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Soil organic carbon storage and its influencing factors in the riparian woodlands of a Chinese karst area

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ABSTRACT

Riparian woodlands have recently been recognized as important carbon (C) storage regions with a considerable potential of sequestering C to mitigate global warming. Understanding soil organic carbon (SOC) storage in riparian woodland and the differences in SOC storage between riparian woodlands and other adjacent land types is important to effectively assess SOC storage in riparian woodlands and the influences of riparian land-use changes on SOC pool. Therefore, we thoroughly investigated C storage in the riparian woodlands along the Lijiang River watershed, located in a karst area in southwestern China. The goals of the study were to quantify the SOC density (SOCD) in the riparian woodland (0–20 cm depth of upper soil) [$N = 54$, the plot area was 1130.88 ± 136.13 m^2 (mean value with standard deviation)]; to compare the differences in SOCD in the riparian woodland [bamboo-dominated ($N = 9$) and non-bamboo-dominated woodlands ($N = 45$)], the adjacent grasslands ($N = 13$) and the farmlands [croplands ($N = 17$) and orchards ($N = 17$)]; and to assess the influence of soil texture, plant litter and soil root biomass on the SOCD of the riparian woodlands. The results showed that the average SOCD in the riparian woodlands of the Lijiang River watershed was 35.79 ± 9.51 t/ha. The SOCD in the non-bamboo-dominated woodland was 36.91 ± 9.63 t/ha, which was higher than that in the bamboo-dominated woodlands (29.86 ± 4.90 t/ha) by 7.05 t/ha (about 23.59%) ($p < 0.05$) and was higher than that in the adjacent grasslands (27.77 ± 7.35 t/ha), croplands (28.93 ± 7.30 t/ha) and orchards (21.26 ± 8.20 t/ha) by 32.91%, 27.58% and 73.61%, respectively ($p < 0.01$). However, the SOCD in the bamboo-dominated woodlands was only higher than that in the orchard by 8.60 t/ha (about 40.45%) ($p = 0.012$). In the non-bamboo-dominated woodlands in the Lijiang riparian watershed, the SOCD showed a significant negative correlation with soil sand content ($r = -0.69$) and a significant positive correlation with the silt ($r = 0.59$) and clay content ($r = 0.61$) ($p < 0.01$). The SOCD showed a significant positive correlation with plant litter ($r = 0.44$) and soil root biomass ($r = 0.38$) ($p < 0.05$). Finally, the results indicate that the non-bamboo-dominated riparian woodland in the karst area stores more SOC compared with the adjacent grassland and farmland. However, converting riparian vegetation into bamboo woodland did not increase the accumulation of SOC and even caused some SOC loss in the Lijiang riparian area.

1. Introduction

Riparian zones are important corridors between terrestrial and aquatic ecosystems for exchanging material, energy and information and have unique biotic, biophysical and landscape characteristics (Naiman et al., 1993; Vidon et al., 2010; Bedison et al., 2013; Sutfin et al., 2016). As an important part of riparian ecosystems, riparian woodlands play a crucial role in stabilizing riverbanks, trapping and removing nutrients, providing habitats for terrestrial organisms and maintaining ecosystem stability, among other roles, which have been widely and systematically researched (Seth, 1999; Dosskey et al., 2010; Bedison et al., 2013). Riparian woodlands have recently been recognized as important carbon (C) storage areas with a considerable potential to sequester C and mitigate global warming (Hazlett et al., 2005; Cierjacks et al., 2010; Ricker and Lockaby, 2015; Ruffing et al., 2016). Further studies of soil organic carbon (SOC) storage in riparian woodlands and its influencing factors are essential for understanding and enhancing its role in mitigating the increasing atmospheric carbon dioxide (CO_2) concentrations. Furthermore, SOC in riparian woodlands is an important measurement index for evaluating soil quality and ecosystem health status (Were et al., 2015; Celentano et al., 2016).

