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ORIGINAL ARTICLE

Soil organic carbon associated in size-fractions as affected by different land uses in karst region of Guizhou, Southwest China

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Abstract Land use change has a significant effect on soil organic carbon (SOC), especially on labile organic carbon (LOC) due to its rapid response to soil changes and carbon supply. The objective of the study was to assess the effects of different land uses on soil fraction size distribution, SOC and LOC concentrations and their stocks in karst region of Guizhou Province, Southwest China. Studies were based on soil sampling in paddy, dryland, abandoned cultivated land for 3-years (AC-3), and abandoned cultivated land for 15-years (AC-15) in the 0–10, 10–20, and 20–30 cm depths in karst mountain area of Guizhou Province. Three fraction-size classes [macro (250–2000 μm), micro (53–250 μm), silt + clay (<53 μm)] were fractioned, and SOC and LOC concentrations in whole soil (non-fractionated) and different fraction sizes were also determined. The results showed that paddy contained the highest SOC and LOC concentrations in whole soil and different size-fractions as compared with other land uses down to 30 cm depth. However, the proportions of LOC to SOC were higher in AC-3 than the other land uses, especially pronounced in whole soil, which ranged from 17.5 to 26.3 % in different soil depths. Paddy also contained 23.7 % (100.9 Mg ha^{-1}) more SOC and 17.6 % (19.7 Mg ha^{-1}) more LOC stocks than dryland, whereas the SOC and LOC stocks in AC-15 and dryland were very close to each other in each soil depth. In paddy field, we found that macro-sized fractions contributed the greatest quantities of SOC to whole soil. In addition, paddy had significantly higher SOC stock values in macro-sized fractions than the other land uses in the both 0–10 and 10–20 cm depths. In the present study, there were no obvious increases of SOC and LOC pools among whole soil and different soil size-fractions after 15 years of land abandonment. These results suggest that natural recovery of SOC may take a long time after land abandonment, and paddy could serve as an important land use type for long-term carbon sequestration in karst region of Southwest China.

Keywords Soil organic carbon · Size fraction · Land use · Karst region

Introduction

The soil organic carbon (SOC) pool is about 2.6 times the biotic pool (Post et al. 1990; Eswaran et al. 1993) and twice the atmospheric pool. SOC is considered to be a key component of soil organic matter (SOM), which is responsible for soil functions and sustainability of agricultural ecosystems (Chen and Xu 2008; Xu et al. 2009). Measuring the quantity and spatial distribution of SOC is essential for evaluating soil function and understanding soil carbon (C) sequestration processes (Lal 2004). Soil labile organic carbon (LOC) is a very dynamic proportion of SOC, accounting for much of the fluctuation over time (Wang et al. 2005). In addition, LOC can influence terrestrial C storage through its impact on nutrient supply to plants (Zhang et al. 2005; Luo et al. 2009). Currently, LOC has attracted more attention because of its control over CO_2 fluxes between terrestrial ecosystems and the atmosphere (Trumbore et al. 1990).

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Physical protection of organic carbon within soil fractions is an important mechanism for C sequestration (Jastrow 1996; Six et al. 2002). Recently, the physical fractionation method has been generally used to reveal the effects of different land use practices on SOC storage and stability (Chen et al. 2010). Different components of SOC have different residual time, ranging from labile to stable forms (Haile et al. 2010). Based on soil physical fractionation techniques, three soil fraction size classes can be roughly established: the macro-sized (250–2000 μm), micro-sized (53–250 μm), and silt + clay-sized (<53 μm). Many studies have indicated that SOC associated in macro-sized fractions is often more labile than SOC in the silt + clay-sized fraction, while micro-sized fraction is the building block of soil structure and more stable in storing SOC as compared to macro-sized fraction (Tiessen and Stewart 1983).

Guizhou Province is located in the heart of karst mountain area of Southwest China and has 73 % of the total area being made of karst landscapes (Zhang et al. 2001). Compared to other regions in China, the mosaic of rock and soil increases the complexity of topography and diversity of microhabitats in the karst region of Southwest China (Chen et al. 2012). Due to great population pressure, rugged topographic conditions, and unsustainable land use practices, the limestone area of Guizhou Province has become one of the most severe karst rocky desertification regions in Southwest China. To face the challenge of ecological degradation, some ecological rehabilitation projects have been carried out in a short time in karst region of Southwest China. A rapid land use change occurred during 1999 where many farmlands have been abandoned or with the dominant conversion of farmland to grassland. The land use change in such a short time may lead to re-allocation of the SOC. Recently, Chinese scientists have paid more attention about the effect of land use change on SOC in karst region of Southwest China (Yuan et al. 2007; Chen et al. 2012). However, studies on soil carbon dynamics were mainly focused on SOC change in whole soil, and very little effort has been devoted to the effect of land conversion on SOC distribution among size-fractions, especially for the LOC associated with different soil size-fractions as affected by different land uses in karst region of Southwest China. The objective of this study were to: (1) investigate the SOC and LOC distribution in whole soil and different soil size-fractions (250–2000, 53–250, <53 μm) as affected by different land uses, and (2) evaluate the SOC stored in different land use types in a small scale in karst region of Guizhou Province.

