and Protecting the Environment in China [J]. Journal of Ecology and Rural Environment, 1996, 12 (3): 1 - 6.

[12] Ding J Z, Lai L M, Zhao X C, et al. Effects of desertification on soil respiration and ecosystem carbon fixation in Mu Us sandy land [J]. Acta Ecologica Sinica, 2011, 31 (6): 1594 - 1603. (In Chinese with English abstract).

[13] Zeng Y N, Feng Z L. Effect of desertification on soil organic carbon pool of grassland in headwater area of Yellow River [J]. Journal of Desert Research, 2008, 28 (2): 208 - 211. (In Chinese with English abstract).

[14] Duan Z, Xiao H L, Dong Z B, et al. Estimate of total CO2 output from desert field sandy land in China [J]. Atmospheric Environment, 2001, 35: 5915 - 5921.

[15] Gong Z T. Soil environmental change [M]. Beijing: China science and technology press, 1992. (In Chinese).

[16] Lal R. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2 enrichment [J]. Soil & Tillage Research, 1997, 43: 81 - 107.

[17] Fang H J, Yang X M, Zhang X P, et al. Effect of soil erosion on soil organic carbon in cropland landscape [J]. Progress in Geography, 2004, 23 (2): 77-87. (In Chinese with English abstract).

[18] Lessa A S N, Anderson D W, Chatson B. Cultivation effects on the nature of organic matter in soils and water extracts using CP/MAS 13C NMR spectroscopy [J]. Plant & Soil, 1996, 184 (184): 207 - 217.

[19] Lai R. Soil erosion and the global carbon budget [J]. Environment International, 2003, 29(4): 437 - 450.

[20] Guo T L, Xie J B, Kong Z H, et al. Experimental study on soil organic loss in redsoil erosion under different simulated rainfall intensity and slope gradient [J]. Ecology and Environmental Sciences, 2015, 24 (8): 1266-1273. (In Chinese with English abstract).

[21] Jia S W. 2009. Soil organic carbon loss under different slope gradients in Loess Hilly Region [J]. Research of Soil and Water Conservation, 16 (2): 30 - 33. (In Chinese with English abstract).

[22] Chen W N, Dong G R, Dong Z B. Research progress and trend of soil erosion in northern China [J]. Advance in Earth Sciences, 1994, 9 (5): 6 - 12. (In Chinese with English abstract).

[23] Yan H, Wang S Q, Wang C Y, et al. Impact of wind erosion on carbon cycle of fragile ecosystem in northern China [J]. Quaternary Sciences, 2004, 24 (6): 672-677. (In Chinese with English abstract).

[24] Zhu M J, Yan P, Song Y, et al. The influence of wind erosion on soil carbon pool of cropland and an assessment [J]. Research of Soil and Water Conservation, 2008, 15 (1): 226-231. (In Chinese with English abstract).

[25] Lal R, Kimble J, Follett R. Knowledge gaps and researchable priorities. In: Lal R, Kimble J M, Follett R F, Stewart B A. (Eds.) Soil Processes and the Carbon Cycle [M]. CRC Press, Boca Raton, FL, 1998.

[26] Liu A S. 1996. Soil species of Guangdong [M]. Beijing: Science Press. (In Chinese).

[27] Spaccini R, Zena A, Igwe C A, et al. Carbohydrates in water stable aggregates and particle size fractions of forested and cultivated soils in two contrasting tropical ecosystems
[28] Osher L J, Matson P A, Amundson R. Effect of land use change on soil carbon in Hawaii [J]. Biogeochemistry, 2001, 53 (1): 1-22.

[29] Rithie J C, McCarry C W. Cesium and carbon in a small agriculture watershed [J]. Soil & Tillage Research, 2003, 69: 45 - 51.

[30] Harden J W, Sharpe J M, Parton W P, et al. Dynamic replacement and loss of soil carbon on eroding cropland [J]. Global Biogeochem Cycles, 1999, 14 (4): 855 - 901.

[31] Farshid N, Ahmad R S A. A kinetic approach to evaluate salinity effects on carbon mineralization in a plant residue amended soil [J]. Journal of Zhejiang University Science B, 2006, 7 (10): 788 - 793.

[32] Rasul G, Appuhn A, Muller T, et al. Salinity-induced changes in the microbial use of sugarcane filter cake added to soil [J]. Applied Soil Ecology, 2006, 31: 1 - 10.

[33] Xie J, Li Y, Zhai C, et al. CO2 Absorption by alkaline soils and its implication to the global carbon cycle [J]. Environmental Geology, 2009, 56: 953 - 961.

[34] Li L, Qiu S J, Tan F F, et al. Effects of salinity and exogenous substrates on the decomposition and transformation of soil organic carbon in the Yellow River Delta [J]. Acta Ecologica Sinica, 2013, 33 (21): 6844 - 6852. (In Chinese with English abstract)

[35] Dai H M, Liu C, Gong C D, et al. Soil carbon pool in Northeast Plain of China and its relations between the soil properties[J]. Quaternary Sciences, 2013, 33 (5): 986-994. (In Chinese with English abstract).

[36] Fan H W, Jia X H, Zhang J G, et al. Influence of soil degradation and desertification on soil carbon cycling in arid zones [J]. Journal of Desert Research, 2002, 22 (6): 525 - 533. (In Chinese with English abstract).

[37] Cui J, Chen Y M, Cao Y, et al. Evolution Characteristics of soil organic carbon components and carbon management index in Caragana microphylla plantations in Loess Hilly Region [J]. Research of Soil and Water Conservation, 2013, 20 (1): 53 - 56. (In Chinese with English abstract).

[38] Six J, Contant R T, Paul E A, et al. Stabilization mechanisms of soil organic matter: implication for C-aturation of soils [J]. Plant and Soil, 2002, 241: 155 - 176.

[39] Hu C, Cao Z P, Ye Z N, et al. Impact of soil fertility maintaining practice on soil microbial biomass carbon in low production agro-ecosystem in northern China [J]. Acta Ecologica Sinica, 2006, 26 (3): 808-814. (In Chinese with English abstract).

[40] Tang J, Mao Z L, Wang C Y, et al. Regional land use structure optimization based on carbon balance: a case study in Tongyu County, Jilin Province [J]. Resources Science, 2009, 31 (1): 130-135. (In Chinese with English abstract).

[41] Wang W Y, Wang Q J, Wang G. Effects of land degradation and rehabilitation on soil carbon and nitrogen content on alpine Kobresia meadow [J]. Ecology and Environment, 2006, 15 (2): 362 - 366. (In Chinese with English abstract).

[42] Zeng Y N, Ma Z L, Feng Z D. Potential to sequestering carbon from atmosphere through rehabilitating desertified land in the headwater of the Yellow River [J]. Journal of Mountain Science, 2009, 27 (6): 671 - 675. (In Chinese with English abstract).

[43] Zhu Bingbing, Li Zhanbin, Li Peng, et al. Dynamic changes of soil erodibility during process of land degradation and restoration [J]. Transactions of the CSAE, 2009, 25 (2): 56 - 61. (In Chinese with English abstract).