Catena 113 (2014) 9–17

Contents lists available at ScienceDirect

Catena

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

Organic farming has little effect on carbon stock in a Mediterranean dehesa (southern Spain)

Luis Parras-Alcántara [a,*], Luisa Díaz-Jaimes [a,b], Beatriz Lozano-García [a], Pilar Fernández Rebollo [c], Félix Moreno Elcure [d], María D. Carbonero Muñoz [c]

[a] Department of Agricultural Chemistry and Soil Science, Faculty of Science, Agrifood Campus of International Excellence — ceiA3, University of Cordoba, 14071 Cordoba, Spain
[b] Agricultural Research Institute INIA, Bramón 5001, Táchira, Venezuela
[c] Department of Forestry Engineering ETSIAM, Agrifood Campus of International Excellence — ceiA3, University of Cordoba, 14071 Cordoba, Spain
[d] University of Táchira — UNET, Research Dean, Building B, 5001 Táchira, Venezuela

ARTICLE INFO

Article history:
Received 18 March 2013
Received in revised form 8 September 2013
Accepted 12 September 2013

Keywords:
Soil organic carbon
Quercus ilex
Management practices
Conventional tillage
Organic farming

ABSTRACT

Understanding soil dynamics is essential for making appropriate land management decisions, as soils can affect the carbon content from the atmosphere, emitting large quantities of CO_2 or storing carbon. This property is essential for climate change mitigation strategies as agriculture and forestry soil management can affect the carbon cycle. The Mediterranean dehesa (Mediterranean grassland ecosystem with scattered oak trees — grazing system with *Quercus ilex* spp. *ballota*) is a silvopastoral system that integrates forestry, agricultural and livestock practices. The dehesa is characterized by the preservation of forest oaks that provide environmental services including carbon capture and storage. This paper shows the relationships between soil properties and soil organic carbon (SOC) in two soil types: Cambisols (CM) and Leptosols (LP), with two management systems: organic farming (OF) for 20 years and conventional tillage (CT) in a Mediterranean dehesa of southern Spain without cropping. An analysis of 85 soil profiles was performed in 2009 in Los Pedroches Valley (Cordoba, southern Spain). The SOC stock (SOC-S) was greater in CM (75.64 Mg ha^{-1}) than in LP (44.01 Mg ha^{-1}). Physical parameters were the main variables affecting soil development. SOC-S was very similar in OF and CT (CM [74.90 Mg ha^{-1}-CT; 76.39 Mg ha^{-1}-OF] and LP [44.77 Mg ha^{-1}-CT; 43.25 Mg ha^{-1}-OF]). Data analysis showed that management practices had little effect on SOC storage in the study zone. Significant differences between soil types and management practices were found in SOC content for different horizons. The stratification ratio was >2 in both soils types (CM and LP) and management systems (OF and CT). These results indicate that the soil is of high quality, and that management practices have little influence on SOC-S in Los Pedroches Valley.

1. Introduction

The dehesa is a Mediterranean silvopastoral system formed by grasslands with scattered oaks (usually *Quercus ilex* or *Quercus suber*). Dehesas cover an area of approximately 3.1 Mha (Moreno and Pulido, 2009) in Spain and Portugal (where this system is locally known as *montado*), and are characterized by achieving a balance between production and conservation. The dehesa is a pasture where the herbaceous layer is comprised of either cultivated cereals such as oat, barley and wheat or native vegetation dominated by annual species, which are used as grazing resources (Joffre et al., 1999). It has few oak trees that are sometimes mixed with pine. In addition, the dehesa is a practice dedicated to the combined production of Iberian swine, sheep, fuel wood, coal and cork, as well as hunting. The dehesa is also considered an agroforestry system (Scarascia-Mugnozza et al., 2000). According to Reisner et al. (2007), the dehesa is the most well-known traditional agroforestry system in the world.

These Iberian open woodland rangelands (dehesas) have been studied from different points of view: hydrologically (Ceballos and Schnabel, 1998; Cerdà et al., 1998) with respect to soil organic matter (OM) content (Pulido-Fernández et al., 2013), as well as in relation to gully erosion, land use and topographical thresholds (Gómez-Gutiérrez et al., 2009); soil erosion and runoff production (Cerdà et al., 2010; Schnabel, 1997); soil degradation (Schnabel et al., 2006); and management practices (Corral-Fernández et al., 2013), among others. However, little is still known about soil behaviour in the dehesa as its lithology can be highly heterogeneous (mainly igneous and metamorphic).

Oak ecosystems do not have special soil requirements (Reisner et al., 2007), and are a significant carbon sink that can fix in their roots up to two-thirds of the carbon fixed by a terrestrial ecosystem (Snowdon et al., 2001).

According to Wang et al. (2010), the soil carbon stock capacity depends not only on abiotic factors such as the mineralogical composition and the climate, but also on soil use and management (Zinn et al.,

* Corresponding author. Tel.: +34 957211092; fax: +34 957212146.
E-mail address: qe1paall@uco.es (L. Parras-Alcántara).

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http://dx.doi.org/10.1016/j.catena.2013.09.002

2007). Many authors have proposed soil management techniques for improving soil properties and diminishing atmospheric CO_2 concentrations such as restrictions on tillage (Corral-Fernández et al., 2013; Parras-Alcántara et al., in press) or the addition of organic residues (Lozano-García and Parras-Alcántara, 2013; Lozano-García et al., 2011). Organic farming (OF) and the use of sustainable practices in general (Aranda et al., 2011) are other options.

