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Effects of riparian land use changes on soil aggregates and organic carbon

Jin Qian[a,b,*], Jingjing Liu[a,b], Peifang Wang[a,b,*], Chao Wang[a,b], Jing Hu[c], Kun Li[a,b], Bianhe Lu[a,b], Xin Tian[a,b], Wenyi Guan[a,b]

[a] *Key Laboratory of Integrated Regulation and Resource Development on Shallow Lakes, Ministry of Education, Hohai University, Nanjing, 210098, People's Republic of China*

[b] *College of Environment, Hohai University, Nanjing, 210098, People's Republic of China*

[c] *Department of Soil and Water Science, University of Florida, Gainesville, FL 32611, United States*

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ABSTRACT

Soil aggregation processes play a crucial role in re-establishing soil structure and function, and protecting soil organic carbon (SOC) to sustain soil fertility and quality. There is a strong interest in preventing soil erosion in the interface of terrestrial and aquatic ecosystem. The relationship between soil aggregates and SOC in riparian zones is not as well studied as in terrestrial ecosystems. The aim of this study was to investigate the effects of conversion of abandoned lands to cultivated lands on organic carbon (C) and soil structure. Soil samples and plant residues were collected from abandoned lands and cultivated lands which had been converted from abandoned lands over 10 years ago. Results show that SOC content and storage increases by 1.64 times and 6.75 $Mg\ hm^{-2}$, respectively, after the land use change. For cultivated lands, 11.94% of macro-aggregates (> 2 mm) were broken into micro-aggregates (< 2 mm), resulting in the mean weight diameter (MWD) and geometric mean diameter (GMD) decreases of 1.01 and 1.11 mm, respectively, while the fractal dimension (FD) increased by 0.28. The SOC content of micro-aggregates (10.88–15.02 $g\ kg^{-1}$) was higher than that of macro-aggregates (10.10–11.63 $g\ kg^{-1}$) for both abandoned and cultivated lands. The SOC content of micro-aggregates for cultivated lands (14.46–15.02 $g\ kg^{-1}$) was higher than abandoned lands (10.80–11.14 $g\ kg^{-1}$). The content of microbial biomass carbon (MBC) increased by 1.52 times due to increases in root biomass and the plant residue returned to soil, which were mainly caused by the changes in cultivation practices and soil water conditions. Our results show that total SOC storage increased by the land use conversion from abandoned to cultivated lands, indicating that planting aquatic plants might be an effective method of preventing C loss from riparian ecosystems. The findings of this study provided insights into the changes in soil aggregates and soil C sequestration following the land use changes in riparian areas.

1. Introduction

Soil organic carbon (SOC) content regulates various physical, chemical, and biological processes in soils (Mikha and Rice, 2004). Soil aggregations protect SOC, and sustain soil fertility and quality (Angers et al., 1997; Fattet et al., 2011; Jastrow et al., 1998; Oades, 1984). The original mineral particles, cementing with bacteria, fungi and plant debris, form small aggregates (< 0.25 mm). The free small aggregates are then cemented into large aggregates by transient cementing agents (microbial and plant source polysaccharide) and temporary cementing agents (root and mycelium) (Tisdall and Oades, 1982). Riparian SOC stock and the degree of soil aggregation can be significantly influenced by riparian plants (Blazejewski et al., 2005; Kimura et al., 2017). Differences in riparian plant composition influence the input of organic matter quantity and quality, and the soil carbon (C) source (Heikkinen et al., 2014). For instance, root exudates (e.g., polysaccharides and enzymes) have been reported to directly affect soil physicochemical and microbiological properties, soil aggregation, and SOC content (Eisenhauer et al., 2012; Materechera et al., 1992). Therefore, riparian plants are one of the key factors regulating soil structure, the stability of soil aggregation, and thus soil C sequestration capacity (Dosskey et al., 2010; Wang et al., 2014).

