Ecological Engineering 90 (2016) 105–112

Contents lists available at ScienceDirect

Ecological Engineering

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

Effects of age and land-use changes on soil carbon and nitrogen sequestrations following cropland abandonment on the Loess Plateau, China

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ARTICLE INFO

Article history:
Received 10 June 2015
Received in revised form 25 January 2016
Accepted 26 January 2016
Available online 11 February 2016

Keywords:
Dynamics
Land-use change
Restoration and revegetation
Soil depth
Carbon–nitrogen correlation.

ABSTRACT

Vegetation restoration and revegetation on land abandonment of cropland has a major impact on the landscape of the Loess Plateau in China. Such processes can alter soil carbon (C) and nitrogen (N) pools and cycling. However, few studies have examined the effect of cropland abandonment on soil C and N sequestration in various land-use types over time. We studied the effects of age and land-use change types on soil C and N sequestration in top 1-m soil depth in the transition from forest to grassland in the center of the Loess Plateau. The results show that age as well as land-use change types had a significant effect on soil C and N sequestrations. Soil C and N sequestrations in the surface soils (0–10 cm) had always increased since cropland abandonment. In the first 10 years, the orchard (OL) and man-made grassland (alfalfa) had higher soil C and N sequestrations than the other types of land uses, such as natural grassland (NG), shrubland (SL), orchard (OL) and woodland (WL). Moreover, in the later stage since cropland abandonment (>20 years), the SL had the high soil C and N sequestrations followed by WL and NG. In addition, the correlations between soil C and N sequestrations were greater in surface soil layers than that in deeper layers, and soil C sequestration was approximately 8–10 times that of soil N sequestration after cropland abandonment. Our study suggests that to get long-term (>20 years) soil C and N sequestration benefits, planting shrubs is a better restoration type in the transition from forest to grassland than natural grassland and woodland on the Loess Plateau, and orchard and man-made grassland (alfalfa) influenced by fertilization also have a good soil C and N sequestration benefits in the short time (<20 years) .

1. Introduction

Soils has twice as much carbon (C) stored in the soils as in the atmosphere, which play a major role in global C cycles (Davidson et al., 2000). Whether soils act as C sinks or sources has become a major focus of research on global climate change (Degryze et al., 2004; Laganière et al., 2010). Local land-use changes can play an important role in environmental and ecological changes, thus contributing to the global change (IPCC, 2007). Reports from around the world indicate that the soil organic carbon (SOC) declines by 20–43% after natural forest or perennial grassland is converted to agricultural land (Don et al., 2011; Wei et al., 2014a). In contrast, the conversion of cropland into forest or grassland has been shown to increase SOC by increasing C derived from new vegetation, thus simultaneously decreasing C loss from decomposition and erosion (Laganière et al., 2010; Shi et al., 2013; Deng et al., 2016). Thus, afforestation and revegetation have been proposed as effective methods for reducing atmospheric CO_2 due to C sequestration in vegetation and soils (UNFCCC, 2009; IPCC, 2007).

Terrestrial carbon–nitrogen (C–N) interactions have attracted considerable interest because of their importance in determining whether the C sink in land ecosystems could be sustained over the long term (Reich et al., 2006). It has been suggested that nitrogen (N) dynamics are a key parameter in regulating terrestrial C sequestration in the long term (Luo et al., 2004). Increased N deposition could reduce atmospheric CO_2 by stimulating forest biomass accumulation (Giardina et al., 2003). Specifically, C sequestration will be sustainable in land ecosystems if it allows for increased N inputs into an ecosystem (Rastetter et al., 1997). In contrast, N limitation would directly constrain terrestrial C sequestration (Schlesinger

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http://dx.doi.org/10.1016/j.ecoleng.2016.01.086
0925-8574/

and Lichter, 2001), a process that is fundamental to either mitigating or deferring global warming (Schlesinger and Lichter, 2001). Globally, Yang et al. (2011) have stated that substantial increases in C pools over age sequence are accompanied by N accretion in forest ecosystems. Therefore, there is a need to identify and describe biogeochemical cycles at the regional spatio-temporal scale, which is the scale at which landscape policies are implemented. Elucidating N dynamics in soils has important implications both for the sustainable management of regional land resources and for predictions of future C and N cycling globally.

Recently, many studies have examined the dynamics of soil C and N stocks following vegetation restoration (Knops and Tilman, 2000; Yang et al., 2011; Li et al., 2012). However, different studies have obtained variable results. For example, Deng et al. (2014) reported that soil C stock first declined in the initial stage and then increased after cropland abandonment. Morris et al. (2007) observed that top 1-m soil C stock was accumulated following afforestation on abandoned cropland, while Smal and Olszewska (2008) documented that soil C stock has significantly decreased in Scots pine (*Pinus silvestris* L.) forests along sandy post-arable soils. In addition, Sartori et al. (2007) reported that mineral soil C stock exhibits an insignificant change during forest stand development. Moreover, Knops and Tilman (2000) found that N accumulated in surface soil (0–10 cm) remained unchanged in subsoil (10–60 cm) following afforestation of cropland abandoned for 60 years. Li et al. (2012) found that soil N stocks decreased after afforestation with pine but increased with hardwood afforestation. However, the dynamic pattern is still unclear because different land-use conversion types and soil depths were mixed together, and there were large differences among depths and land-use conversion types in temporal C and N stock changes. In addition, because the relationships between soil C and N stock and climate, land-use types and soil properties in different soil depths have never been examined, the implications for the depth distributions of soil C and N are still unknown. Thus, our understanding of soil C and N dynamics in different soil depths and land-use conversion types remains incomplete.

