Science of the Total Environment xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

Land-use impacts on profile distribution of labile and recalcitrant carbon in the Ili River Valley, northwest China

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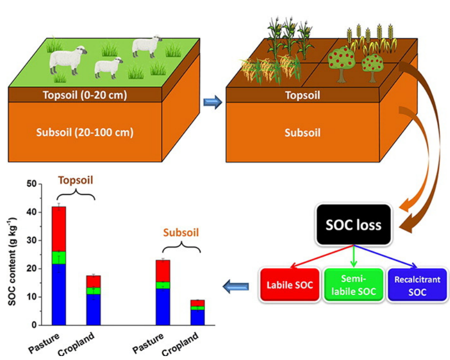
HIGHLIGHTS

- Effects of land-use on labile and recalcitrant pool of SOC were studied.
- Labile SOC and recalcitrant SOC contents were lower in croplands than in pastures.
- The proportions of SOC fraction in TOC in subsoil were similar to those in topsoil.
- Recalcitrant SOC pool in subsoil could be also decreased by agricultural land-use.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 4 January 2017
Received in revised form 9 February 2017
Accepted 10 February 2017
Available online xxxx

Editor: Jay Gan

Keywords:
Soil organic carbon
Labile carbon
Recalcitrant carbon
Land-use
Ili River Valley

ABSTRACT

There is a growing evidence that the decomposition of recalcitrant carbon (C) can be stimulated by environmental changes, such as fresh C supply and increased temperature. However, the effect of land-use on profile distribution of recalcitrant C content is still poorly understood. In this study, soil samples were collected to a depth of 100 cm from pastures and four major croplands including maize field, wheat field, paddy and apple orchard in the Ili River Valley, northwest China, to investigate the effects of land-use on profile distribution of labile organic C (LOC), semi-labile organic C (SLOC), recalcitrant organic C (ROC) and their relative proportions in total organic C (TOC), and evaluate whether such effects can be different between topsoil (0–20 cm) and subsoil (20–100 cm). The results showed that soil ROC accounting for 49.4–66.3% of TOC for different land-uses, implying that ROC is the major form of soil organic C (SOC). Soil TOC contents of croplands were 20.4–85.2% lower than those of pastures along the soil profile, indicating that SOC pool may be decreased by agricultural land-uses. The lower contents of LOC, SLOC and ROC in croplands than in pastures suggested that the decreases in TOC content in croplands are not only due to the decreases in labile C pool but also the reductions in recalcitrant C pool. The differences in SOC fractions among land-uses were similar in topsoil and subsoil, while the proportions of each SOC fraction in TOC did not differ significantly between the two soil layers in most cases, indicating that each SOC fraction in subsoil can be also influenced by land-use types. Therefore, it is suggested that the ROC in subsoil, which plays a crucial role in C sequestration, should be taken into account when estimating the effect of land-use on SOC kinetic.

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http://dx.doi.org/10.1016/j.scitotenv.2017.02.087
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1. Introduction

Soils, which have been identified as the largest organic carbon (C) pool in the biosphere, play a key role in the global C cycle. The global soil organic C (SOC) pool in the top 100 cm is approximately 1500 Pg (1 Pg = 1 Gt = 10^{15} g) C, which is two times of the global biotic C pool and three times of the global atmospheric C pool (Batjes, 1996). Therefore, small changes in SOC pool may have substantial impacts on the concentration of atmospheric carbon dioxide (CO_2) (Belay-Tedla et al., 2009). Additionally, SOC is critical to ensure secure food production because it provides substrate and energy, as well as protects the biodiversity that helps to preserve soil quality and the functioning of ecosystem (Lal, 2011; Guimarães et al., 2013). Thus, the maintenance and sequestration of SOC become great challenges that humankind must face to address the twin crisis of global change and food insecurity (Lal, 2011).

Land-use has been recognized as a key factor that determines the size and kinetic of SOC pool because it can influence the balance between input (e.g. plant litter) and output (e.g. mineralization of SOC) of soil organic matter (SOM) by altering plant community and land management practice (Dawson and Smith, 2007; Poeplau and Don, 2013). Globally, soils have lost 40–90 Pg C due to historic land-use, mainly through deforestation and reclamation (Smith, 2008). As an example, Wu et al. (2003) estimated that about 7.1 Pg SOC have been lost as a result of land-use with an average SOC density decrease of 0.8 kg C m^{-2} in China, and most of the loss occurred in cultivated soils. Unfortunately, the trend of net SOC loss from land-use change is still going on. An evidence is that the estimated net emission of SOC caused by land-use change is about 1.1 $\pm$ 0.7 Pg C per year in the first decade of 2000s at a global scale (Poeplau and Don, 2013). Since SOM is a complex and heterogeneous entity consisting of a continuum of materials, which have different degrees of stabilization and turnover times, the response of SOC to land-use can be better understood by separating SOC into different fractions (Del Galdo et al., 2003; Leifeld and Kögel-Knaber, 2005; Lützow et al., 2006; Cheng et al., 2008). In general, SOC pool can be chemically divided into labile organic C (LOC), semi-labile organic C (SLOC) and recalcitrant organic C (ROC) using acid hydrolysis method (Rovira and Vallejo, 2002). Compared with ROC, labile C pools of LOC and SLOC have smaller sizes while higher bioavailability, thus they are more sensitive to environmental changes while ROC dominates long-term C storage (Belay-Tedla et al., 2009; Ding et al., 2012). However, recent studies suggested that ROC pool can be also changed after environmental changes, such as supply of fresh C (Fontaine et al., 2007), increase of temperature (Xu et al., 2010), application of fertilizer (Ding et al., 2012), addition of nitrogen (N) (Jiang et al., 2014) or short-term invasion of alien plant (Cheng et al., 2008). Some studies have indicated that soil ROC content can be also affected by land-use, but the results are inconsistent among studies due to different soil properties, different SOM inputs or different soil depths (Zhang et al., 2014; Wasak and Drewnik, 2015; Yang et al., 2016). Since the changes in SOC fractions may affect both nutrient supply and soil C sequestration, it is necessary to fractionate and quantify the labile and recalcitrant pools to have a better understanding of the impact of land-use on SOC kinetic (Belay-Tedla et al., 2009; Ding et al., 2012).

