Geoderma 268 (2016) 14–21

Contents lists available at ScienceDirect

Geoderma

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

Changes in soil organic carbon pools along a chronosequence of land abandonment in southern Spain

Sylvain Trigalet [a,*], Miguel A. Gabarrón-Galeote [b], Kristof Van Oost [a], Bas van Wesemael [a]

[a] Georges Lemaître Centre for Earth and Climate Research, Earth and Life Institute, Université Catholique de Louvain, B-1348 Louvain-la-Neuve, Belgium
[b] University of Málaga, Geomorphology and Soils Laboratory, Málaga, Spain

ARTICLE INFO

Article history:
Received 28 July 2015
Received in revised form 5 January 2016
Accepted 13 January 2016
Available online 22 January 2016

Keywords:
SOC pools
Land abandonment
Chronosequence
Stabilization
Fractions

ABSTRACT

Land abandonment is the dominant land use change in the Mediterranean and the resulting vegetation recovery has a strong influence on soil organic carbon (SOC). Yet, the gradual changes in SOC pools during secondary succession remain poorly studied. As SOC is a mixture of pools with distinct functional properties, isolating these pools may provide a better understanding of the decadal SOC dynamics. Topsoil samples were collected along a chronosequence of cropland abandonment in the region north of Málaga (Spain). Five fractions were isolated: particulate organic matter (POM), dissolved organic carbon (DOC), SOC bound to silt and clay (s + c), SOC attached to sand particles or occluded in aggregates (S + A) and a chemically resistant fraction (rSOC). The significant increase in the S + A mass over time indicated aggregation processes along the vegetation recovery stages. Carbon concentrations within S + A or rSOC fractions did not change over time. In contrast, carbon in the s + c fraction significantly increased after three decades from 7.9 g C·kg^{-1} to 20.4 g C·kg^{-1} at the final stage of the chronosequence. Hence, in addition to the frequently reported increases in POM, carbon was also allocated to the more stable SOC fractions. Taking active carbon (DOC + POM; high turnover rate) and intermediate carbon (s + c, S + A; low turnover rate) as indicators for carbon turnover, the proportion of active carbon increased from 17% to 39% along the chronosequence. Consequently, the proportion of slow cycling carbon decreased from 72% to 54%. These results show that the proportion of labile carbon increases along the secondary succession while, at the same time, the slow cycling carbon fractions sequester carbon (from 0.6 to 1.12 kg C·m^{-2}).

1. Introduction

Soil organic carbon (SOC) is the largest terrestrial organic carbon pool and therefore plays an important role in the global C cycle. At the decadal time scale, land use changes (LUCs) can strongly influence whether a particular area acts as a source or a sink for atmospheric CO_2 (Freibauer et al., 2004; Lal, 2004). Understanding how SOC reacts to different anthropogenic forcings is crucial to ensure that soil quality and sustainability are not degraded. This is especially relevant in Mediterranean region, where soils have been highly degraded due to anthropogenic pressure over decades, and in some cases centuries. While a number of studies have analysed SOC stocks subject to land use changes (LUCs) at the regional scale in Europe (e.g. Sleutel et al., 2003; Bradley et al., 2005; Wiesmeier et al., 2012; Poeplau and Don, 2013), few have been carried out in the Mediterranean region (Rodríguez-Murillo, 2001; Muñoz-Rojas et al., 2012, 2015). Even fewer have focused on the most frequent LUC in this region over the last decades, i.e. land abandonment, defined here as the cessation of ploughing and crop cultivation (though grazing may continue) (Novara et al., 2012, 2013; Kurganova et al., 2010). Such studies are necessary, particularly in the Mediterranean, to understand the gradual changes to C sequestration resulting from vegetation succession after abandonment.