Materials and methods

Study area

This study was conducted in the Karst Ecosystem Research Station, Puding County, Guizhou Province, Southwest China (28°20′48″N, 105°48′49″E). This catchment is a 'normal' karst hill peak-cluster depression landform with an area of 1.29 km^2 and an elevation of 1300–1500 m above sea level. The mean annual rainfall is 1300 mm, of which, more than 65 % is received during the summer monsoon months (June to September). The mean annual temperature is 15.1 °C. Soil types of the study site are predominantly calcareous soil according to the USDA Taxonomy system (Soil Survey Staff in USDA 1992).

Land uses

To compare the SOC and LOC changes in different land use types, four types of land use (paddy, dryland, abandoned cultivated for 3-years, and abandoned cultivated for 15-years) were selected. All sites had the same soil type and similar topography. The paddy field has been cultivated for more than 100 years before the experiment. The dryland has been intensively cultivated at least 50 years, and mainly used for growing maize (*Zea mays L*) during summer season (April–August) and radish (*Raphanus sativus L*) or rape flower (*Brassicacapestris*) during winter season (November–March). Two kinds of abandoned cultivated land (abandoned 3- and 15-years, respectively) were selected to compare the effects of land abandonment on SOC and LOC in this study. Both abandoned cultivated for 3-years (AC-3) and abandoned cultivated for 15-years (AC-15) had in fact abandoned from long-term cultivated dryland, according to local elder farmer interview. During the period of abandonment, the AC-3 and AC-15 have become homes to native grasses (*Ficus tikoua*, *pteris vittata*, *Miscanthus floridulus*), and few shrubs (*Pyracantha fortuneana, Rosacymosa*) were also found in AC-15.

Soil sampling

Soil sampling was performed in late July 2011. At each selected land use, soil samples were collected from three depths (0–10, 10–20, 20–30 cm) from three randomly selected sampling plots (20 m × 20 m). The five subsamples were taken randomly in an "S" formation at each sampling plot, and then all soil samples from one plot were composited together to gain a representative sample. Soil bulk density (BD) was measured in all three layers by the core method using metal cylinders of 100 cm^3. The core samples were dried at 105 °C for 24 h and then weighed. All samples were air-dried and through a 2-mm mesh, roots and coarse plant debris were removed and stored at room temperature for further analysis.

Size fractionation

The soil samples were physically fractionated into three fraction size classes (250–2000 μm, 53–250 μm, and <53 μm), according to a procedure from Haile et al. (2010). Briefly, a 100 g of the composite sample was submerged in deionized water with disruptive forces of slaking for about 5 min prior to placing it on top of 250 μm sieve. The sieving was done manually by moving the sieve up and down approximately 50 times in 2 min. The fraction remaining on the top of a 250 μm sieve was collected in a hard plastic pan and allowed to oven-dry at 65 °C and weighed. Water plus soil <250 μm was poured though a 53 μm sieve and the same sieving procedure was repeated. The overall wet sieving procedure yielded a macro-sized fraction, 250–2000 μm; a micro-sized fraction, 53–250 μm; and a silt + clay-sized fraction, <53 μm.

SOC and LOC analyses

The SOC in whole and fractioned soil was analyzed by H_2SO_4–$K_2Cr_2O_7$ pyrogenation method (Nelson and Sommers 1982). The LOC in whole soil and fractioned soil was measured by the $KMnO_4$ oxidation method (Blair et al. 1995). Briefly, a 25 ml of 333 mmol L^{-1} $KMnO_4$ was dispensed into each sample (having at least 15 mg C) in 50 ml plastic screw-top centrifuge tube. The similar volume of $KMnO_4$ dispensed into an empty screw-top centrifuge tube to sever as blank. The centrifuge tubes were shaken on a reciprocating shaker for 1 h at 12 rpm and then centrifuged for 5 min at 2000 rpm. A 1 ml aliquot of the solution supernatant was diluted to 250 ml and absorbance was measured on a spectrophotometer (Varian Cary 100, USA) at 565 nm. The LOC was calculated from the changing amount of $KMnO_4$.

The SOC or LOC pool, expressed as Mg ha^{-1} for a specific depth, was computed by multiplying the SOC or LOC concentration (kg Mg^{-1}) with bulk density (Mg m^{-3}), depth (m), and weight of the fraction in whole soil (%) (Batjes 1996):

$$\begin{aligned}&\text{SOC (LOC)pool}_{\text{layer}}\,(\text{Mg ha}^{-1})\\&=\text{SOC (LOC)concentration}_{\text{layer}}\,(\text{kg Mg}^{-1})\times\ \text{BD}_{\text{layer}}\,(\text{Mg m}^{-3})\\&\times D\,(\text{m})\ \times 10^{-3}\,\text{Mg kg}^{-1}\ \times 10^{4}\,\text{m}^{2}\ \text{ha}^{-1}\end{aligned}$$

Statistical analysis

F-protected least significant difference (LSD) test was used to compare the mean differences between land use patterns on soil fraction size classes, concentrations of SOC and LOC in whole soil, macro-, micro-, and silt + clay-sized fractions at all sites. All statistical tests were performed with SAS v9.2 (SAS Institute, CaryNC) and differences were considered significant when $P < 0.05$.

