Ecological Indicators 73 (2017) 331–337

Contents lists available at ScienceDirect

Ecological Indicators

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

Soil organic carbon fractions are affected by different land uses in an agro-pastoral transitional zone in Northeastern China

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ARTICLE INFO

Article history:
Received 15 May 2016
Received in revised form 4 October 2016
Accepted 5 October 2016

Keywords:
SOC
Oxidizable C fractions
Land use
Carbon management index

ABSTRACT

Soil organic carbon (SOC) consists of various C fractions with different stabilities and chemical compositions that are differently affected by changes in land use. A better understanding of the responses of different C fractions to land uses is vital for maintaining soil quality and mitigating global warming. Using data from a short-term land use experiment in northeastern China, this paper investigated the effect of five land uses, corn cropland (Corn), alfalfa grassland (Alfalfa), artificial grassland of *Lyemus chinensis* (AG), *Lyemus chinensis* grassland for mowing (AG + Mow) and restored grassland (RG), on the dynamics of total SOC and four SOC fractions with increasing degrees of oxidizability at 0 to 50 cm depths. The results show that land use had a significant effect ($P < 0.05$) on the total SOC and SOC fractions of very labile C (F1), labile C (F2) and less labile C (F3), while the difference in recalcitrant C (F4) was less pronounced. SOC in the study area was characterized by a predominantly very labile C fraction, and the percentages of F1 to total SOC were more than 40% for all land uses. Compared with Corn, the treatments AG + Mow, AG and RG decreased the percentage of F1 to SOC (by 4.49%, 6.53% and 3.55%, respectively) and increased the percentages of F2 (by 3.32%, 2.77% and 6.60%, respectively) and F3 (by 4.47%, 3.46% and 0.3%, respectively) to SOC. These findings suggest that land-use type is a major factor that influences soil C fractions and that labile C fractions contribute a large part of the total SOC. In addition, grassland colonization of croplands improves soil C sequestration in northeastern China.

1. Introduction

Soil organic carbon (SOC) is one of the major pools of carbon. It is the main source of energy for soil microorganisms and the basis of soil fertility, playing a vital role in regulating climate, water supplies and biodiversity, and therefore improving the ecosystem services that are essential to human well-being (Lal, 2004; Benbi et al., 2015). C sequestration in soils is a feasible strategy for reducing the concentration of CO_2 in the atmosphere (Yang et al., 2012). Hence, understanding the dynamics and storage potential of organic C in soils could not only improve soil quality and sustainability but also mitigate global warming, providing “win-win” benefits (Lal, 2004; Schmidt et al., 2015).

Land use is a major factor that influences the balance of SOC between inputs and losses of organic C in soils and hence leads to sequestration or emission of CO_2 (Houghton, 2003). The growing need for C sequestration has stimulated great efforts to monitor the dynamics of organic C in soils, especially under the conditions of different land use or agricultural management practices (Syswerda et al., 2011; Poeplau and Don, 2013; Prasad et al., 2016). Worldwide, land-use changes, such as deforestation and the conversion of grassland to cropland, have contributed to approximately 35% of the total anthropogenic CO_2 emissions since 1850 (Foley et al., 2005). The conversion of native vegetations to croplands accelerates soil heterotrophic and typically loses at least 20% of original organic C after long-term conventional tillage (Wang et al., 2009; Syswerda et al., 2011). However, some efficient land uses have a positive effect to maintain SOC, and even increase SOC storage. No tillage and organic agricultural techniques have been acknowledged as efficient agricultural practices in cropland to increase SOC sequestration and reduce the decomposition of SOC (Bayer et al., 2009; Wang et al., 2014). In addition, colonization of natural or artificial vegetation through restoration in degraded land has been reported as useful to regain SOC (Gabarron-Galeote et al., 2015). Continuous input of above- and below ground biomass and the

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http://dx.doi.org/10.1016/j.ecolind.2016.10.002
1470-160X/

improvement of soil aggregates are the main reasons for the accumulation of SOC in these land uses (Novara et al., 2014; Thomazini et al., 2015).

SOC has been described as the most complex and least understood component of soils because of the heterogeneous mixture of organic compounds and association with soil minerals (Lehmann and Kleber, 2015; Blanco-Moure et al., 2016). With the aim of revealing the complex components of SOC and better understanding their mechanisms of stabilization, several physical, chemical and biological methods have been proposed to separate and isolate SOC fractions with different properties, functions and stability (Kogel-Knabner, 2000; Haynes, 2005; von Lutzow et al., 2007). Knowing the influence of land uses on SOC fractions representing SOC pools is thus crucial, since it leads to a better understanding of SOC dynamics than the study of the total SOC (Chan et al., 2001; Gabarron-Galeote et al., 2015). The dynamics of some of the most important labile C fractions to soil management practices have been studied. However, several studies found that labile C fractions were sensitive to soil management practices (Barreto et al., 2011; Li et al., 2016), while other studies found no significant effect of land uses on the dynamics of labile C fractions (Conant et al., 2003; Leifeld and Kogel-Knabner, 2005; Wang et al., 2014). These inconsistencies in labile C fractions resulting from land uses may be related to different factors, such as the quantity and quality of vegetation residues, land-use intensity, environmental conditions and soil properties (Blanco-Moure et al., 2016). Although the responses of labile C fractions to land uses are different, the dynamics also can provide valuable information about mechanisms of C sequestration and stability.