Current studies showed that the total riparian area of the earth is 0.8×10^6 to 2.0×10^6 km^2, and its SOC storage is approximately 16–125 Pg, which could account for 0.5–8.0% of the global SOC storage (991–2469 Pg) (Leopold et al., 1964; Tockner and Stanford, 2002; Hiederer and Kochy, 2011; Mitsch and Gosselink, 2015; Sutfin et al.,

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2016). Thus, any land use changes in the riparian zones can significantly mitigate or enhance CO_2 concentrations in the atmosphere. Changes to the SOC in the riparian zone depend on the ratio between the SOC inflows and outflows during changes to the riparian land use (Guo and Gifford, 2002). Compared to other land uses, woodlands, which are an important part of the riparian zone, usually contain higher SOC (Coleman et al., 2004; Bedison et al., 2013; Ricker et al., 2014). In their research on woodlands and agricultural crop soil in the riparian zone of the North Central United States, Coleman et al. (2004) found that the soil organic carbon density (SOCD) in woodlot woodlands was 175.32 t/ha and was higher than that in agricultural croplands by 112.72 t/ha (0–128 cm depth of upper soil). Bedison et al. (2013) reported that the SOCD in forest riparian sites was higher than that in non-forest riparian sites, with values of 100.3 and 90.6 t/ha (0–30 cm depth of upper soil), respectively. Therefore, the conversion of riparian woodlands to other land uses, particularly to farmlands, can cause a loss of the SOC pool in riparian woodlands (Hazlett et al., 2005; Sutfin et al., 2016).

Although many studies have assessed the difference of SOC content in different land use types of riparian zones. However, whether the above results are similar for the soil of riparian woodlands of the karst area is unknown. Karst geomorphology is a unique and important geomorphological type that is generally characterized by extensive outcropping of soluble rocks, rapid and frequent hydrological processes and thin soil layers. It is a vulnerable ecosystem that is created by acidic water on carbonate bedrock. This karst geomorphology has a profound effect on regional water resources and C cycle (Bonacci et al., 2009; Liu et al., 2015). Understanding the differences in SOC content between riparian woodlands and other land uses in the karst region is important to scientifically manage and protect riparian woodlands and can also enhance our understanding of SOC in the riparian zones of this geomorphic region.

Due to its location in the ecotone of the river and adjacent upland, the factors influencing SOC accumulation in riparian woodlands are also multiple and complex. The vegetation in the riparian woodland is an important contributor to the SOC cycle via the processes of photosynthesis, root absorption and decomposition, as well as the reduction of plant litter and dead root to produce SOC microcirculation. Vegetation can also stabilize and protect riparian soil and reduce surface erosion and trap sediment, thereby affecting the accumulation and distribution of riparian SOC (Dosskey et al., 2010; Bullinger-Weber et al., 2014; Bätz et al., 2015). The dead plant litter and roots of riparian vegetation are known to be important sources for increasing the SOC storage (Gift et al., 2010; Don et al., 2010; Ricker et al., 2014; Sutfin et al., 2016). Based on the fixed-point observations in the riparian woodland, Ricker et al. (2014) found that the annual average input of leaf litter was 2.4 t C/ha yr in riparian woodlands, and the annual average input of root C was 1.0 t C/ha yr (0–100 cm depth of upper soil). Riparian soil is an important carrier of organic carbon (OC), and its natural properties, such as texture, water content and pH, also have a significant effect on the conversion and decomposition of OC (Bechtold and Naiman, 2006; Rieger et al., 2014; Graf-Rosenfellner et al., 2016). In some studies, the SOC content was positively correlated with soil silt and clay content in riparian soil, i.e., soil with a relatively high fine fraction content (silt and clay) had higher SOC content than soil with coarser fractions (sand) (Bechtold and Naiman, 2006; Hoffmann et al., 2009). To understand the function of riparian woodlands in sequestering SOC, we need to deeply understand the effect of each environmental factor on SOC accumulation. However, few comprehensive studies examining this have been conducted in the riparian zones of karst regions, and further research is needed.