Results

Fraction size distribution

Fraction proportion varied with land uses and size classes, but followed a similar trend with depth (Fig. 1). Significant differences in macro-sized (250–2000 μm) and micro-sized fraction (53–250 μm) were detected among different land uses for all soil depth classes. The proportions of macro-sized fraction to total soil mass were highest in paddy, followed by dryland, AC-15, and were lowest in AC-3. In contrast, the micro-sized fraction proportions were highest in AC-3, followed by AC-15, dryland, and were lowest in paddy. In addition, the proportions of micro-sized fraction to soil mass in AC-3 accounted for 52.2 and 53.0 % in 0–10 and 10–20 cm depth, respectively. However, relatively higher silt + clay-sized fraction (<53 μm) proportions were found in dryland at each depth, but no significant differences were observed (Fig. 1).

Soil organic carbon (SOC) and labile organic carbon (LOC)

Differences in land uses resulted in variations of SOC and LOC concentrations in whole soil and different size fractions (Figs. 2, 3). The SOC and LOC concentrations decreased with depth in all land uses. For whole soil, paddy had higher SOC concentration values down to 30 cm depth, and especially obvious in the 0–10 and 10–20 cm depths. In the 0–10 cm depth, SOC concentration was 35.8 % lower in AC-15, 37.4 % lower in dryland, and 45.4 % lower in AC-3 as compared with paddy. For the 10–20 cm depth, the corresponding values were 39.0, 29.1, and 44.4 % for AC-15, dryland, and AC-3, respectively. In the present study, no definite trends of SOC concentrations change with fraction sizes were found.

As shown in Fig. 3, higher LOC concentrations in whole soil and different soil-sized fractions were also found in paddy at the 0–10 and 10–20 cm layers (except for silt + clay-sized fraction), whereas no significant

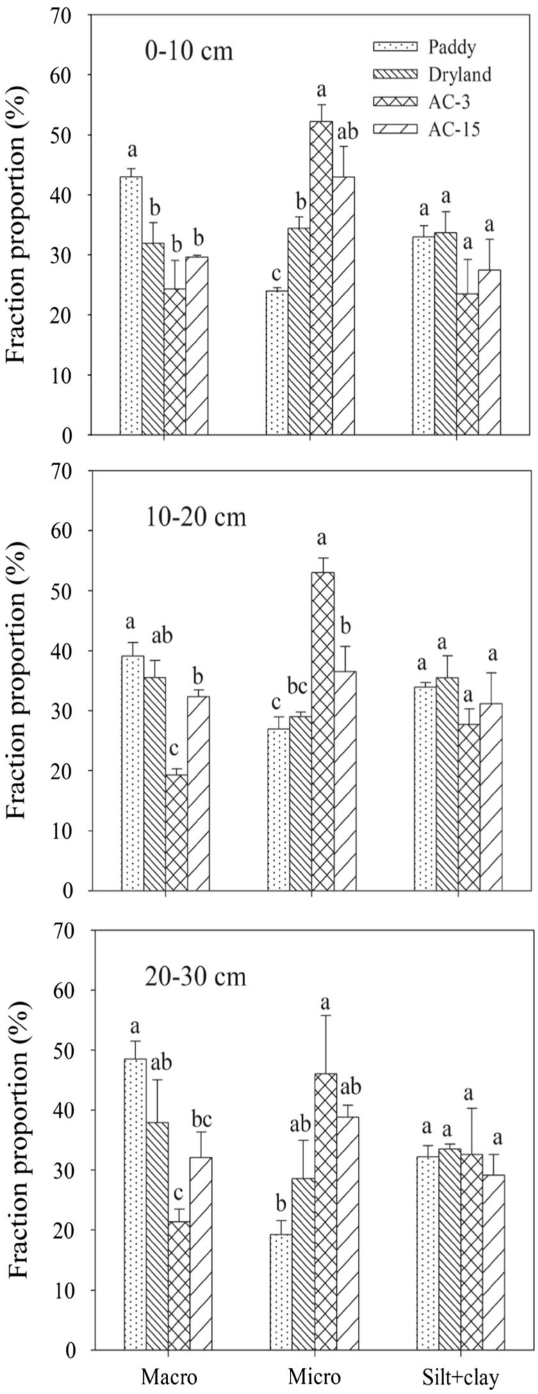

Fig. 1 Effect of land use on fraction-size distribution. AC-3 is abandoned for 3 years cultivated soil; AC-15 is abandoned for 15 years cultivated soil. *Bars* followed by *different letters* at the *top* within a fraction size class are significantly different between land uses at $P < 0.05$ by LSD test