Many studies focus on the dynamics of labile C fractions within SOC changes under soil disturbance, but the variations in less labile and recalcitrant C fractions have been rarely reported, and these C fractions have been considered to be unaffected by land use and very stable (Yang et al., 2012). However, there is robust evidence that the decomposition of relatively recalcitrant C is faster than previous assumptions (Klotzbucher et al., 2011; Lehmann and Kleber, 2015). Knowing the responses of stable C fractions to land uses will help us understand the mechanisms of soil C cycles. Therefore, the objectives of this study were to (1) investigate the dynamics of total SOC and oxidizable SOC fractions under different land uses in an agro-pastoral transitional zone, and (2) examine if the less labile and recalcitrant C fractions are sensitive to land use.

2. Materials and methods

2.1. Study site

The study site is located in the Changling Ecological Research Station for Grassland Farming at Songnen Plain, NE China (44°33′N, 123°31′ E). The study site is relatively flat with an elevation of approximately 145 m a.s.l. The area is characterized by a temperate, semi-arid continental monsoon climate. The annual average air temperature is between 4.9 °C and 6.4 °C. The annual average precipitation varies from 250 mm to 500 mm, with 70–80% of total precipitation occurring between June and September. The pan evaporation approximates 1600 mm. The frost-free period is approximately 140 days. The soil type is alkali-saline with a soil texture of 23% sand, 35% silt and 42% clay, which is classified as Aqui-Alkalic Halosols in the Chinese soil taxonomic system or as a Salic Solonetz in the World Reference Base for Soil Resources. The pH of the soil is between 8.0 and 11.0. The dominant native species include *Leymus chinensis, Chloris virgata, Puccinellia* spp. and *Polygonum gracilius*. The vegetation coverage measures 50–90%, with 100–200 g m^{-2} of standing biomass in the peak season.

2.2. Experimental design and soil sampling

The experiment was established in early May 2011 at a cropland and run for 5 years until soil sampling. Five treatments (land uses) were designed in a complete block design with four replications. The five land uses consisted of conventional corn cropland (Corn), artificial alfalfa grassland (Alfalfa), artificial grassland of *Lyemus chinensis* (AG), artificial grassland of *Lyemus chinensis* and mowing for hay every year (AG + Mow) and restored grassland (RG). The block size was approximately 60 m × 50 m, whereas the plot size was 12 m × 50 m for the Corn and Alfalfa treatments and 6 m × 50 m for the AG, AG + Mow and RG treatments. There was a 2 m buffer between the blocks and a 1 m buffer between the plots. The cropland was under continuous corn monoculture since 2011. The conventional cropland followed the common practice in Songnen Plain, which is to plow the soil at least twice down to 20 cm before the crop growing season. Fertilizers (74 kg N ha^{-1}, 22 kg P ha^{-1}, and 41 kg K ha^{-1}) are applied at sowing and mid July. The artificial alfalfa grasslands were set up in May 2014. Before 2014, these plots were croplands without tillage (no tillage) and the other practices were the same as for the described conventional cropland. Due to the poor soil conditions and semi-arid climate, the growth of corn was very poor in the no-tillage cropland from 2011 to 2013. Considering the poor natural conditions and the development of local animal husbandry, we changed the no-tillage cropland to alfalfa grassland in May 2014. In the two types of artificial grasslands besides alfalfa grassland, seeds of *Lyemus chinensis* were sowed in May 2011 with a density of approximately 2000 seeds/m^2. Reseeding has a positive effect to recover the vegetation in the artificial grassland, and the aboveground biomass reached approximately 100–120 g/m^2 in early September 2011. The aboveground biomass of one type of artificial grasslands mowed for hay once a year at the peak biomass and the vegetation from another type were kept as litter to return to the soil. The cropland was abandoned in 2011 in the RG plots to restore grassland without any disturbance.

Soil samples were collected during early September 2015 to a depth of 50 cm at five intervals of 0–10, 10 to 20, 20 to 30, 30 to 40, and 40–50 cm with a 4 cm diameter soil core sampler. A composite sample for each depth was made by mixing samples from 5 randomly selected locations at least 6 m apart from each other and 1 m away from the plot boundary within each plot. Soil samples were air dried, separated from the visible plant materials, passed through a 2-mm sieve, and then ground through a 0.25-mm sieve for C analysis.

2.3. Soil analysis

Total SOC content under different land uses was determined following a modified Mebius method (Yeomans and Bremner, 1988). Different SOC fractions under a gradient of oxidizing conditions were measured by the modified Walkley-Black method (Walkley and Black, 1934) as defined by Chan et al. (2001). The method uses 5, 10 and 20 ml of 36 N H_2SO_4 that resulted in 12.0, 18.0 and 24.0 N H_2SO_4, respectively. Therefore, it involves mixing a 1 N dichromate solution with H_2SO_4 in different proportions. Hence, total SOC was divided into four different fractions according to their decreasing order of oxidizability or lability.

Fraction 1 (F1, very labile): Organic C oxidized by 12 N H_2SO_4.

Fraction 2 (F2, labile): Difference of oxidizable organic C extracted between 18 N and 12 N H_2SO_4.

Fraction 3 (F3, less labile): Difference of oxidizable organic C extracted between 24 N and 18 N H_2SO_4.

Fraction 4 (F4, recalcitrant): Difference of oxidizable organic C extracted by 24 N H_2SO_4 and total SOC content.