Catena 85 (2011) 58–66

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Effects of vegetation restoration on soil organic carbon sequestration at multiple scales in semi-arid Loess Plateau, China

Yafeng Wang, Bojie Fu *, Yihe Lü, Liding Chen

State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, PR China

ARTICLE INFO

Article history:
Received 1 October 2010
Received in revised form 17 November 2010
Accepted 17 December 2010

Keywords:
Semi-arid environment
Cesium-137
Loess plateau
Vegetation cover
Multiple scales
Soil organic carbon
Ecological restoration
Soil erosion

ABSTRACT

Soil organic carbon (SOC) sequestration by vegetation restoration is the theme of much current research. Since 1999, the program of "Grain for Green"has been implemented in the semi-arid Loess Plateau, China. Its scope represents the largest vegetation restoration activity in China. However, it is still unclear for the SOC sequestration effects of vegetation cover change or natural succession promoted by the revegetation efforts at different scales under the semi-arid conditions. In this study, the changes in SOC stocks due to the vegetation restoration in the middle of Loess Plateau were estimated at patch, hill slope transect and small watershed scale from 1998 to 2006. Soil samples were taken from field for the determination of cesium-137 (^{137}Cs) and SOC contents. Vegetation cover change from 1998 to 2006 at the small watershed scale was assessed using Geographic Information System. The results showed that cropland transforming to grassland or shrubland significantly increased SOC at patch scale. Immature woodland, however, has no significant effect. When vegetation cover has no transformation for mature woodland (25 years old), SOC has no significant increase implying that SOC has come to a stable level. At hill slope scale, three typical vegetation cover patterns showed different SOC sequestration effects of 8.6%, 24.6%, and 21.4% from 1998 to 2006, and these SOC increases mainly resulted from revegetation. At the small watershed scale, SOC stocks increased by 19% in the surface soil layer at 0–20 cm soil depth from 1998 to 2006, which was equivalent to an average SOC sequestration rate of 19.92 t C y^{-1} km^{-2}. Meanwhile, SOC contents showed a significant positive correlation ($P<0.001$) with the ^{137}Cs inventory at every soil depth interval. This implied significant negative impacts of soil erosion on SOC sequestration. The results have demonstrated general positive effects of vegetation restoration on SOC sequestration at multiple scales. However, soil erosion under rugged topography modified the spatial distribution of the SOC sequestration effects. Therefore, vegetation restoration was proved to be a significant carbon sink, whereas, erosion could be a carbon source in high erosion sensitive regions. This research can contribute to the performance assessment of ecological rehabilitation projects such as "Grain to Green" and the scientific understanding of the impacts of vegetation restoration and soil erosion on soil carbon dynamics in semi-arid environments.

1. Introduction

Soil organic carbon (SOC) is a dynamic component of terrestrial systems, with both internal changes and external exchanges with the atmosphere and the biosphere (Zhang and McGrath, 2004). Restoring soil carbon is essential to enhancing soil quality, sustaining and improving food production, maintaining clean water, and reducing increases in atmospheric CO_2 (Lal, 2004). SOC plays important roles in enhancing crop production (Stevenson and Cole, 1999) and mitigating greenhouse gas emissions (Post and Kwon, 2000). SOC is related to atmospheric CO_2 levels with soils having the potential for C release or sequestration, depending on vegetation cover, land management and climate (Lal, 2004). Developing technologies to reduce the rate of increase of atmospheric CO_2 concentration is an important issue of the 21st century (Lal, 2008).

Terrestrial ecosystems play a significant role in the global carbon cycle because soils contain a stock of carbon that is about twice as large as that in the atmosphere and about three times that in vegetation (Smith et al., 2008). In semi-arid areas, which are characterized by fragile ecological systems, soil organic carbon is greatly susceptive to environment changes, especially to vegetation cover change. During the past two centuries, vegetation cover practices, such as deforestation and tillage, have resulted in a net loss of soil carbon to the atmosphere. Another crucial process that can drastically alter the soil C stock at the catchment scale is land cover change. In recent years, many studies have been conducted to estimate the

* Corresponding author. State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, P. O. Box 2871, Beijing 100085, PR China. Tel./fax: +86 10 62923557.
E-mail address: bfu@rcees.ac.cn (B. Fu).

0341-8162/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.catena.2010.12.003

effects of land cover changes on soil carbon stocks. During land cover change, soil may act either as a carbon source or as a carbon sink, depending on the ratio between the carbon of inflows and outflows. Studies addressing SOC dynamics when land is converted from one cover type to another would be valuable in improving our understanding and increasing our predictive capability over both short and long timescales (Post and Kwon, 2000). The review of Guo and Gifford (2002) indicated a decrease of 59% in SOC due to a change from pasture to cropland. The highest losses recorded for the conversion from pasture to crops were found in areas where precipitation range is 400–500 mm. They also found an up to 53% increase of SOC after the change from crop to secondary forest. Other studies indicated that after 20 years of afforestation the total amount of soil C increased by 23% in the first 10 cm of soil in humid Mediterranean conditions (Galdo et al., 2003). Wang et al. indicated that it is only in 5 cm depth of soil surface that SOC contents are significant for different land covers at semi-arid climate of the hilly Loess Plateau of China (Wang et al., 2010). Reductions of 10% to 40% of the soil C in cultivated soils compared with the non-cultivated soils have been reported in China with the highest losses from the semi-arid and subhumid areas (Wu et al., 2003). In central Spain, results show extensification using longer-term pasture rotations (e.g. 5-year) could increase SOC levels (Boellstorff, 2009). Therefore, sequestering additional soil C can be achieved through improved management techniques on current agricultural lands and by the transformation of cultivated soils to forest or grassland ecosystems (Guo and Gifford, 2002; Guo et al., 2004; Heath et al., 2003).