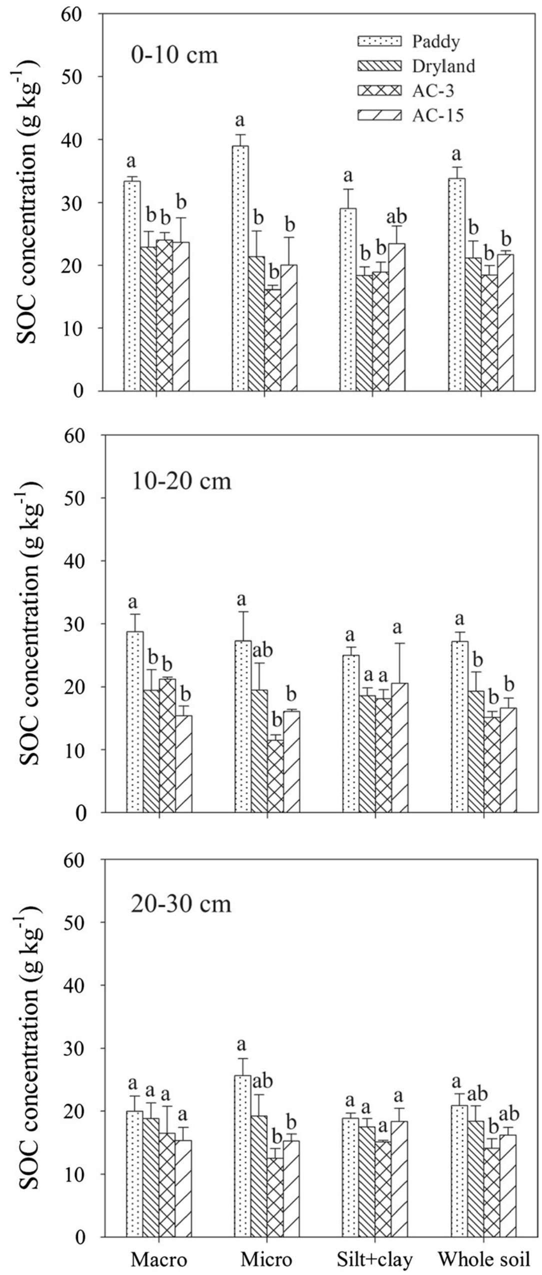

Fig. 2 Effect of land use on SOC concentration in whole soil and soil fractions. AC-3 is abandoned for 3 years cultivated soil; AC-15 is abandoned for 15 years cultivated soil. *Bars* followed by *different letters* at the *top* within a fraction size class are significantly different between land uses at $P < 0.05$ by LSD test

differences were detected at the 20–30 cm depth. The LOC concentrations in whole soil were only slightly increased by 6.54 % in the 0–10 cm depth, but decreased at both 10–20 and 20–30 cm depths as compared with dryland after 15 years of land abandonment.

Changes in proportion of LOC to SOC

The proportions of LOC to SOC ranged from 15.4 to 25.7 %, 15.8 to 23.4 %, 19.6 to 33.3 %, and 17.51 to 26.31 % in macro-, micro-, silt + clay-sized fraction, and whole soil, respectively, down to 30 cm soil profile (Fig. 4). The proportions of LOC to SOC varied with land uses and different sized fractions (Fig. 4). In the whole

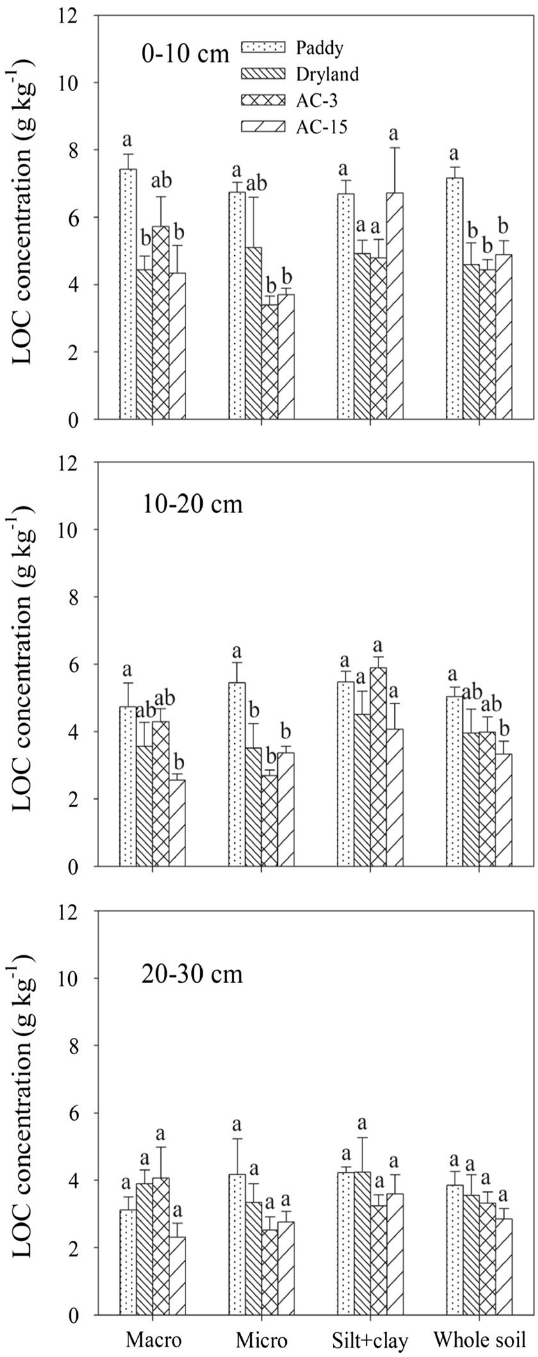

Fig. 3 Effect of land use on LOC concentration in whole soil and soil fractions. AC-3 is abandoned for 3 years cultivated soil; AC-15 is abandoned for 15 years cultivated soil. *Bars* followed by *different letters* at the top within a fraction size class are significantly different between land uses at $P < 0.05$ by LSD test

soil, the proportions of LOC to SOC varied from 17.5 to 26.3 %; in the macro-sized fraction, it ranged from 15.4 to 25.7 %; in the micro-sized fraction, it ranged from 15.8 to 23.4 %; and in the silt + clay fraction, the range was 19.6–33.3 %. The proportions of LOC to SOC showed an increasing trend in AC-3 and dryland in macro-sized fraction with depth, whereas an opposite trend was detected in AC-15 and paddy. For AC-3, the changes in proportions of LOC to SOC in macro-sized fraction differed from that in micro- and silt + clay-sized fraction down to 30 cm layer; a similar trend was also found in other land uses. In a word, the higher proportions of LOC to SOC were found in AC-3 throughout the 30 cm layer, especially obvious in whole soil (Fig. 4).

