Land Use Policy 78 (2018) 258–265

Contents lists available at ScienceDirect

Land Use Policy

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

Influence of stand type and stand age on soil carbon storage in China's arid and semi-arid regions

Jianjun Cao[a], Xiaofang Zhang[a], Ravinesh Deo[b,c], Yifan Gong[a], Qi Feng[b,*]

[a] College of Geography and Environmental Science, Northwest Normal University, Lanzhou 730070, China
[b] Key Laboratory of Ecohydrology of Inland River Basin, Alashan Desert Eco-Hydrology Experimental Research Station, Cold and Arid Regions Environmental Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 73000, China
[c] School of Agricultural, Computational and Environmental Sciences, International Centre for Applied Climate Sciences (ICACS), Institute of Agriculture and Environment (IAg&E), University of Southern Queensland, Springfield, QLD 4300, Australia

ARTICLE INFO

Keywords:
Climate change
Afforestation
Land use type
Soil organic carbon
The Loess Plateau

ABSTRACT

Afforestation implemented on available lands that have a poor fertility with a low primary productivity is considered to be a significant land use change issue globally, especially in the current phase of increasing atmospheric CO_2 concentrations. However, different stand types and stand ages, where afforestation is initiated, may have a different effect on soil carbon storage. Two stand types, including the apricot and poplar stand, both with 40 years, and two stand ages, including the apricot stand with 40 years and apricot stand with 16 years were sampled on the Loess Plateau, to explore the differences in soil carbon storage between both of them, respectively. The results showed that the total soil carbon storage up to the 1.0 m soil depth for the poplar stand was 79.07 Mg ha^{-1}, and for the apricot stand with 40 years was 88.36 Mg ha^{-1}, while for the apricot stand with 16 years, it was 56.16 Mg ha^{-1}. About 50% the soil carbon was stored in the 0-0.4 m soil layer for all these forested lands. This ascertains that the soil carbon was very sensitive to climate change and anthropogenic disturbances. Based on these results, if we are interested in combating global warming issue, the apricot trees can be a preferred option for future plantations. However, these plants are likely to consume more water than any other vegetation types. Since water is a limited resource both in arid and semi-arid regions, a tradeoff between soil carbon and soil water should also be considered in future afforestation policy options.

1. Introduction

Estimatedly, about two-thirds of the terrestrial ecosystems' organic carbon is nominally fixed by forests, and thus, forests are seen to play an important role in the climate system and the global carbon cycle (Fan et al., 2007; Zhong et al., 2017; Tei and Sugimoto, 2018). With global warming as a major environmental challenge (Korkanç, 2014), forest plantation has been considered widely as a strategic way to absorb the CO_2 from the terrestrial atmosphere (Chen et al., 2007; Zhou et al., 2009; Haghdoost et al., 2012; Krause et al., 2018). In China and also in many other nations, the implementation of afforestation is considered to be a strategic policy decision taken for former agricultural lands, marginal croplands, wasteland and deserts, particularly for those that have a poor soil fertility and productivity, to prevent soil degradation and restore the degraded landscapes that were severely affected by soil erosion processes (Cao and Wang, 2010; Zeng et al., 2014; Nunez-Mir et al., 2015; Han et al., 2017). The global total forest area has expanded by approximately 5×10^6 ha y^{-1} over the period 2005 to 2010 (Du et al., 2015), and that forest plantations in China now cover about 6.9×10^7 ha, accounting for one third of the world's total forest plantation areas (Chen et al., 2016). With the inevitable changes in land use, the lands' former short production cycles are extending to a much longer cycle on the forested landscapes (Cao and Wang, 2010; Ren et al., 2016). Although it has been widely reported that afforestation is expected to improve the carbon sequestration (Humpenöder et al., 2014; Han et al., 2017; Lu et al., 2018), there is some evidence that soil carbon sequestration generally varies among the different tree species and age of the plantations (Zeng et al., 2014), because a community of plants is seen to play a dominant role in the soil's carbon accumulation process (Wu et al., 2017).

The Loess Plateau of Northern China is famous for its deep loess and unique landscapes (Liu et al., 2014). However, this Plateau has also become one of the most serious soil erosion regions and the most vulnerable area to the desertification effect, due to long-term,

* Corresponding author.
E-mail address: qifeng@lzb.ac.cn (Q. Feng).

https://doi.org/10.1016/j.landusepol.2018.07.002
Received 19 May 2018; Received in revised form 28 June 2018; Accepted 1 July 2018

unreasonable land use management practices (Fu et al., 2011). To reverse this trend, at least partially, environmental restoration and protection programs have frequently been applied to restrict farming activities and also to increase the vegetative cover on steeper slopes (Liu et al., 2014). For example, in 1978, the Three-North (Northeast, North Central, and Northwest China) Forest Shelterbelt Program, which is the earliest large-scale afforestation program in China (Wang et al., 2011), was implemented. Another such program was also implemented in 1999 known as the "Grain for Green" (Tui Geng Huan Lin) Project. Both programs aimed to return about 32 million ha of cultivated hillside (slope $\geq 25°$) lands across China to the forestlands by the year 2010 (Chen et al., 2010).

With the enforcement of these projects into a practical reality to address the landscape degradation and soil fertility issues in non-vegetated lands, different stand types and different stand ages began to co-exist, and their capacities to facilitate the sequestration of carbon were intensively studied (*e.g.* Guo and Gifford, 2002; Chang et al., 2011; Dang et al., 2017). However, due to extensive inconsistency of these results, ground-truth observation data depending on specific locations are still required (Farley et al., 2005; Ilstedt et al., 2007; Jia et al., 2017). This is necessary to better understand the linkage between plantation forestry strategies and the storage of soil carbon (Silva and Dudley, 2009; Dangal et al., 2017), and also to achieve sustainable strategies for land use policy development and implementation of the most appropriate solution (Cao and Wang, 2010; Lu et al., 2016). This can therefore act as an appropriate decision support tool for forest management and culm cutting techniques that are likely to yield optimal benefits from the forest (Dangi et al., 2009).

