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Soil quality assessment based on carbon stratification index in different olive grove management practices in Mediterranean areas

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ABSTRACT

In Mediterranean areas, conventional tillage increases soil organic matter losses, reduces soil quality, and contributes to climate change due to increased CO_2 emissions. CO_2 sequestration rates in soil may be enhanced by appropriate agricultural soil management and increasing soil organic matter content. This study analyzes the stratification ratio (SR) index of soil organic carbon (SOC), nitrogen (N) and C:N ratio under different management practices in an olive grove (OG) in Mediterranean areas (Andalusia, southern Spain). Management practices considered in this study are conventional tillage (CT) and no tillage (NT). In the first case, CT treatments included addition of alperujo (A) and olive leaves (L). A control plot with no addition of olive mill waste was considered (CP). In the second case, NT treatments included addition of chipped pruned branches (NT1) and chipped pruned branches and weeds (NT2). The SRs of SOC increased with depth for all treatments. The SR of SOC was always higher in NT compared to CT treatments, with the highest SR of SOC observed under NT2. The SR of N increased with depth in all cases, ranging between 0.89 (L-SR1) and 39.11 (L-SR3 and L-SR4).The SR of C:N ratio was characterized by low values, ranging from 0.08 (L-SR3) to 1.58 (NT1-SR2) and generally showing higher values in SR1 and SR2 compared to those obtained in SR3 and SR4. This study has evaluated several limitations to the SR index such as the fact that it is descriptive but does not analyze the behavior of the variable over time. In addition, basing the assessment of soil quality on a single variable could lead to an oversimplification of the assessment. Some of these limitations were experienced in the assessment of L, where SR1 of SOC was the lowest of the studied soils. In this case, the higher content in the second depth interval compared to the first was caused by the intrinsic characteristics of this soil's formation process rather than by degradation. Despite the limitations obtained SRs demonstrate that NT with the addition of organic material improves soil quality.

1. Introduction

The main agricultural system in Mediterranean areas is olive grove (OG) with 9.5×10^6 ha (Fernández-Romero et al., 2014). Olive grove soils suffer from severe erosion rates due to management techniques (conventional tillage — CT), the slope and the low tree density (Gómez et al., 2003; Cerdà et al., 2010) for millennia (Vanwalleghem et al., 2010), which resulted in soil degradation of the agriculture soils (Cerdà et al., 2009; García-Orenes et al., 2012) and high-cost of eroded soil restoration plans(Colen et al., 2015). The impact of land management and soil water erosion on soil quality is very well known (Cerdà and Doerr, 2007; Novara et al., 2013; Cerdà et al., 2014; Brevik et al., 2015; Zhang et al., 2015). Soil is essential for life inasmuch as it provides various important roles: supports, regulates, provisioned and provides cultural services (Banwart et al., 2015). This includes the provision of plant nutrients, regulation of water flow, and natural and anthropogenic compound degradation (Franzluebbers, 2002; Brevik and Sauer, 2015). All these services provided by soil are shown as a soil quality index. Soil quality is the capacity of soils to sustain biological yield, maintain the environment and improve animal and plant health (Muñoz et al., 2007). Additionally, soil quality is also important for humans, as it enables food security and economic revenue due to better and more productive crops (Lal, 1999; Imaz et al., 2010; Brevik and Sauer, 2015). It is only when soil can develop its functions with plenitude and when it is managed suitably that sustainable agriculture can be achieved and land degradation is reduced (Morugán-Coronado et al., 2013; Souza et al., 2014; Zornoza et al., 2015). Over time, scientists have developed techniques for assessing soil quality and they were applied in different regions and soil types and managements (Das et al., 2014; Beniston et al., 2015; Zhao et al., 2015) and highlighted the biological view of soil quality (Paz Ferreiro and Fu, 2014) although some socioeconomic approaches are also found (Teshome et al., 2014). Nortcliff (2002), Duval et al. (2013) and other authors highlighted the importance and challenging exercise of finding quantitative indexes that were able to define the soil quality of a particular site accurately, measuring the

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combined effects on the relevant soil properties over a period and offering comparability between soils. Soil quality should be easy to measure, able to reflect short and long-term changes in soil properties, be sensitive to land use changes, and accessible to as many users as possible (Shukla et al., 2006). Moreover, specific agro-ecosystems may require different soil property measurements (Shukla et al., 2006; Imaz et al., 2010). In addition, there are complex interactions between climate, soil composition, landscape position and land management that hinder soil quality determination based on a single factor (Ogle et al., 2012). Therefore, there is no consensus with regard to the exact characteristics that a soil should have to be considered of the highest quality (Duval et al., 2013). There are two general approaches for this. The first considers that soils with the maximum quality are those in equilibrium with all their environmental components (climax soils). The second approach considers that soils with the highest productivity but lowest environmental burden are those with the maximum quality (Duval et al., 2013).