In southern Spain, extensive LUCs have affected organic carbon stocks in soils. In studying these effects, Muñoz-Rojas et al. (2015) reported SOC losses after several LUCs, including intensification and expansion of agriculture as well as deforestation. In contrast they reported SOC increases, particularly in the topsoil, after afforestation, resulting in a sequestration of 9 Mg ha^{-1} of SOC between 1956 and 2007. Quantifying SOC dynamics in such areas is necessary to assess the impact of land abandonment. Nevertheless, it can be challenging to understand SOC dynamics because it comprises various heterogeneous pools with different turnover rates and stability (Novara et al., 2013). As indicated by Post and Kwon (2000), the turnover rate of the different SOC compounds varies due to the complex interactions between biological, chemical, and physical processes in the soil. Although there may be a continuum of decomposability and turnover time of soil organic carbon compounds, fractionation techniques are often used to define and delineate various relatively discrete soil organic carbon pools (Post and Kwon, 2000). Isolating organic matter with distinct functional properties provides an insight into the dynamics and the stability of eventual C sequestration at each stage after land abandonment.

* Corresponding author.
E-mail address: sylvain.trigalet@uclouvain.be (S. Trigalet).

http://dx.doi.org/10.1016/j.geoderma.2016.01.014
0016-7061/

While only a few studies have focused on bulk SOC changes over decades in southern Spain, those focused on SOC fraction changes after a LUC are even rarer. In a large-scale study across Europe, Poeplau and Don (2013) examined the sensitivity of both SOC stocks and fractions, using a paired plot approach. They showed that SOC fractions are affected by LUC throughout the entire soil profile. Particulate organic matter was the most sensitive to LUC. According to these authors, afforestation shifts SOC from stable to labile pools, and subsoil carbon fractions were affected by LUC in the same direction as in the topsoil. Although 24 sites distributed over Europe were used for their study, only two sites focused on Mediterranean environments, as the lowermost latitude was located in the north of Italy. Moreover, this study mainly focused on end members on land use changes. In order to improve our understanding of the temporal dynamics of SOC dynamics after land abandonment, our study focuses on transient stages, based on age of abandonment, rather than end members such as cropland, grassland and forests.

In this study, we focus on SOC functional pools within a chronosequence of cropland abandonment at a site near Malaga. This local approach reduced the variability of environmental factors compared to a regional or continental study (Goidts and van Wesemael, 2007; Poeplau and Don, 2013; Wiesmeier et al., 2014). The small spatial extent ensures a more homogenous system of land abandonment in similar climate and lithology conditions. In a previous study, a simplified fractionation scheme along a precipitation gradient in Andalucía was applied based on a simple particle-size fractionation scheme (Gabarrón-Galeote et al., 2015b). The main goal was to assess SOC fraction dynamics in soils from similar environments but with contrasting precipitation levels, at the regional scale. The largest effect of precipitation was found in the silt and clay fraction, while SOC in the coarse fraction (0.25 to 2 mm) was mostly controlled by land abandonment and related factors such as vegetation, litter quality and soil conditions (Gabarrón-Galeote et al., 2015b). The simple fractionation scheme was not completely satisfactory to describe the temporal dynamics within the system, since each particle-size based soil fraction was a mixture of younger and older compounds. Although any fraction is only an approximation to the theoretically existing labile–stable dichotomy, other fractionation processes may help to better refine distinct functional pools with different turnover rates. Among such alternative protocols, the fractionation scheme introduced by Zimmermann et al. (2006) has become a widely-used routine to separate appropriate pools. Contrary to the simple protocol used by Gabarrón-Galeote et al. (2015b), this routine assesses parameters such as dissolved organic carbon, chemically resistant carbon and chemically non-recalcitrant carbon associated with silt and clay particles. It is also possible to disentangle non-occluded POM from aggregates. Thus, the added value of this scheme lies in the combination of physical and chemical fractionation. As the present study focuses on the temporal dynamics of the system rather than a spatial analysis, we limited our study to the intermediate part of the precipitation gradient (Almogia) where the colonization process by vegetation was gradual along a few decades.

In general, the aim of this study is to quantify the dynamics of functional soil organic carbon pools during recovery after land abandonment in a Mediterranean environment. We specifically focus on:

a) The dynamics of aggregation,
b) The dynamics of the active vs slow cycling organic carbon pools,
c) The sensitivity of different pools to gradual changes in land covers after abandonment,
d) The implications for C sequestration in soils on the longer term.