SOC and LOC pools in whole soil

As shown in Fig. 5a, the SOC pools were highest in paddy (100.9 Mg ha^{-1}) and lowest in AC-3 (71.7 Mg ha^{-1}), respectively, whereas the values in AC-15 (81.4 Mg ha^{-1}) and dryland (81.6 Mg ha^{-1}) were very close to each other down to 30 cm depth. Furthermore, higher SOC pools were also found in paddy, and significant differences were detected at both the 0–10 and 10–20 cm depths (Fig. 5a).

The highest LOC pools were measured in the paddy (19.7 Mg ha^{-1}) and decreased in the order of AC-3 (17.7 Mg ha^{-1}), dryland (16.7 Mg ha^{-1}), and AC-15 (16.5 Mg ha^{-1}) in the 0–30 cm depth, and there were no significant differences among different land uses (Fig. 5b). The amount of LOC pool was also not statistically significant to each other among selected land uses at each depth (except for paddy significant higher than dryland at 0-10 cm depth). The proportions of LOC to SOC followed the order of AC-3 (24.52 %) > dryland (20.52 %) ≈ AC-15(20.20 %) > paddy (19.51 %) down to 30 cm depth (Fig. 5b).

SOC and LOC pools in different fraction-size classes

The SOC pools associated in the macro-sized fractions were 25.72, 43.08, 29.68, and 20.27 Mg ha^{-1} in AC-15, paddy, dryland, and AC-3 down to 30 cm depth, respectively (Table 1). The mean values indicated that paddy had significantly higher macro-sized SOC pools than other land uses. Similarly, LOC pools associated in macro-sized fractions in paddy were 85.1, 37.7, and 66.2 % higher than in AC-15, dryland, and AC-3 down to 30 cm depth, respectively. The SOC and LOC pools in micro-sized fractions ranged from 24.84 (dryland) to 29.84 Mg ha^{-1} (AC-3) and 4.81 (paddy) to 6.55 Mg ha^{-1} (AC-3), respectively, in different land uses. For silt + clay-sized fraction, the corresponding values ranged from 22.06 (AC-3) to 29.91 Mg ha^{-1} (paddy) and 5.87 (AC-15) to 6.66 Mg ha^{-1} (paddy), respectively. Nevertheless, except that paddy had significantly higher SOC and LOC pools associated in macro size-fractions than other land uses at both the 0–10 and 10–20 cm, no significant differences were found among dryland, AC-3, and AC-15 (Table 1).

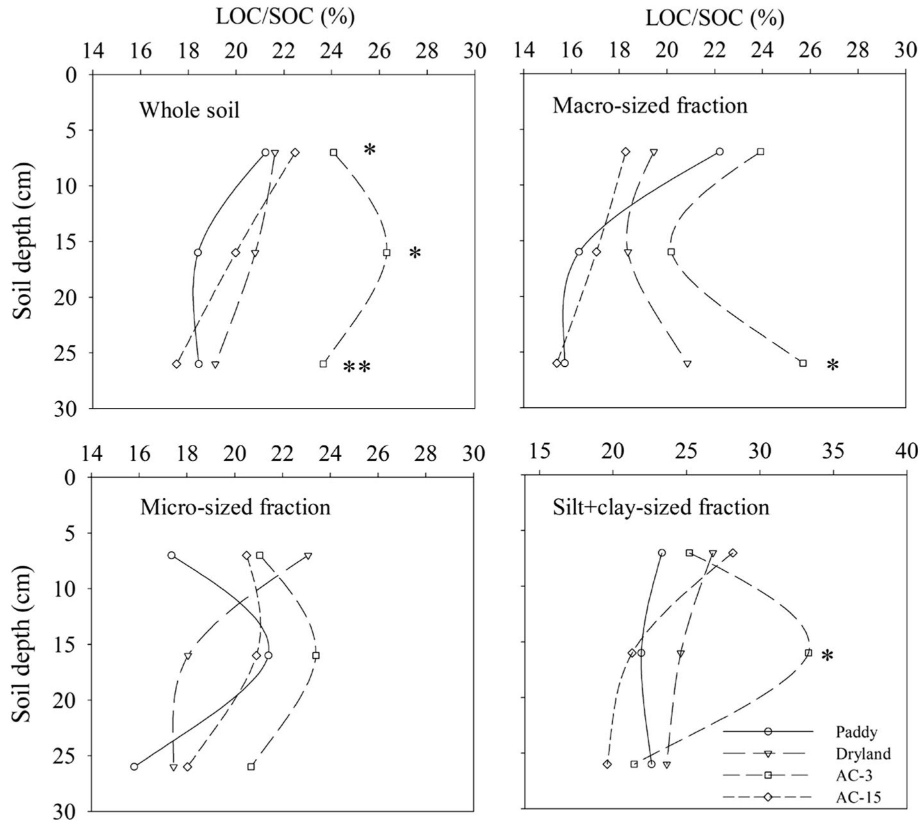

Fig. 4 Effect of land use on the proportion LOC to SOC in whole soil and soil fractions. *Asterisks* indicate significant difference between fraction size classes (*$P < 0.05$ and **$P < 0.01$)