Changes in land use and/or management practices have contributed to soil degradation and soil erosion; processes which have accelerated in recent decades (Cerdà et al., 2010). This effect is especially notable in the dehesa due to the sparse vegetation cover resulting from persistent drought and grazing pressure. This, together with the water repellency of the soil, may cause low infiltration rates in the dehesa (Cerdà et al., 1998), leading to significant soil OM losses. In this line, a small increase or decrease in soil carbon content due to management practices can generate a significant net exchange of carbon between the soil carbon pool and the atmosphere (Freibauer et al., 2004; Houghton, 2003). This situation (soil erosion by water and/or land use change) has a significant impact on this large pool of soil organic carbon (SOC) (Van Oost et al., 2005).

Soil properties are another crucial aspect related to soil carbon storage capacity. According to Lal (2009), clayey soils can sequester more carbon than sandy soils, and this is important as dehesa soils are not usually clayey soils.

Climate, soil use and management affect the carbon spatial distribution. Under Mediterranean climatic conditions, soils are characterized by low SOC content, poor structure and high erodibility (Hernanz et al., 2002). Authors such as Hontoria et al. (2004) have reported that climate, soil use and management are particularly relevant in the SOC content in Mediterranean climates. However, Lal (2009) noted that climatic factors and soil characteristics may affect the sequestration of organic and inorganic carbon although use and management are more important, especially in agrosystems, which incorporate more biomass and maintain a positive nutrient balance. This situation closes the carbon cycle by the integration of arboreal, herbaceous and animal components (Sánchez, 2000), and this integration provides greater carbon sequestration in soil (Nair et al., 2009).

Another key issue is to determine soil quality indicators based on SOC content and distribution. In this context, the stratification ratio (SR) of SOC is used as an indicator of soil quality (Franzluebbers, 2002; Franzluebbers et al., 2007; Sá and Lal, 2009). An increase in SR may be related to the rate and amount of SOC sequestration (Franzluebbers, 2002; Moreno et al., 2006).

Due to the complexity of the system and the lack of standardized accounting methods to quantify the contribution of OF components as a carbon sink, there are few studies on the effects of OF on carbon sequestration in dehesas.

The aims of this paper are therefore i) to assess the vertical distribution of SOC in the entire soil profile and analyse the soil properties affecting SOC; ii) to determine the effects of different management practices such as organic farming (OF) or conventional tillage (CT) on SOC stocks (SOC-S) in Cambisols (CM) and Leptosols (LP); and iii) to analyse the quality of these soils based on SR in a Mediterranean dehesa of Los Pedroches Valley in southern Spain.

2. Material and methods

2.1. Study site and management type

The study area is located in Los Pedroches Valley (Cordoba, southern Spain) between 38.39 and 37.15°N, 4.90 and 4.15°W and comprises 0.29 Mha of dehesa land (Fig. 1). Los Pedroches Valley is characterized by cold winters and warm, dry summers with temperatures ranging from −2 °C to 40 °C (extreme temperatures) and an average annual rainfall of 600 mm. The moisture regime is dry Mediterranean with continental features due to altitude. The relief is smooth and characterized by an undulated topography with slopes ranging from 3 to 8%. The parent materials are granites.

Fig. 1. Mediterranean dehesa in Los Pedroches Valley, Cordoba (southern Spain).

Two soil management practices were selected: OF for 20 years and CT in CM and LP soil types (IUSS Working Group WRB, 2006). The management characteristics are described in Table 1. For all soil types and management practices, the average density of *Q. ilex* spp. *ballota* in the dehesa is 15–25 trees ha^{-1} (data provided by the Department of Organic Production of Andalusia for the study area). The dehesas studied were silvopastoral systems without cropping.

2.2. Sampling and analyses

Random samples from 49 CM (27 in OF and 22 in CT) and 36 LP (17 in OF and 19 in CT) profiles (entire soil profiles) were collected in 2009. The profiles in CT and OF were identified with the geo-referenced information provided by the Department of Organic Production of Andalusia using geographic information systems. The entire soil profile was collected in open areas and low slope gradients (<3%).

The soil samples were air-dried at constant room temperature (25 °C), and sieved (2 mm) to remove coarse soil particles. The analytical methods are described in Table 2.

Table 1
Management categories in Los Pedroches Valley.

Management	Abbreviation	Characteristics
Conventional tillage	CT	Isolated trees of variable densities (15–25 trees ha^{-1}, mostly holm and cork oaks)[a], and patches of shrubs (*cistaceae*, *fabaceae* and *lamiaceae*) with an herbaceous pasture layer mostly composed of *therophytic* species. Ploughing (annual passes with a disc harrow and/or cultivator) is aimed at growing grain for livestock or at clearing the encroaching shrubs. Livestock (Iberian swine, sheep, cattle and exceptionally fighting bulls) are introduced to provide organic fertilizer to the soil.
Organic farming	OF[b]	Isolated trees of variable densities (15–25 trees ha^{-1}, mostly holm and cork oaks)[a], and patches of shrubs (*cistaceae*, *fabaceae* and *lamiaceae*) with a herbaceous pasture layer mostly composed of *therophytic* species and livestock (Iberian swine, sheep, cattle and exceptionally fighting bulls) are introduced to provide organic fertilizer to the soil as in CT. Without ploughing. Animal manure from the farms may be incorporated.

[a] Data provided by the Department of Organic Production of Andalusia.
[b] For 20 years (1989–2009).