Ecological Engineering 95 (2016) 501–504

Contents lists available at ScienceDirect

Ecological Engineering

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

Short communication

Variation of soil organic carbon and land use in a dry valley in Sichuan province, Southwestern China

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ARTICLE INFO

Article history:
Received 20 January 2016
Received in revised form 20 June 2016
Accepted 26 June 2016
Available online 9 July 2016

Keywords:
Dry valley
Land use
Soil carbon
Restoration
Reforestation

ABSTRACT

In dry valleys in southwestern China, soil organic carbon (SOC) storage is very sensitive due to changes in land use. Characterizing SOC content variations is key to improving SOC sequestration and future land management. This study evaluated land-use changes, especially reforestation, and the effects on SOC variability in a small dry watershed in the Minjiang river valley. Multivariate methods indicate that the SOC content was affected by land uses and topographical features, including elevation, slope position, and gradient. SOC content for shrubland was significantly higher than for other land use. Reforestation greatly improves SOC content and a positive relationship was found between SOC content and the number of reforestation years. Forest restoration and shrubland restoration from farm land would increase the soil carbon storage level by 6% and 8%, respectively. Our results suggest that natural shrub restoration and plantation management are effective ways for improving soil carbon sequestration in dry valleys.

1. Introduction

In southwestern China, there are large areas of dry valleys with a unique topography and climate that are vulnerable to human disturbance and do not recover easily from such disturbances due to low water availability (King et al., 2012). The dry valley in the Minjiang river basin, which is situated in the middle of the Hengduan Mountains, is the second largest dry valley in China (Li et al., 2006). According to the "National Eco-environmental Protection Project" of China, it is a central region for ecological construction. As a result of topographic variability and human disturbance, land use mosaics with ecological vulnerability and sensitivity are characteristic of this valley. Significant land-use change, vegetation dynamics, and reforestation in the region have been identified since the late 1980s (Bao et al., 1995; Liu et al., 2002).

As a major soil quality indicator, SOC is one of the most important factors for sustaining the global biosphere and for developing sustainable ecosystem management practices (Stevenson and Cole, 1999). However, SOC studies have had a high degree of uncertainty, as SOC variability is influenced by many factors. Usually, the statistical techniques of multivariate methods have been widely used in evaluations of soil properties (Liu et al., 2007; Zhao et al., 2012). Although soil variations across landscapes are often analyzed using such techniques as regression and geostatistical analysis (Western et al., 1998), the multivariate canonical correspondence analysis (CCA) method has been widely applied in soil-environment research when considering the landscape characteristics, in situ soil conditions, or land cover (Qiu et al., 2001).

Land use significantly influences the degree and direction of SOC changes in time and space (Doetterl et al., 2013; Lei et al., 2016). Evaluating and monitoring SOC variations is vital for assessing the direction of change caused by land-use management and ecological restoration (Jian et al., 2010; Liu et al., 2002). As far as we know, few studies of SOC storage changes arising from land-use changes in dry valleys have been conducted due to topographical complexity. These areas should be researched for their particularity and importance due to their ecological sensitivity and vulnerability. In terms of land-use change, forest plantations in the region have been rapidly established since the "Grain for Green Program" was initiated in 1999. However, the impact of forest plantation on SOC has caused a great deal of confusion (Dostálek et al., 2007; Liu et al., 2002). An improved understanding of dynamic processes may help in developing successful forest management practices.

To serve as an example to characterize the SOC variability under different land uses and reforested conditions, we selected a small dry catchment with a forest plantation history of more than 30 years. Thus, the objectives of this study were to characterize the

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http://dx.doi.org/10.1016/j.ecoleng.2016.06.101

relative importance of factors (e.g., land use and topography) influencing SOC and to assess SOC changes due to reforestation storage and different land management practices.

2. Material and methods

2.1. Study area

The study area, the Fengyi catchment, is located in the middle of the upper reaches of Minjiang river valley in Sichuan province (Fig. 1). The topography is characterized by the complex distribution of hills and valleys with an average elevation difference of over 1000 m. The mean annual precipitation of this area is approximately 900 mm, and the mean annual temperature is 9 °C. Soil types in this area are classified as mountainous umber and brown soils.

2.2. Land use investigation and estimation of SOC storage in the small watershed

Historically, most of the land use in the catchment has been gradually transformed from farmland to planted forestland. However, current land use still exhibits great landscape heterogeneity. Shrubland in the catchment includes *Campylotropis macrocarpa (Bunge) Rehder, Quercus spinosa David, Rosa rubus Lévl. et Vant.,* and *Rhododendron sutchuenense Franch*, among others. The main plantation tree is the Chinese pine (*Pinus Sinensis*), farmland is mainly dominated by maize and soybeans, and orchards consist mainly of apple and pear trees. A land-use map (1:100000) was digitalized for the spatial analysis of land-use distribution.