Huining county, a representative area in the Loess Plateau, has implemented some of these projects. In the 1978 project, both the poplar tree (*Populus tremula* L.) and the apricot tree (*Prunus armeniaca* L.) were planted, while in the 1999 project, only the apricot tree was planted. The poplar stand can be regarded as one form of a pure ecological forest following the belief that the production of poplar could be a potential carbon sink due to the rapid accumulations of above- and below- ground biomass (Zhang et al., 2011). On the other hand, the apricot stand can be regarded as an eco-economic forest, because of its primary goal to reduce soil erosion and also to help farmers to maintain their incomes by sell of the almonds (Cao et al., 2018b). At present, there exist two different stand types (*i.e.*, the 40-year old poplar stand *vs* the 40-year old apricot stand) and two different stand ages (*i.e.*, the 16-year old apricot stand *vs* the 40-year old apricotstand). In a recent study, Cao et al. (2018b) have explored the effects of the stand type and stand age on soil water moisture, but, to date, no report about their influences on soil carbon storage (SC) has been established in any other independent study.

The present paper aims to investigate the influence of the stand type and stand age on SC, to purposely explore the balance between soil carbon and soil moisture based on our previous study (Cao et al., 2018b). In this paper, the hypothesis is that the SC is influenced by either the stand type or the stand age,and that the SC is positively correlated with the stand age. This study synthesizes reliable results to either prove or disprove the proposition, and expects to advance new understanding of SC based on stand type and stand age in China's arid and semi-arid region, that could also have wider implications for other regions where land use and land cover change is being addressed by afforestation options.

2. Materials and methods

2.1. Study area

Huining County (located at 104°29′- 105°31′E, 35°24′- 36°26′N) lies in central Gansu Province at the Northwest Loess Plateau at an average altitude of 2025 m extending over an area of about 6.4×10^5 ha. Annual average temperature in this region ranges from 6 °C to 9 °C with an annual rainfall of 180–450 mm, mainly attributable to a temperate semi-arid climate. The region is characterized by complex tectonic structures, most of which are based on metamorphic rocks and granites.

By the end of 2015, the county's total afforested areas had reached to about 7.1×10^4 ha, representing a forest coverage rate of approximately 12.47% (Cao et al., 2018b). In the county's northern and central regions, although the trees planted in 1978 were deforested for wood, some forests have been protected integrally up till now. Together with the trees planted in 1999, this provides a good opportunity for researchers, such as the one pursued in this paper, and also for land use policy-makers to explore the effects of the stand type and stand age on SC.

2.2. Experimental design

During the period July to September 2017, four sites were selected as the sampling area, the greater details of which are available in an earlier study of Cao et al. (2018b). In each forested site, nine plots were arranged both in an up-down fashion and on the contour at a 10 m spacing. In all these sites, 81 plots were investigated, and each forested land type had a total of 27 plots. In each plot, a set of three 1 m × 1 m quadrats, spaced along the diagonal (*i.e.*, at both ends and a midpoint), had their soil profile excavated to a depth of 1.0 m. Soil samples were taken for a profile depth range of 0-0.1 m, 0.1–0.2 m, 0.2–0.4 m, 0.4–0.6 m, 0.6–0.8 m and 0.8–1.0 m, using a cutting ring whose volume was equivalent to 1×10^{-4} m^3 (Wu et al., 2016). A soil depth of 1.0 m is likely to reflect the main root distribution of the forest (Han et al., 2017). In each quadrat of the apricot stand, above-ground biomass (AGB) was collected. While in the poplar stands, vegetative cover and plant diversity were very low due to the physical barrier of litter (Fig. 1C) to germination (Chen et al., 2015), so AGB was not collected.

2.3. Soil and biomass analysis

Soil bulk density (SBD g cm^{-3}) was determined from the undisturbed core segments as the dry soil mass per unit volume, while the soil organic carbon (SOC g kg^{-1}) was determined with wet dichromate oxidation using an air-dried homogenized subsample of 0.2 g soil and titration with $FeSO_4$ (Qin et al., 2016). Fresh biomass was oven dried at 80 °C to a constant weight (over a 24 h period) and was then expressed by the dry weight (g) (Cao et al., 2013). The SC in each soil layer was calculated following existing methods (Shang et al., 2014):

$$SC_i(t\ ha^{-1}) = C_i \times SBD_i \times T_i \quad (1)$$

In Eq. (1), C_i is the concentration (%) of SOC in the i^{th} soil layer, and T_i is the thickness of the soil layer.

The total of soil carbon storage (TSC) in 1.0 m soil depth can be stated as follows:

$$TSC = \sum_{i=1}^{i=6} SC_i = \sum_{i=1}^{i=6} C_i \times SBD_i \times T_i \quad (2)$$

2.4. Data analysis

Data were analyzed using SPSS 22.0 statistical software (SPSS Inc. Chicago, USA), and expressed as the mean ± standard deviation. One-way analysis of variance was applied to determine the statistically significant differences in the soil pH, SBD and SOC between the different stand types and stand ages at equivalent to a significance level stipulated by a value of $p \leq 0.05$. The Pearson's Product Moment Correlation (r) was used to identify the statistically significant relationships between the measured variables. The Origin Pro 9.0 software was then adopted to visualize for the data through appropriate visual and statistical diagnostic plots.