Discussion

According to our study, different land use types had a significant effect on soil fraction-size distribution. The distribution of macro-sized fraction under different land use types showed relatively higher in paddy at each soil depth. Compared with dryland, the macro-sized fraction was 37.7, 10.1, 28.0 % higher in paddy, at 0–10, 10–20, 20–30 cm, respectively. Wang et al. (2014) showed that about 14 % of macroaggregates were lost after conversion from paddy to vegetable field. Similar results were also reported by Luo et al. (2011) in karst region of Southwest China, where they observed that the macro-sized fraction (stability soil aggregate) in paddy was greater than that in dryland. For all land use types, micro-sized fraction accounted for more than 45 % in total soil at each soil depth in the AC-3, followed by AC-15, dryland, and paddy. This phenomenon might be attributed to the soil organic matter input and the growth of fungi that build the soil particles and microaggregates together in the early natural recovery stages (Beare et al. 1994; Six et al. 2000). Among all the land uses, the silt + clay fraction was slightly higher in dryland at all soil depths (Fig. 1). Tillage is one of the most important factors to destroy soil aggregates. Frequent tillage in dryland can cause macro- or micro-sized fraction to break into silt + clay fraction (Lal 1993). Furthermore, the use of agrochemicals in dryland tends to reduce the activity of soil fauna, causing adverse effects on soil aggregation (Saha et al. 2011).

The SOC is the balance between the C input from aboveground litterfall and belowground rhizo-deposition, and released by decomposition (Jandl et al. 2007). As shown in Fig. 2, the SOC concentration was highest in the paddy at each soil depth. The high annual organic matter input resulting from rice biomass production (Pan and Zhao 2005), and low organic carbon mineralization under wet condition, could be the reason for higher SOC accumulation in paddy (Olk et al. 2000). However, we found that the SOC concentration was especially pronounced at the 0–10 cm and 10–20 cm depths, which was 59.8 and 41 % higher than dryland at the corresponding depth, indicating that the effect of paddy on SOC distribution occurs mainly at the upper depth (0–20 cm). Interestingly, after 3 years of land abandonment, the SOC concentration in AC-3 was still lower than dryland. This finding was consistent with the previous work of Desjardins et al. (2006). The lower SOC values in AC-3 may contribute by return to continuous aerobic conditions, and the small amount of new inputs of organic residues during the early years of abandonment, leading to accelerate the mineralization of SOC.

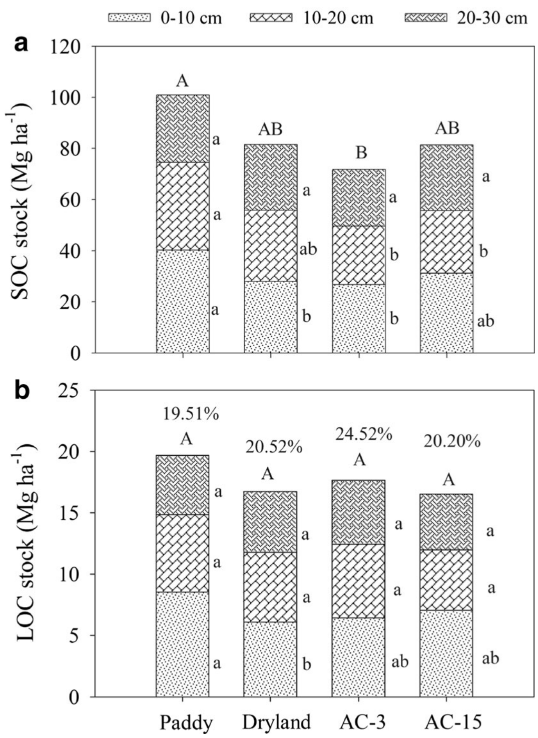

Fig. 5 Effects of land use on SOC **a** and LOC **b** pools. AC-3 is abandoned for 3 years cultivated soil; AC-15 is abandoned for 15 years cultivated soil. *Capital letters* refer to significant differences between land uses in total SOC pool or total LOC pool at $P < 0.05$ by LSD test. *Lowercase letters* refer to significant differences between land uses in total SOC pool or total LOC pool at $P < 0.05$ by LSD test. *Numbers* above *bars* indicate proportions of total LOC pool to total SOC pool

LOC has a greater turnover rate (or shorter mean residual time in soils) of several weeks to months or years as compared to more recalcitrant pools, and therefore, LOC has been suggested as an early indicator of land use changes on SOC (Banger et al. 2010). Saha et al. (2011) observed that among all the SOC fractions, LOC mostly affected by land use types, and the eroded land was 91.6 % lower than in grassland. In the present study, the LOC concentration remained the highest value in paddy at each soil depth. As shown in Table 2, SOC was significantly correlated with LOC ($P < 0.01$). The high LOC concentration could be attributable to the high SOC concentration in paddy. Compared with AC-3, a slight increase in LOC concentration at each soil depth in AC-15 was observed in this study (Fig. 3). However, the LOC concentration in AC-15 was only slightly higher at 0–10 cm depth, while lower at 10–20 and 20–30 cm as compared with dryland. The organic matter inputs into the soil occurs mainly in the surface horizons and decrease sharply with depth (Albaladejo et al. 2013). This may be the reason for LOC content to firstly increase in the 0–10 cm layer.