Twenty-nine typical plots were investigated representing the main land uses, including orchard land (4 sites), shrubland (8 sites), cultivated land (4 sites) and reforested land (13 sites). The number of years of reforestation was determined via the increment core method and by asking local farmers. Landscape variables, including altitude, landscape position and aspect were recorded for each plot. Soil samples were obtained using cores (5-cm diameter) from three random soil profiles at each land use site at a depth of approximately 0–30 cm in a representative 100 m^2 sampling plot. The samples were air-dried and sieved to determine soil properties, including total nitrogen (TN), available phosphorus (AP), soil water content (SW), available potassium (AK), SOC and pH. SOC storage change was estimated according to previous studies (Lu et al., 2014). We focused on SOC in the topsoil to infer organic carbon effects, as the SOC of the top soil (0–30 cm) changes more noticeably than that in deep soil layers (Raiesi, 2012).

To identify the relative importance of different influencing factors of soil properties, we used CCA for direct gradient analysis. Dependent variables included TN, AP, SW, AK, SOC and pH. Furthermore, elevation, slope position, land-use type, slope aspect and slope degree were selected as the landscape feature indicators and as environmental independent variables (Bagheri et al., 2011). Qualitative data have to be coded before analysis according to previous studies (Liu et al., 2007). The software program Canoco 4.0 was used for data processing (Centre for Biometry, 1998), and One-way analysis of variance (ANOVAs) was used to test the effects of different variables on SOC.

3. Results

3.1. Spatial variability of land use and SOC

In the Fengyi catchment, plantations cover the largest area, followed by shrub land, farmland, and orchard land. As expected, farmland distributed in the low zone of the catchment and the artificial forest had a high elevation (Fig. 2a). Generally, the farmland is dispersed on a gentle hill/slope near a village (Fig. 2b). Our results reveal the SOC content to have a positive linear relationship with elevation. The linear equation can be expressed as $SOC = 0.0117x - 16.62$ ($R^2 = 0.46^{**}$, n = 29). The SOC content on 25°–35° and >35° slopes dominated by plantation and shrubland were significantly greater than on 0°–15° and 15°–25° slopes. However, no significant differences were found between 25°–35° and >35° slopes, 0°–15° and 15°–25° slopes (Fig. 2c). The SOC content in shrubland on an upper slope was higher than that at a middle position. Furthermore, only shrubland revealed significant differences between different slope positions, and shrubland and plantations had higher SOC values than farmland and orchards (Fig. 2d).

3.2. Analysis of soil properties and landscape features relationship using CCA method

The CCA method was used to further quantify the relative importance of influencing factors associated with soil properties and landscape features. CCA showed that the cumulative percentage variance of the first and second axis were 62% and 95%. As shown in Fig. 3, it is clear that landscape characteristics significantly impact different soil properties, especially SW content, AP and pH. For SOC, elevation has a positive effect on its content. In addition, land-use type, slope position and slope degree are the primary factors that impact SOC content.

In this small catchment, we investigated 13 plantation sites with different years of growth. As an important restoration measure, reforestation can improve or degrade soil fertility in various ways. Little consistent evidence was obtained due to considerable differences in plantation species, climate zones, and local soil conditions. However, our results suggest that reforestation can alter SOC content in the dry valley significantly. After reforestation, SOC increased from 11 g/kg to 65 g/kg, yielding a positive relationship between SOC and the number of reforested years in the dry valley. The equation can be expressed by $Y = 0.1813x + 0.1724$ ($R^2 = 0.47$).

3.3. Ecological restoration concerning SOC storage change

For this small valley, we estimated the SOC storage change under different restoration scenarios. Scenario I, II, and III indicate the current status, the agricultural land converted to shrubland, and the agricultural land converted to forestland (Fig. 4). The results indicated that current land use had the lowest SOC storage, while shrubland and forest restoration would increase the storage level by 8% and 6%, respectively. Thus, our results support the conclusion that shrubland may be an effective choice for restoring soil properties as it can improve soil conditions at the ecosystem level. When the policy "change farmland to forestland" was introduced, reforestation, especially conifer replanting, garnered considerable interest, and our study confirms that SOC increased due to reforestation in the dry valley.

4. Discussion

A number of ecological effects remain unclear for restoration management in dry valleys in China. Following the Wenchuan earthquake in the Minjiang river valley in 2008, ecological restoration, rehabilitation, and reintegration-oriented interventions are increasingly needed.

Our results indicate that topographical factors in the study area were not the only factors controlling the SOC. Land-use distribution and ecosystem management play an important role in SOC storage as well. The data shows that long-term cropland management farmland has adverse effects on SOC storage. In this respect,