Until now, studies on the effect of land-use on SOC fractions have mainly focused on the topsoil (0–20 cm), which contains high level of SOC and can be easily affected by environmental disturbance (Ding et al., 2012; Wang et al., 2013; Jiang et al., 2014). By contrast, information on the response of SOC fractions to land-use in subsoil is comparatively fewer. Globally, the proportion of organic matter stored in soils below 30 cm varies from 30% to 63% for different soil types in a depth of 100 cm (Batjes, 1996), thus subsoil may has the ability to sequester high amounts of SOC (Lorenz and Lal, 2005; Rumpel and Kögel-Knabner, 2011). The main sources of organic matter in subsoil are considered as root (litter and exudates), dissolved organic matter and physically/biologically transported particulate organic matter (Rumpel and Kögel-Knabner, 2011). The relative contribution of these four sources to SOC in subsoil are poorly understood but they are proved to be influenced by vegetation types (e.g. litter quality and root distribution) and management practices (e.g. tillage and fertilization), which are determined by land-use (Rumpel and Kögel-Knabner, 2011). In an incubation study, Xu et al. (2010) found that temperature sensitivity of SOC increased with the increase of SOC recalcitrance and soil depth, indicating that the responses of SOC fractions in subsoil to environmental changes may be different from those in topsoil. Therefore, the influence of land use on SOC fractions in subsoil should be also taken into account in the context of climate change.

Grassland ecosystems play a significant role in the regional climate and the global C cycle since they occupy approximately 20% of the global land surface and contain >10% of the global SOC stock (Scurlock and Hall, 1998). The area of grassland in China is the third largest in the world, covering about 40% of total territory of the country (Fan et al., 2008). However, large area of grasslands in China has been converted into croplands as a consequence of food demand and pursuit of economic benefit (Akiyama and Kawamura, 2007). As an example, the area of grassland in the Ili River Valley, which is a traditional pastoral region in Xinjiang, northwest China, decreased by 13.5% during 1985–2005, while the area of cropland increased by 10.1% (Chen et al., 2010). As a typical inland arid and semi-arid zone in the world, Xinjiang has a low annual precipitation with 130 mm on average due to far from ocean and the blockage of the moisture from Indian Ocean by the Qinghai-Tibet Plateau (Li et al., 2011). However, the Ili River Valley in northwest Xinjiang has a relatively humid climate under the influence of the westerly circulation, which makes the Valley as 'the wet island of central Asia'" (Xu et al., 2011). Due to the abundant water, soil and heat resources, the Valley becomes an important base of agro-pastoral production in Xinjiang. Yet, information on the effect of land-use on vertical distribution of SOC, its labile and recalcitrant pools in this semi-arid region is still scarce. In this study, we aimed to: (1) clarify the profile characteristics of LOC, SLOC, ROC contents and their relative proportions in total organic C (TOC) under different land-uses; (2) investigate whether the effects of land-use on SOC fractions can be different between topsoil (0–20 cm) and subsoil (20–100 cm) in the Ili River Valley. The following hypotheses were tested: (1) both labile pool and recalcitrant pool of SOC are lower in agricultural land-uses than in grasslands; (2) recalcitrant pool of SOC in subsoil can be also affected by land-use.

2. Materials and methods

2.1. Study area

The Ili River Valley (80°09′ E-84°56′ E, 42°14′ N-44°50′ N) is located in the western part of the Tianshan Mountains in Xinjiang Uygur Autonomous Region, northwest China (Fig. 1). It is an inland continental river valley which surrounded on three sides by mountains. Its climate is temperate continental and alpine with an average annual precipitation ranging from 200 mm to 800 mm. The average annual temperature and evaporation are 2.9–9.1 °C and 1260–1900 mm, respectively. The frost-free period is approximately 130–180 d, while the annual sunshine duration is 2700–3000 h on average (Xu et al., 2011). The Kunes River, Tekes River and Kash River, which are three major tributaries of the Ili River, are main rivers in this area (Xu et al., 2011). Typic Argigypsid and Typic Haploboroll (USDA, 1994) are major soil types in this area. Land-uses in this area are mainly cropland and pasture, covering approximately 78.2% of the total area (Ait et al., 2009).

Please cite this article as: Liu, X., et al., Land-use impacts on profile distribution of labile and recalcitrant carbon in the Ili River Valley, northwest China, Sci Total Environ (2017), http://dx.doi.org/10.1016/j.scitotenv.2017.02.087