Conant et al. (2001) reported that the mean annual rate of carbon sequestration when restoring rangeland varies from 0.11 to 3.04 Mg ha^{-1}, with a mean recovery value of 0.54 Mg ha^{-1}. As shown in Fig. 5a, we found that SOC stock between dryland and AC-15 was very close to each other. The SOC stock only increased with the rate of 0.21 Mg ha^{-1} year^{-1} in the 0–10 cm depth after 15 years land abandonment. This value was lower than annual accumulation rate of "Grain for Green Project" in China (0.37 Mg ha^{-1} year^{-1}) (Zhang et al. 2011a, b). Shang et al. (2012) also reported that after 10 years cessation of cultivation, the organic carbon content could reach 90 % of the content in native meadows in Northwest China. In many revegetation places in China, Chen et al. (2007), for example, found that conversion from farmland to shurbland or grassland was a good choice for SOC sequestration. Piao et al. (2009) reported that the annual accumulation of SOC could reach to 1.84 Mg ha^{-1} year^{-1} due to conduct shurbland. The coarse soil texture and low soil surface area are main factors driving low SOC accumulation (Richter et al. 1999). Karst soils are characterized by thin, coarse, and very erosive and degenerative (He et al. 2008). Moreover, the lower residue litter inputs in karst region may lead to slow down the SOC recovery as compared with non-karst regions (Chen et al. 2012). Therefore, we suggest that it is necessary to conduct some engineering programs (afforestation or herb plantation) to accelerate SOC recovery in karst region.

The SOC and LOC concentrations in different land uses widely varied in different size classes (Figs. 2, 3). Tisdall and Oades (1982) found that the SOC concentrations increased with increasing fraction-size classes. Nevertheless, Elliott (1986) reported that macro-sized fractions were more enriched in SOC than micro-sized fraction because they are essentially composed of smaller fractions and intra-fraction organic binding agents. In this study, although no definite trends of SOC or LOC concentrations were found with in different fraction sizes, results showed that the changes of SOC and LOC concentrations in different size classes were significantly correlated ($P < 0.01$) with SOC in whole soil (Table 2), indicating that LOC and SOC associated in soil fractions all increased with the total SOC and LOC content of the soil. In addition, we detected that the macro-sized fraction was significantly correlated with the total SOC ($P < 0.05$) (Table 2). This result was in accordance with Zhang et al. (2011a, b), who also found that the significant correlation between SOC and macro-sized fraction can indicate the importance of SOC in soil structural stability in the northwestern Loess Plateau of China. Macro-sized fraction can physically protect original and recently inputted organic matter from microbial disturbance and mineralization (Oorts et al. 2006; Razafimbelo et al. 2008; Wei et al. 2013). As shown in Table 1,

Table 1 SOC and LOC pools in different soil fractions at different soil depths

Size fraction (μm)	Soil depth (cm)	Distribution of SOC and LOC pools in different size fractions at various depth in different land uses				
			Paddy soil	Dryland	AC-3	AC-15
Macro (250–2000)	0–10	SOC	17.09 (1.00)a	9.74 (1.84)b	8.38 (1.50)b	10.12 (1.92)b
		LOC	3.81 (0.40)a	1.88 (0.33)b	2.09 (0.56)b	1.84 (0.37)b
	10–20	SOC	13.95 (0.31)a	9.75 (0.47)b	6.18 (0.62)c	7.40 (1.17)c
		LOC	2.27 (0.08)a	1.79 (0.27)ab	1.26 (0.20)b	1.22 (0.11)b
	20–30	SOC	12.04 (1.10)	10.19 (2.67)	5.71 (1.72)	8.20 (2.67)
		LOC	1.88 (0.20)	2.11 (0.53)	1.44 (0.48)	1.24 (0.41)
Micro (53–250)	0–10	SOC	11.17 (0.93)	9.55 (1.52)	12.16 (0.78)	11.84 (1.62)
		LOC	1.93 (0.12)	2.26 (0.57)	2.57 (0.21)	2.30 (0.38)
	10–20	SOC	8.99 (0.94)	8.03 (1.24)	9.18 (0.93)	8.63 (0.99)
		LOC	1.85 (0.27)	1.45 (0.21)	2.15 (0.21)	1.81 (0.24)
	20–30	SOC	6.28 (1.11)	7.26 (1.12)	8.50 (1.04)	9.36 (1.14)
		LOC	1.03 (0.28)	1.27 (0.20)	1.83 (0.50)	1.70 (0.27)
Silt + clay (<53)	0–10	SOC	11.44 (1.57)	8.34 (1.57)	6.54 (1.82)	8.85 (1.10)
		LOC	2.62 (0.17)	2.25 (0.46)	1.67 (0.49)	2.47 (0.27)
	10–20	SOC	10.81 (1.40)	9.64 (1.32)	7.62 (1.37)	8.70 (1.69)
		LOC	2.34 (0.20)	2.34 (0.40)	2.45 (0.27)	1.79 (0.22)
	20–30	SOC	7.66 (0.82)	8.24 (0.24)	7.90 (2.36)	8.30 (1.18)
		LOC	1.70 (0.10)	1.94 (0.33)	1.77 (0.68)	1.61 (0.19)

