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Research article

Dynamics of soil organic carbon in density fractions during post-agricultural succession over two lithology types, southwest China

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A B S T R A C T

Agricultural abandonment has been proposed as an effective way to enhance soil organic carbon (SOC) sequestration. Nevertheless, SOC sequestration in the long term is largely determined by whether the stable SOC fractions will increase. Here the dynamics of SOC fractions during post-agricultural succession were investigated in a karst region, southwest China using a space-for-time substitution approach. Cropland, grassland, shrubland and secondary forest were selected from areas underlain by dolomite and limestone, respectively. Density fractionation was used to separate bulk SOC into free light fraction (FLFC) and heavy fraction (HFC). FLFC contents were similar over dolomite and limestone, but bulk SOC and HFC contents were greater over limestone than over dolomite. FLFC content in the forest was greater than in the other vegetation types, but bulk SOC and HFC contents increased from the cropland through to the forest for areas underlain by dolomite. The contents of bulk SOC and its fractions were similar among the four vegetation types over limestone. The proportion of FLFC in bulk SOC was higher over dolomite than over limestone, but the case was inverse for the proportion of HFC, indicating SOC over limestone was more stable. However, the proportions of both FLFC and HFC were similar among the four vegetation types, implying that SOC stability was not changed by cropland conversion. Exchangeable calcium explained most of the variance of HFC content. Our study suggests that lithology not only affects SOC content and its stability, but modulates the dynamics of SOC fractions during post-agricultural succession.

1. Introduction

Soil is one of the greatest pool of carbon (C) globally, with soil organic C (SOC) pool about four times as much as the vegetation C pool or three times as much as the atmospheric C pool (Lal, 2004). Thus, the understanding of how SOC pool responds to anthropogenic disturbances is crucial for predicting future climate-C cycle feedback. Agricultural abandonment has been proposed as an effective way to enhance SOC sequestration (Guo and Gifford, 2002; Smith, 2008; Pongratz et al., 2009; Li et al., 2012). Nevertheless, knowledge of bulk SOC pool increase following agricultural abandonment has limited implications for predicting climate-C cycle feedback since the bulk SOC pool is a mixture of substrates varying in stability (von Lützow et al., 2007; Schmidt et al., 2011). In practice, SOC is often divided into labile (with turnover times of less than 1 year), intermediate (with turnover times of years to decades) and passive (with turnover times of >100 years) fractions (Trumbore, 1997). No change in bulk SOC pool may result from increase of labile fractions and decrease of non-labile fractions, or *vice versa* (Neff et al., 2002). If only the labile SOC increases, the role of SOC sequestration following agricultural abandonment would be minor from the perspective of mitigating climate change, since the labile SOC fraction only accounts for a small proportion in the bulk SOC pool and has a very short turnover time (Trumbore, 1997). In contrast, a detectable increase of the non-labile fractions would have a substantial impact on atmospheric CO_2 given their larger pool sizes and much longer turnover times (Trumbore, 1997). In

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order to better predict climate-C cycle feedback, it is imperative to reveal how SOC fractions change following agricultural abandonment.

According to a conceptual model, the labile SOC fraction is not protected and susceptible to decomposition in short terms (Six et al., 2002). Nevertheless, other SOC fractions are under protection via three mechanisms, i.e., (i) chemical protection via binding between SOC and minerals, (ii) physical occlusion in micro-aggregates and (iii) biochemical stabilization via the intrinsic properties of the organic matter (Six et al., 2002). In order to separate the SOC fractions, different methods have been proposed, including density fractionation, which separates bulk SOC into free light fraction (FLFC), occluded light fraction (OLFC) and heavy fraction (HFC) or more (Lützow et al., 2007). During post-agricultural succession, SOC fractions may vary in different patterns, including (i) bulk SOC and its fractions are not changed (Leifeld and Kögel-Knabner, 2005; de Oliveira Marques et al., 2015), (ii) bulk SOC and its fractions increase (Compton and Boone, 2002), (iii) bulk SOC and HFC contents decrease but FLFC content increases (John et al., 2005; Liu et al., 2010; Llorente et al., 2010), and (iv) bulk SOC and HFC contents are not changed but FLFC content is changed (Roscoe and Buurman, 2003). The possible mechanisms underlying the differential responses of SOC fractions may be due to changed patterns of detritus inputs and decomposition (Davidson and Janssens, 2006; Baah-Acheamfour et al., 2015), or due to variation in soil physicochemical properties including hydrous iron oxides Al_{ox}/Fe_{ox} and Ca, which may chemically protect SOC via covalent or electrostatical bonds (Kaiser et al., 2012). Nevertheless, so far the mechanisms underlying the dynamics of SOC fractions following agricultural abandonment have not well understood.