The Loess Plateau is suffering severe soil and water losses (Liu et al., 2007). To control soil erosion and restore ecosystems, China has launched the "Grain for Green" Programs (GGP) aimed at restoring degraded cropland to forest and grassland. In the study area, the cropland had already been abandoned, and the process of natural and artificial restoration was underway. Although the initial goal of the GGP was to control soil erosion, the program strongly affects C and N cycling in soil. Consequently, many studies have focused on changes to soil C and N accumulation following cropland abandonment on the Loess Plateau (Zhang et al., 2013a; Deng et al., 2013). However, those studies only focused on one simple type of conversion and obtained inconsistent results. Therefore, a comprehensive study of soil C and N dynamics that considers different land-use conversion types (e.g., forest, shrub and grassland) at different ages is greatly needed. Our study aims to examine: (1) dynamics of soil C and N sequestrations in different agricultural and forest land uses, (2) the effects of restoration age as result of cropland abandonment on soil C and N sequestrations and (3) the relationship between soil C and N sequestrations estimated based on changes in C and N stocks at different times following cropland abandonment.

2. Material and methods

2.1. Study area

All study sites are located in Ansai County, Shaanxi Province, China (36°30′45″–37°19′31″N, 108°5′44″–109°26′18″E; 1,012–1,731 m a.s.l.) in the center of the Loess Plateau (Fig. 1). The study area is characterized by a semi-arid climate and a deeply incised hilly-gully Loess landscape. The mean annual temperature range is 9.1 ± 0.1 °C (1970–2010), and the mean annual precipitation is 503 ± 15 mm (1970–2010), of which 70% falls between July and September. The sand, silt and clay contents are 65%, 24% and 11%, respectively, and soil pH ranged from 8.3 to 8.9.

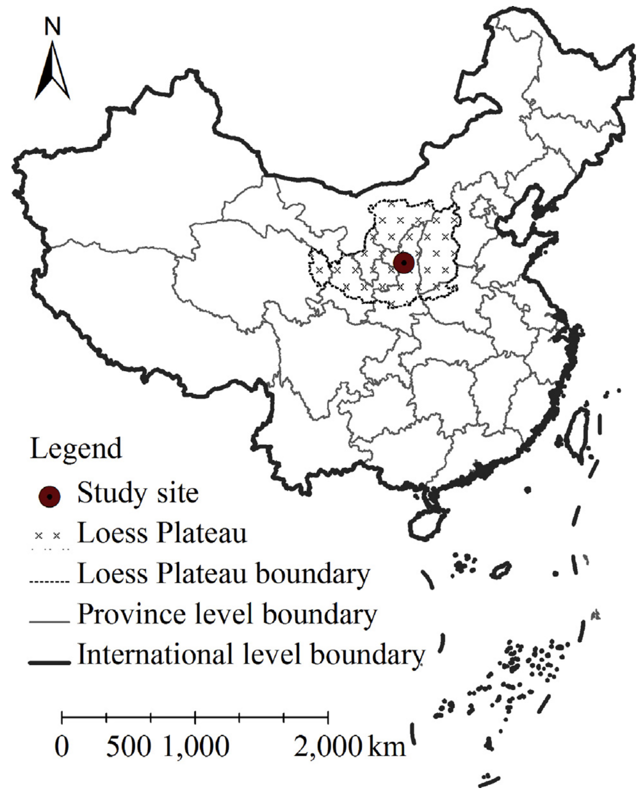

Fig. 1. Location of the study area (Ansai County, China).

2.2. Sampling design and data collection

In our study, we used the "space" for "time" method to study vegetation restoration/revegetation changed over time, which is a common method used to monitor plants and soils under similar climatic conditions following the sequence of vegetation development (Sparling et al., 2003; Li et al., 2007; Deng et al., 2013).

We conducted field surveys between July 10 and September 10 in 2011 and 2012 when the plant community biomass peaked. In total, we have chosen five land-use change types after cropland abandonment, and the sampling areas of the communities involved were determined according to their types. There were three 20 m × 20 m plots chosen in each forestlands (*Robinia pseudoacacia*), three 10 m × 10 m plots chosen in each shrublands (*Caragana microphylla*, *Hippophae rhamnoides*), three 2 m × 2 m plots chosen in each herbaceous communitiy (*Artemisia sacrorum*, *A. capillaries*, *A. giraldii*, *Aneurolepidium dasystachys*, *Bothriochloa ischaemum*, *Heteropappus altaicus*, *Lespedeza bicolor*, *Stipa bungeana*, *Setaria viridis*, etc.), three 2 m × 2 m plots chosen in each man-made alfalfa grassland (*Medicago sativa*), and three 10 m × 10 m plots chosen in each apple orchard, respectively. Each plot was at least 30 m from the other plots. We randomly selected 95 soil sites from growing vegetation between 1 and 56 years old. The restoration ages of each land-use types were achieved from the descriptions found in contracts between local farmers and local governments established. All of the stages of vegetation restoration or revegetation in this