To enhance our understanding of SOC in the riparian zones of karst regions and the function of the riparian woodlands in SOC sequestration in this region, the goals of this research were to (Bai et al., 2016) quantify the SOCD of different woodland types in the riparian zone of karst regions, (Bao and Su, 2015) compare the differences of the SOCD in riparian woodlands and adjacent farmlands and grasslands, and (Bätz et al., 2015) assess the influences of different factors on the SOCD of riparian woodlands. The Lijiang River lies in the southwest region of China and is a karst river where the riparian zone has abundant woodland resources. Therefore, the riparian zone of the Lijiang River watershed, southwestern China was selected as the study area.

2. Materials and methods

2.1. Study area

The study area lies in the Lijiang River watershed located in southwestern China (23°23′N–25°59′N, 110°18′E–111°18′E). The Lijiang River belongs to the upper reaches of the Guijiang River in the Pearl River Basin and originates from the northeast side of Mao'er Mountain, which is the highest peak in South China (2141.5 m). This river flows from north to south. The main stream is 214 km long, and the total basin area is 12,285 km^2. In 2014, the karst landscape of the Lijiang River watershed was listed as a World Natural Heritage Site.

The Lijiang River watershed lies in low latitudes, and is affected by a subtropical moist monsoon climate. The average annual temperature is 17.8–19.1 °C, the annual evaporation is 1377–1857 mm, and the average annual precipitation is 1500–2600 mm (1960–2010) (Duan et al., 2014). This river is a mountain river with a swift, soaring plunge water level that produces strong and frequent riparian scouring. It is mainly recharged by the rain, and the water level changes quickly in response to precipitation. The mean annual total runoff is 41.8×10^9 m^3, and the mean annual runoff is 120–130 m^3/s (1961–2000). The runoff is extremely uneven throughout a year. The flood season is between March and August, and the runoff nearly accounts for 80% of the total annual runoff. September to February is the dry season. The annual total sediment discharge in the Lijiang River is 124.3×10^5 t, and the mean annual sediment concentration is 0.282 kg/m^3 (Huang and Cheng, 2008).

The riparian soil of the Lijiang River watershed is dominated by red loam. The upper soil (0–3 m depth) of the riparian zone is composed of sandy loam and silty loam, whereas the lower soil (below 3 m depth) is sandy gravel. The river bed is mainly made up of gravel and coarse sand with little silt. The riparian zone of the Lijiang River watershed has abundant plant resources, with 167 families, 549 genera and 905 species. The major tree species are *Pterocarya stenoptera* C. DC., *Cinnamomumcamphora* (L.) J. Presl, *Sapiumsebiferum* (L.) Roxb. and *Bambusa sinospinosa* McClure. The main fruit species are *Citrus sinensis* (L.) Osb., *Citrus maxima* (Burm.) Merr. and *Castaneamollissima* Bl. The main shrub species are *Flueggeasuffruticosa* (Pall.) Baill., *Adina rubella* Hance and *Ligustrumsinense*Lour. The main herb species are *Cynodondactylon* (L.) Pers., *Polygonumhydropiper* L. and *Arthraxonhispidus* (Thunb.) Makino. Among them, bamboo is a prevailing and local landscape plant, which is widely planted in the riparian of the Lijiang River watershed. It is indispensable to tourism of the Lijiang River and is also an important source of timber economy for the residents living along the river. In the past few years, tourist activities, such as hiking, biking and picnic on the riparian in the Lijiang River watershed have rapidly developed and have seriously affected the riparian woodlands (Wei, 2004; Ren et al., 2014; Bao and Su, 2015) (Fig. 1).

2.2. Sampling selection

In this study, 54 sampling plots of riparian woodlands along a 136 km section of in the Lijiang River watershed from Xingan to Yangshuo City were selected to investigate and sample. These plots were based on a field investigation of the riparian zone and regional remote sensing images of the Lijiang River watershed. To standardize the sampling, all the plots were parallel to the river; the width of the longitudinal parallel to the river was not <30 m, and the width of the transverse was not <8 m. The onset transverse boundary of the plot was