AC-3 is abandoned for 3 years cultivated soil; AC-15 is abandoned for 15 years cultivated soil. Different lowercase letters with a row indicate significant differences between land uses at $P < 0.05$ by LSD test. Values in parentheses are standard errors (SE)

Table 2 Correlation coefficients between soil size-factions, SOC and LOC

Size fraction	SOC	LOC	SOC stock	LOC stock
Fraction content				
Macro	0.4844 **	0.2405	0.4396**	0.1398
Micro	−0.4842**	−0.2609	−0.4419**	−0.1262
Silt + clay	0.1805	0.1281	0.1707	0.0283
SOC content				
Macro	0.8802**	0.6242**	0.8079**	0.7746**
Micro	0.8441**	0.5341**	0.7772**	0.5121**
Silt + clay	0.7424**	0.5578**	0.8059**	0.6688**
LOC content				
Macro	0.6699**	0.5199**	0.6568**	0.8137**
Micro	0.9216**	0.5028**	0.8217**	0.6475**
Silt + clay	0.6452**	0.5421**	0.6248**	0.7817**

** $P < 0.05$

paddy contained significantly higher macro-sized SOC stocks as compared with other land use types. Specifically, the macro-fraction SOC stock accounted for 43, 41, and 46 % of the total SOC, at the 0–10, 10–20, and 20–30 cm, respectively, indicating that the macro-sized fraction was the greatest SOC stock contributor in paddy filed. Currently, many studies have observed that changes in land use cause a small change in the SOC stock of fine particle fractions, but substantial reductions in the stocks of coarse particle fractions (Guggenberger and Zech 1999; Arevalo et al. 2009). Saha et al. (2010) also reported that SOC stock in various fraction-size classes could be a reflection of the changes of plant community in time. In the present study, however, the SOC and LOC stockschanged variously in different fractions under the abandonment sequence (dryland, AC-3, and AC-15). Furthermore, there were no obvious increase whether in SOC or LOC stock associated in macro-, micro-, and silt + clay-sized fraction even after 15 years land abandonment. This phenomenon might be extra evidence suggesting that the natural recovery of SOC is a relatively slow process in karst region.

The proportion of LOC to SOC is used to reflect the stability of soil carbon, and a higher value means greater activity and lower stability of SOC (Zhu et al. 2006). We found that the proportions of LOC to SOC in whole soil ranged from 17.5 to 26.3 %. This result was higher than those obtained by Xu et al. (2012) in a tallgrass prairie (3–5 %) in Oklahoma, USA, but basically consistent with Zhang et al. (2012), who reported that the proportions of LOC to SOC in the 0–20 cm depth ranged from 14 to 20 % in the Northwest of China. The different results among these studies might be attributed to differences in climate situations or soil types, both of which can influence the LOC accumulation. Our study showed that the higher proportions of LOC to SOC were basically observed in AC-3 as compared with paddy, dryland, and AC-15, especially pronounced in whole soil (Fig. 4). The variations in different land use types might be attributed to the changes of plant residue returning, root biomass, and soil microorganisms. Furthermore, the higher proportions of LOC to SOC in AC-3 may be a key indicator for changing the above-ground plants and rebuilding the structure of soil microorganisms.

In our study, paddy contained higher SOC as compared with other land use types. Our result was in accordance with other studies that showed that paddy contained significantly larger SOC stock than nearby dryland in China (Pan et al. 2003; Pan and Zhao 2005). The mechanisms of SOC stored in paddy soil are complicated due to various biochemical processes. The Fe-leaching Stagnic Anthrosols or Fe-accumulic Stagnic Anthrosols are the two important subgroups in storing and sequestering C in paddy soils (Pan et al. 2003). Zhou et al. (2009) believed that Fe oxyhydrates in microaggregates could be important for higher SOC concentration in paddy field. Furthermore, the management style and anaerobic conditions could also contribute to decline of C decomposition in paddy soils (Olk et al. 2000). Paddy has a strong positive contribution to global carbon flux of sequestrate atmospheric CO_2 into soil. Hu et al. (2008) even found that no indication of soil degradation after 2000 years of intensive rice cropping. Therefore, we conclude that paddy could serve as a characteristic carbon sequestration crop due to its ability in increasing SOC stocks and minimizing SOC losses in karst region of Southwest China.

Conclusions

In this study, there were no definite trends of SOC and LOC changes with different soil fraction size classes in all the land uses. Compared with dryland, the SOC pools accrued only 0.21 Mg ha^{-1} a^{-1} in AC-15 in the surface 10 cm depth, whereas the SOC and LOC pools associated in the macro-, micro- and silt + clay-sized fractions had no significant differences after 15 years of land abandonment down to 30 cm depth. These results indicated that the natural SOC restoration will take a long time during the period of land abandonment, and it is necessary to conduct some programs (afforestation or grass plantation) to accelerate SOC recovery in karst region. In our study, paddy contained more SOC and LOC pools than the other selected land uses, suggesting that paddy could serve as an important land use type for long-term carbon sequestration in karst region of Southwest China.

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