Strong aggregate stability enhances SOC conservation and enriches organic C content in aggregates, further resulting in a higher C sequestration potential in soils (Pan et al., 2008; Zhong et al., 2017). Conservation of SOC in soils has been found controlled by the size of aggregate particles (Blazejewski et al., 2005; Wang et al., 2014). Thus, the aggregate particle size should be taken into consideration for the

* Corresponding authors at: Key Laboratory of Integrated Regulation and Resource Development on Shallow Lakes, Ministry of Education, Hohai University, Nanjing, 210098, People's Republic of China.
E-mail addresses: hhuqj@hhu.edu.cn (J. Qian), pfwang2005@hhu.edu.cn (P. Wang).

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goal of enhancing the SOC conservation ability of riparian zones (Arai et al., 2013; Steenwerth et al., 2002). Many studies have suggested that the SOC content of soil aggregates was inversely proportional to particle size (Denef et al., 2007; Liu et al., 2011; van Gestel et al.,1996; Zhong et al., 2017). However, Wang et al.(2016) reported that organic C content in micro-aggregates (< 0.25 mm) decreased with decreasing aggregate size in hilly regions. In addition, a study on prairie ecosystems revealed that macro-aggregates (> 0.25 mm) in soils contained higher organic C concentrations than micro-aggregate size classes (Gupta and Germida, 1988), which are in accordance with those of Hernández-Hernández and López-Hernández (2002) and Wang et al. (2014). The relationship between soil aggregates and SOC has been intensively studied in terrestrial ecosystems, however, it is unclear whether the relationship is similar in riparian soils.

Lake Taihu, located in the Yangtze River delta in eastern China, is the third largest freshwater lake in China. Over the past three decades, approximately 50% of the lake has been eutrophified (Xu et al., 2010; Qin et al., 2007; Townsend-Small et al., 2007). Riparian zones and their aquatic plant communities are essential in regulating the water environment of Lake Taihu (Dosskey et al., 2010; Ewel et al., 2001; Lake, 2005). Riparian zones play an important role in the movement of water and NPS (non-point source) pollutants to water bodies (Schultz et al., 2004; Welsch 1991). Riparian buffers are linear in nature and provide effective connection between the terrestrial and aquatic ecosystems because of their position in the landscape. However, the riparian zones of Lake Taihu have been severely degraded in recent years (Dosskey et al., 2010; Ewel et al., 2001; Lake, 2005). A major consequence of riparian degradation is the loss of SOC (Jones et al., 2010). Soil aggregation, which controls SOC stock and organic matter composition, is an important factor regulating soil erosion in riparian buffer zones (Lowrance et al., 1997; Schultz et al., 2004). To our knowledge, no studies have attempted to identify the effects of land use changes from abandoned to cultivated riparian land on soil aggregates and SOC content. Therefore, the objectives of the study were: (i) to determine changes in soil aggregates and organic C after the land use change and to establish the relationship between changes in soil aggregates and organic C, and (ii) to evaluate the effects of soil aggregation on protecting aquatic ecosystems.

2. Materials and method

2.1. Site description

The sampling sites were located in the riparian zone of Yingcungang River (latitude 31°27′N and longitude 119°59′ E), one of the main inflowing rivers of Taihu Lake, China (Fig. 1). The area experiences a subtropical monsoon climate with average annual precipitation ranging from 1177 to 1570 mm. Annual mean temperatures range from 16 to 19 °C (minimum −9 °C, maximum 36.7 °C). Agriculture is the dominant land use and accounts for approximately 48% of the total area, mainly for rice, wheat, planted rape, and soybean. Areas near the river bank are rich in emergent plants, such as *Phragmites australis*, *Arundo donax*, and *Canna indica* (Chen et al., 2010; Yang et al., 2012).