Lithology regulates many processes at the Earth surface including the fluxes of matter to soils and ecosystems (Hartmann and Moosdorf, 2012). Due to its important role in determining soil physicochemical properties, lithology has been documented to exert substantial influences on the composition and function of plant and microbial communities (Reith et al., 2012; D'Amico et al., 2015). Since soil properties, plant and microbial communities all directly or indirectly contribute to variation of SOC level, it is reasonable to hypothesize that lithology also poses a great influence on SOC stabilization following agricultural abandonment. The available studies, which have related SOC contents to lithology, show that lithology may have or not have significant effects on SOC content (Oyonarte et al., 2008; Turrión et al., 2009; Albaladejo et al., 2013). However, to our knowledge, no studies have been conducted to assess whether lithology plays a role in determining dynamics of SOC fractions or SOC stability during post-agricultural succession.

During the past two decades, several national-scale ecological restoration projects, including the so-called "Grain for Green" project (GGP) have been implemented in China (Shi and Han, 2014). GGP is among the most ambitious ecological restoration programs in the world aiming at converting the low-yield slope cropland or barren land into woodland or grassland (Chang et al., 2011). About 2.7×10^7 ha degraded land has been converted under GGP by the end of 2012, of which 33% and 56% were due to afforestation on cropland and barren land, respectively, while 10% was under spontaneous regrowth after agricultural abandonment (Shi and Han, 2014). In addition to ecological restoration, GGP has been found to substantially increase SOC pool (Zhang et al., 2010; Zhou et al., 2012; Deng et al., 2014; Shi and Han, 2014; Song et al., 2014). Our previous studies based on chronosequence (Yang et al., 2016) or space-for-time substitution (Li et al., 2017) also revealed that bulk SOC would increase rapidly following agricultural abandonment in the karst region, southwest China. The current study was aimed to assess how SOC fractions changed during post-agricultural succession via a space-for-time substitution approach. Our previous study reported that bulk SOC dynamics during post-agricultural succession were modulated by lithology type (Li et al., 2017), i.e., SOC level increased from the cropland through to secondary forest in areas underlain by dolomite while was not significantly different among cropland, grassland, shrubland and secondary forest over limestone. We hypothesized that the dynamics of SOC in density fractions would follow the similar patterns as bulk SOC.

2. Materials and methods

2.1. Study region

This study was conducted in a karst region (24°44′–25°33′N, 107°51′–108°43′E) in Guangxi Zhuang Autonomous Region, southwest China. This region is located in the subtropical humid forest life zone with a monsoon climate. Mean annual temperature (MAT) is about 16.9–21.5 °C, with the lowest monthly mean in January (3.4–8.7 °C) and the highest in July (23.0–26.7 °C). Mean annual precipitation (MAP) ranges from 1400 to 1600 mm with a distinct pattern of dry season (from October to March) and wet season (from April to September). The region is characterized by a typical karst landscape with gentle valleys flanked by steep hills. The lithology in the karst areas is limestone, dolomite, and their mixtures. The soil is calcareous lithosols (limestone soil) over both limestone and dolomite according to the FAO/UNESCO classification system (Anon, 1974).

2.2. Field sampling and analyses

The field sampling was described elsewhere in details (Li et al., 2017). Briefly, a space-for-time substitution approach was adopted. Cropland, grassland, shrubland and secondary forest was selected. The latter three vegetation types represent different stages of spontaneous succession following agricultural abandonment. The selected sampling sites were distributed over areas underlain by either dolomite or limestone. The history of land use was obtained by inquiring native people. The croplands were managed under corn-soybean rotation each year for at least 10 years, and fertilized with N, P and K fertilization rates of about 150, 60 and 120 kg ha^{-1} yr^{-1}. Organic matters including manure/compost were normally not applied except the plant residues of corn and soybean after harvesting. The crops only received precipitation and manual irrigation was not conducted. Tillage was usually not adopted, but disturbance associated with planting and weeding to the surface soil was inevitable. Fertilization was not carried out after agricultural abandonment. The duration of agricultural abandonment was normally greater than 5 years but less than 10 years for grassland, 10–20 years to shrubland, and 30–50 years to secondary forest.

Field investigation and soil sampling were conducted from the mid of May to early June, 2015. Soil samples were collected from 72 sites. At each site, a plot of about 20 m×20 m was selected. Considering that the karst landscape is characterized by gentle valleys flanked by steep hills, the sampling sites were distributed over three slope positions (i.e., toe slope, foot slope and back slope). The slope was typically 15–20°. Obvious organic layer was absent in most of the sampling sites. Since soil depth was much heterogeneous and only shallow soil layers could be found in most of the sampling locations, mineral soils to a depth of 15 cm were collected after removal of organic layer (if available) in order to make comparison among sampling locations. At each site, 10–15 soil cores (0–15 cm depth) were randomly collected and mixed to a composite sample. Additional soil cores were collected to determine bulk density (BD). Soil samples were air dried, crushed and sieved through 2 mm and 0.147 mm to remove roots and stone fragments.