2. Materials and methods

2.1. Study site

The study was carried out in Andalucía, North West of Malaga on the site of Almogía (36°50′N, 4°34′W) (e.g. Ruiz Sinoga and Martinez Murillo, 2009; Martínez-Murillo and Ruiz-Sinoga, 2010; Gabarrón-Galeote et al., 2015a). A total of 16 plots (total surface of 29.1 ha) were selected in an area of ca. 40 × 10 km. The climate is Mediterranean, with cool winters and hot summers that coincide with a severe drought. Within the spatial extent of the study area, precipitation (650 mm yr^{-1}), mean annual temperature (15.5 °C), reference evapotranspiration (ET_0 = 820 mm yr^{-1}), altitude (400 m a.s.l.) and slope (10–20%) are comparable. The location site is close to the Malàguide complex of the Betic range. The lithology is composed of marls, sandstones and unconsolidated clays and soils are Eutric Cambisols (IUSS Working Group WRB, 2006).

A chronosequence of cereal crop abandonment was designed in a previous study (Gabarrón-Galeote et al., 2015a). The "space for time" concept, on which chronosequences are based, has been widely used in SOC dynamic studies due to the usually slow response of SOC to environmental changes (West and Post, 2002; Salomé et al., 2010; De Baets et al., 2013; Novara et al., 2014). This is especially important when studies focus on relatively stable SOC with turnover times ranging from years to decades (Six and Jastrow, 2002). Aerial photographs taken in 1956, 1977, 1984, 1998, 2001, 2004 and 2009 were used to establish age of abandonment categories. Each category is summarized by the mean time of abandonment (yr) which represents a certain period of abandonment by reference to the field campaign in 2013 (Table 1). Abandonment is defined as the cessation of ploughing and sowing, although other uses and activities such as grazing may continue (Bonet and Pausas, 2004). In addition, fields not subjected to LUC since at least 1956 were selected for two reference categories: fields with continuous cultivation and those with (semi) natural conditions.

As described by Gabarrón-Galeote et al. (2015a), the vegetation in (semi) natural sites of this region are dense forests dominated by *Quercus rotundifolia*. These forests have dense understories, with species such as *Quercus coccifera*, *Chamaerops humilis* and *Pistacia lentiscus*. In agricultural systems, cereals and olives dominate, alternating with grasslands and shrublands in abandoned or disturbed fields. These shrublands are dominated by *Cistus* spp., *Genista umbellata* and *Ulex parviflorus*. The study site belongs to the Malacitano biogeographical district (Rivas-Martínez et al., 1997).

In order to test the land use classification, the land use predicted from aerial photographs was compared to land-use maps and in situ observations. The level of accuracy was generally high, with an overall 80% correspondence between predicted and observed land use class (Gabarrón-Galeote et al., 2015a). Once the fields were selected, a stratified random sampling was implemented, resulting in 64 sampling points over the chronosequence (Table 1). The optimum sampling density in each category was estimated using SOC data from a previous sampling campaign carried out in 2009 (Gabarrón-Galeote et al., 2015a) following Eq. (1):

$$n_s = \left(\frac{u_{1-\alpha}/2 \cdot \overline{S}}{r}\right) \quad (1)$$

where n_s is the optimum number of samples in a given area, $u_{1-\alpha/2}$ is the $(1-\alpha/2)$ quantile of the standard normal distribution, $\overline{S}$ is the

Table 1
Area and sample points per category and normalized difference vegetation index.

Date of abandonment	MTA[a] (yr)	Area (ha)	Points (n)	NDVI[b]
Cropland	0	6.2	15	0.16 ± 0.04
2001–2004	10	2.0	4	0.23 ± 0.04
1998–2001	13	4.4	8	0.18 ± 0.03
1984–1998	22	5.8	10	0.19 ± 0.03
1977–1984	33	3.2	8	0.21 ± 0.02
1956–1977	46	5.4	14	0.25 ± 0.02
(Semi) natural	>63	2.1	5	0.24 ± 0.02
	Total	29.1	64	

[a] Mean time of abandonment (MTA) represents a certain period of abandonment by reference to 2013 (Gabarrón-Galeote et al., 2015a).
[b] Normalized difference vegetation index (NDVI).