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Soil organic carbon storage capacity positively related to forest succession on the Loess Plateau, China

Lei Deng [a], Kai-Bo Wang [b], Mei-Ling Chen [a], Zhou-Ping Shangguan [a,*], Sandra Sweeney [c]

[a] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling, Shaanxi 712100, PR China
[b] State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710075, PR China
[c] Institute of Environmental Sciences, University of the Bosphorus, Istanbul, Turkey

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ABSTRACT

Land-use change resulting from natural restoration probably enhances the carbon sequestration capacity of terrestrial ecosystems. To explore those factors which foster changes in the soil carbon pool in forest restoration, a study comparing soil organic carbon at different vegetation succession stages along a 150-year chronosequence was conducted in the Ziwuling forest region located in the central part of the Loess Plateau, China. It showed that in long-term (~150 yr) secondary forest succession the soil organic carbon storage (C*s*), soil organic carbon (SOC), total nitrogen (TN), and C/N ratio all increased rapidly and tended to be at their highest at roughly the 50-year restoration mark. From this point onward the values gradually stabilized indicating that the SOC and the TN accumulated mainly in the early restoration stages. The C*s* was significantly and positively correlated with the SOC, the TN, and the C/N ratio ($P < 0.01$). The C*s* in the soil was higher in the upper rather than the lower soil layers. However, the increments of the C*s* mainly changed in the lower soil layers. Soil water storage was not the key factor influencing the C*s*. The results suggested that changes to the C*s* were the result of the accumulation of the SOC and the TN during forest succession and this capacity has shown to be positively related to forest succession on the Loess Plateau, China.

1. Introduction

Soils play an important role in the global carbon cycle (Post et al., 1990; Schlesinger and Andrews, 2000; Scurlock and Hall, 1998). Soil carbon storage is roughly twice that of atmospheric storage (Davidson et al., 2000). Consequently, soil as either a carbon sink or source has become a focus of research in the scientific debate on global climate change (Knorr et al., 2005; Qiu et al., 2010; Schlesinger and Lichter, 2001). Local land-use and land-cover change can play a key role in both ecological and environmental changes thereby, contributing to global climate change (IPCC, Intergovernmental Panel on Climate Change, 2007; Wilson et al., 2003). Soil degradation is a major threat to the sustainable use of soil ecosystems because it decreases both the actual and potential vegetation cover (Cheng et al., 2012; Jia et al., 2005). Consequently, improving the physical and chemical properties of degraded soil is particularly important for sustainable soil ecosystems (Jia et al., 2005).

Soil organic carbon (SOC) is an essential part of soil physical and chemical properties (Schoenholtz et al., 2000). In addition, it is a key element in the process of trapping atmospheric CO_2 in terrestrial ecosystems through primary production (Post and Kwon, 2000). SOC loss caused by the conversion of natural to cultivated vegetation is well documented (Yan et al., 2012). Globally, 24% of the SOC stock has been lost through the conversion of forestland to cropland (Murty et al., 2002) and 59% through the conversion of pastureland to cropland (Guo and Gifford, 2002). In contrast, where cropland is withdrawn from farming and converted into natural vegetation, SOC accumulates and is locked up for greater periods of time due to the slower turnover rates associated with natural vegetation (Degryze et al., 2004; Post and Kwon, 2000; Zhang et al., 2010). The stock of SOC can be increased by preventing soil erosion (Lal, 2002), increasing organic matter inputs (Smith, 2008), and decreasing both weathering and microbial breakdown (Lal, 2005; Post and Kwon, 2000; Smith, 2008). Guo and Gifford (2002), for example, concluded that SOC storage increased by a remarkable 53% when crop was allowed to convert to secondary forest. However, Vesterdal et al. (2002) observed that afforestation on former arable land did not lead to an increase in SOC within three decades, but rather affected the redistribution of SOC in the soil profile. Understanding the pattern of SOC sequestration following the conversion of cropland to perennial vegetation is important not only to provide information for ecosystem management practices alone but also to support international policies on the mitigation of greenhouse gas emissions (Lal, 2002; Lal, 2004; Post and Kwon, 2000).

It is well known that succession can lead to the recovery of deteriorated soil properties (Jia et al., 2005; Zhao et al., 2010). For this reason, it is essential to understand the process of succession in

* Corresponding author. Tel.: +86 29 87019107; fax: +86 29 87012210.
E-mail address: shangguan@ms.iswc.ac.cn (Z.-P. Shangguan).

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secondary forests in the central part of the Loess Plateau in China where the vegetation cover of the plateau tends to be poor and sparse (Cheng et al., 2012; Jia et al., 2005) and, where simultaneously the plateau suffers from extreme soil erosion resulting in severe soil degradation (Deng et al., 2012; Liu et al., 2007).

Unsustainable land-use practices are one of the most important causes contributing to soil degradation (Jia et al., 2005). Consequently, the Chinese government has instituted various erosion mitigation measures on the Loess Plateau (SFA, China State Forestry Administration, 2002), especially the conversion of cropland into forest- and grassland. In the surroundings of the study area, some cropland has been restored to natural vegetation. Recently, Chinese scientists have increased the attention paid to the succession of secondary forests in the Ziwuling Range (Cheng et al., 2012; Jia et al., 2005; Wang et al., 2010; Zhao et al., 2010). While a lot of research has focused on changes in the aboveground vegetation of secondary forests in the central part of the Loess Plateau (Wang et al., 2010; Zou et al., 2002), few studies have focused on changes to the soil itself (Jia et al., 2005), although studies have already been done on soil properties in other regions of the Loess Plateau (Li et al. 2013; Wang et al., 2012). Furthermore, little investigation has been carried out on soil nutrient dynamics at the different succession stages of these secondary forests.