With rapid economic development and urbanization surrounding the Yingcungang River, the riparian zone in the region has been severely degraded in the last 30 years. In order to achieve riparian ecological restoration, a large portion of abandoned land has been changed to cultivated land in 2006. Abandoned areas at the sample sites have been degenerating from natural riparian lands for approximately a decade. Based on the field survey, the vegetation coverage rate for abandoned land was 15–20%, and the major species were *Sagittariapygmaea*, *Setariaviridis*, *Bermudagrass* and *Zizania caduciflora*. After being converted from abandoned land in 2006, the land is annually cultivated and harvested.

2.2. Sample collection

Six sampling locations were selected for this study in order to evaluate the stability of soil aggregates, and quantify SOC storage (Fig. 1). Site information for both abandoned and cultivated areas are included in Table 1. The amount of residue returned to soil was obtained by the harvest method. Three 1 m^2 sampling plots were set up at each site. The number of plants for each plot was recorded in October. Three plant samples were randomly collected from each plot and dried to constant weights at 60 °C. After rinsing, the plant samples were separated by different organs and dried to constant weight at 60 °C. The dry weights of roots, stalks 15 cm above the surface and the underground biomass were considered as the amount of residue returning to the soil.

In June, 2016, nine parallel samples were collected according to the S-shaped sampling strategy from each plot for both abandoned and cultivated lands (Bissonnais, 1996). A total of 54 surface soil samples (0–15 cm) were collected (9 parallel samples × 3 plots = 27 samples for abandoned lands, and 27 samples for cultivated lands). Soil samples were collected when the water level was −5 mm. To avoid compaction and soil degeneration, soil samples were placed into hard aluminium boxes and transported to the laboratory for further analyses.

2.3. Soil analysis

Soil samples were air-dried, and then passed through a 2 mm soil sieve. Soil water content was measured gravimetrically and expressed as a percentage of soil water to dry soil weight (oven-dried at 105 °C to a constant weight). Soil bulk density (BD) was calculated as the ratio of oven-dried undisturbed core weight to container volume. Soil pH was determined using an acidity agent (soil-water ratio of 1:2.5) (PHS-3E pH Meter, Shanghai Feile Co. Ltd., China). Subsamples of soil were finely ground and passed through a 0.10 mm sieve to analyse SOC, total nitrogen (TN) and total phosphorus (TP). Soil organic C was determined using the Walkley-Black $K_2Cr_2O_7{-}H_2SO_4$ oxidation method (Nelson and Sommers 1982). Microbial biomass C (MBC) was determined by a fumigation-extraction method (Vance et al., 1987). Particulate organic C (POC) was determined following Cambardella and Elliott (1992). Total N and P were quantified by the potassium persulphate oxidation method (Bremner and Mulvaney, 1982), and the colorimetric method after wet digestion with $H_2SO_4 + HClO_4$ (Parkinson and Allen, 1975), respectively.

2.4. Soil aggregates fractionation

The intact samples (after air dried) were broken by hand along natural failure surfaces to obtain a range of aggregate sizes < 10 mm. Leaves, plant roots and gravels were removed with tweezers. Soils were then passed through a 10 mm sieve and thoroughly mixed. The aggregated soils were separated into different size fractions by gently shaking the samples through a range of sieves to obtain different aggregate size fractions, including < 0.053, 0.053–0.25, 0.25–2, and > 2 mm (Zhong et al., 2017). Soil organic C was determined on each soil aggregate fraction (Muruganandam et al., 2009).

Kemper and Rosenau (1986) and Mandelbrot (1983) suggested that fractal dimensions (FD), mean weight diameter (MWD, mm) and geometric mean diameter (GMD, mm) could be used to quantify soil aggregate stability. The MWD and GMD were calculated by the following formulas (Zhang and Horn, 2001).

$$\mathrm{MWD} = \sum_{i=1}^{3} \frac{(r_{i-1} + r_i)m_i}{2} \tag{1}$$

$$\mathrm{GMD} = \exp\left\{\frac{\sum w_i ln\frac{r_{i-1}+r_i}{2}}{\sum w_i}\right\} \tag{2}$$