Recent concerns about rising carbon dioxide (CO_2) concentrations in the atmosphere have led to speculation that a large amount of carbon may be sequestrated in the soil. This may happen through forestation and other vegetation restoration driven by land use conversions (DeGryze et al., 2004).

At regional (Esser, 1995; Fang et al., 2001; Fearnside and Imbrozio Barbosa, 1998; Houghton, 1999; Kerr et al., 2003; Liu et al., 2008; Smith et al., 2000; Tan et al., 2009) and global scales (Esser, 1987; Houghton, 1999), many efforts have been carried out in determining the changes of SOC storage induced by land cover change. However, because of the high inherent natural variability in the world's soils and variable dynamics of carbon loss under different land cover types and change trajectories, accurate estimates of the historic loss are usually hampered by the lack of the required baseline data on soils (Lal, 2009). More accurate estimates on the size of the current SOC storage and the human-induced changes at patch, a piece of land which has uniform land cover and topography, typical comparable hill slope, and watershed scale are highly needed, especially based on dynamic data. This would provide a basis for a better understanding of the dynamic spatial–temporal variations of SOC.

China's Loess Plateau, covering approximately 58×10^4 km^2, is known for its long agricultural history and serious soil erosion. Since the 1950s substantial efforts in soil erosion control and ecological rehabilitation have been made by Chinese government, for example, extensive tree plantation in the loess plateau in the 1970s, integrated soil erosion control at the watershed scale in the 1980s and 1990s. Check-dams have been built in hilly and gully region since 1970s. Despite these efforts, soil erosion was still intensive, and vegetation had not grown up well by the late 1990s. In 1999, another project, Grain-to-Green, was initiated for soil erosion control and land quality improvement using widespread conversion of sloping cropland to forest and grassland on the Loess Plateau. In this project, it was suggested to convert all croplands with slopes of over 25° to green land covered with forest or grass, while the local farmers would receive grain and cash subsidy from the government for the loss of food due to cropland decrease (Chen et al., 2007).

Understanding the effect of vegetation restoration on soil carbon sequestration is valuable in estimating the potential of human in climate change adaptation. This is also one of the important pathways to evaluate the performance of ecological restoration efforts. Meanwhile, understanding landscape structure and functioning requires multiscale information, and scaling functions are the most precise and concise way of quantifying multiscale characteristics explicitly (Wu, 2004). Therefore, the objectives of the present study were: (1) to estimate SOC change responding to vegetation restoration at patch (single vegetation cover) and hill slope (combinations of different vegetation types) scales from 1998 to 2006; (2) to reconstruct the dynamics of SOC inventories at watershed scale; (3) to interpret the mechanism and implications of SOC sequestration in Loess Plateau along with vegetation restoration driven by vegetation cover conversion.

2. Materials and methods

2.1. Study area

The study area is the Yangjuangou catchment (36°42′N, 109°31′), which located in the middle part of the loess plateau in northern Shaanxi Province, China (Fig. 1). It is 14 km east to Yan'an city

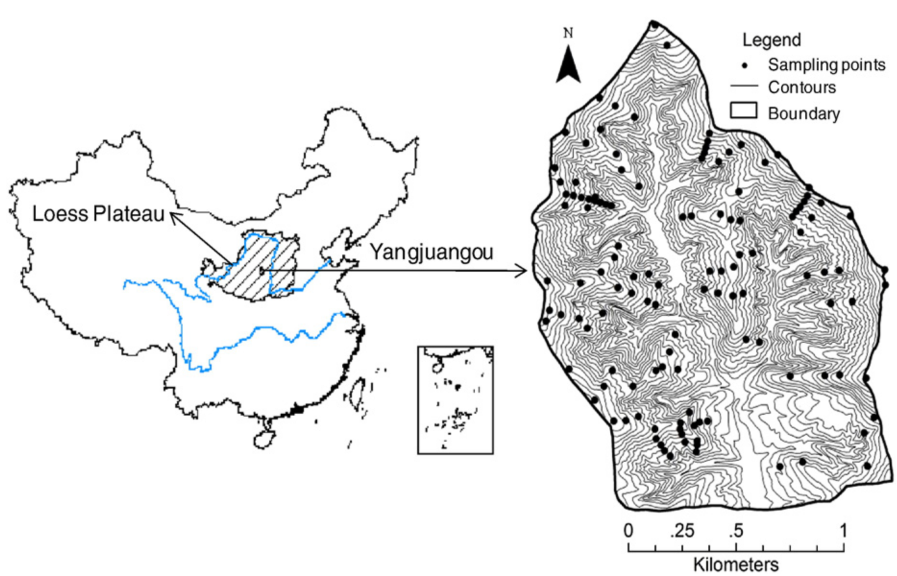

Fig. 1. Location of Yangjuangou catchment and soil sampling locations. (Elevation contours are 10 m interval).