Changes in land use caused by revegetation probably enhance the carbon sequestration capacity of terrestrial ecosystems on the Loess Plateau. Naturally regenerating forests as carbon sinks is no doubt attributed to increases in their biomass carbon storage (Canadell and Raupach, 2008; Fang et al., 2001) capacity. Furthermore, soil carbon sequestration probably occurs more slowly (Vesterdal et al., 2002; Zhou et al., 2006). Thus, the study hypothesized that the stock of SOC varied with forest vegetation age through succession. Therefore, the objectives of the study were to investigate: (1) the dynamics of soil organic carbon storage with the succession of secondary forests, (2) the effects of vegetation succession on the level of SOC storage, and (3) those factors affecting SOC storage.

2. Materials and methods

2.1. Study area

The study was conducted on the Lianjiabian Forest Farm of the Heshui General Forest Farm of Gansu (35°03′–36°37 N′, 108°10′–109°18′E, 1211–1453 m a.s.l.), located in the hinterland of the Loess Plateau, the Ziwuling forest region, covering a total area of 23,000 km^2 (Fig. 1). The altitude of the region's hilly and gully landforms averages 1500 m a.s.l., their relative height difference is about 200 m, the area's annual temperature is 10 °C, annual rainfall is 587 mm, accumulative temperature is 2671 °C, and the annual frost-free period is 112–140 days. The region's soils are largely loessal having developed from primitive or secondary loess parent materials (Cheng et al., 2012), which are evenly distributed 50–130 m deep above red earth consisting of calcareous cinnamon soil (Jia et al., 2005), and soil pH ranged from 7.92 to 8.31. The area is covered in species-rich uniform forests with a forest canopy density ranging between 80%–95% (Cheng et al., 2012). The natural biomes of the region are deciduous broadleaf forests of which the climax vegetation is the *Quercus liaotungensis* Koidz forest. Throughout the region, *Populus davidiana* Dode and *Betula platyphylla* Suk communities dominate the pioneer forests; *Sophora davidii* (Franch.) Skeels, *Hippophae rhamnoides* (Linn.), *Rosa xanthina* Lindl and *Spiraea pubescens* Turcz are the main shrub species; and *Bothriochloa ischaemum* (Linn.) Keng, *Carex lanceolata* Boott, *Potentilla chinensis* (Ser) and *Stipa bungeana* Trin are the main herb species (Wang et al., 2010).

In the Ziwuling forest region, secondary forests naturally regenerated on abandoned land after great numbers of local residents were displaced during the national conflict of 1842–1866. Chen (1954) investigated the vegetation recovery of the Ziwuling forest region in the 1950s and determined that after about a century *P. davidiana* made up 70% of the vegetation cover. Zou et al. (2002), who investigated succession throughout the region three times

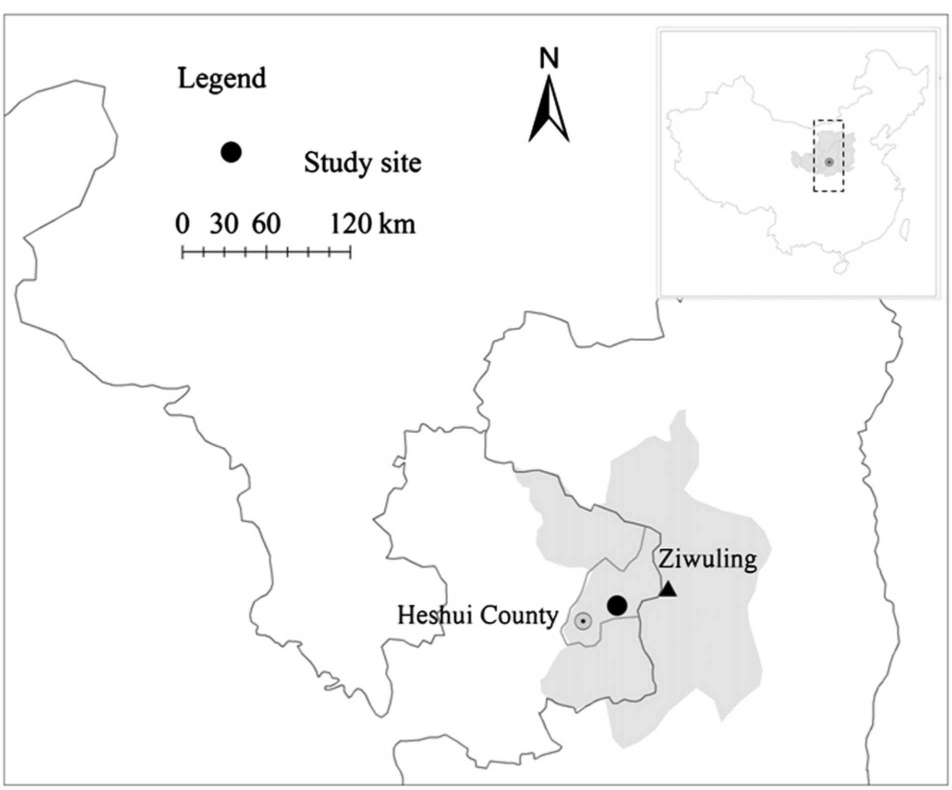

Fig. 1. Location of the Lianjiabian Forest Farm in the Loess Plateau.