Soil quality assessment encompasses inherent and dynamic soil properties, and all interactions should be accounted for (Karlen et al., 2003; van Leeuwen et al., 2015). The more important factors that influence soil quality are tillage, crop rotation, type of manure (if applied), climate and soil type (Imaz et al., 2010). One of the main causes of land degradation is unsustainable agriculture. For this reason, the type of tillage has been of great interest with regard to soil quality investigation (Lal et al., 1998). In this respect, in soils with moderate to steep slope, CT contributes to increased soil erosion and degradation, which reduces soil organic matter (SOM) (Lozano-García et al., 2011). Furthermore, CT influences on nutrients losses and leads to the deterioration of physical, chemical and biological soil properties, thereby reducing soil quality (Salvo et al., 2010; Parras-Alcántara and Lozano-García, 2014). In this line, and as consequence of this effect, several alternatives have been examined in the last two decades. No-tillage (NT) systems have been demonstrated to improve soil properties and reduce soil erosion compared to CT (Moreno et al., 1997; Franzluebbers, 2002; Melero et al., 2009a, 2009b; Parras-Alcántara et al., 2013a). Conservation tillage has also received attention, as it combines the improvement of soil properties and agricultural wastes recycling, two objectives of sustainable agriculture (Moreno et al., 2006; Govaerts et al., 2009). This is especially important, because some properties such as water retention, soil organic carbon (SOC), carbonates and nutrient content can be improved with conservation tillage in Mediterranean soils in Southern Spain (Moreno et al., 1997). The adoption rate of these alternatives (conservation tillage) has been slow in Europe, with only 1% of the total area that is managed with NT in the world. Spain has currently 650,000 ha under this management (56% of the total area under NT in Europe) (Derpsch and Friedrich, 2010).

One of the most significant properties that have been researched in the context of soil quality is SOC. Authors such as Quiroga et al. (2005) believe that SOC is the best indicator to measure soil quality and soil productivity. However, other authors like Duval et al. (2013) indicate that SOC alone is a poor indicator of soil quality, as SOC only shows short-term changes. Also, SOC is not always the best indicator of changes in soil management in semi-arid conditions, as low soil moisture and high temperature limit SOC accumulation, which delays the effects of sustainable management practices on SOC content for several years (Chan et al., 2003; Moreno et al., 2006; Melero et al., 2012; Blanco-Moure et al., 2013). Moreover, the influence of management practices such as tillage type on SOC and other soil properties like N content can vary with soil depth, crop and site specific characteristics (Chatterjee and Lal, 2009; Du et al., 2010; Mishra et al., 2010).

In this respect, the stratification ratio (SR) of SOC and N with depth are good indicators of soil functioning (Franzluebbers, 2002; Sá and Lal, 2009; Corral-Fernández et al., 2013). Also, SR of C:N ratio is also influenced by tillage and the addition of crop residues (Lozano-García and Parras-Alcántara, 2013). As a result, C:N ratio and its SR are considered good soil quality indicators because they reflect C and N interactions in soils (Puget and Lal, 2005; Lou et al., 2012). With regard to this, authors like Franzluebbers (2002) proposed to evaluate soil quality based on the SR index, indicating that the SR of each property can be related to an aspect of soil quality. Furthermore, the SR of SOC is a good indicator of SOC sequestration rate (Franzluebbers, 2002; Moreno et al., 2006; Brye et al., 2006). Higher SR of SOC indicates that soil management enhances soil quality. This is because the top soil layer is influenced by land management but the second layer (subsequent layers) are less affected (Franzluebbers, 2002, 2010; Ferreira et al., 2012). Additionally, the time that the specific management technique has been in place affects SR of SOC as well, which is useful for medium to long-term analysis (De Oliveira et al., 2013). These indicators are especially relevant for Mediterranean areas, given the limitations to SOC accumulation that derive from climatic conditions. Also, high SR of SOC and N indexes reflect undisturbed soil and high soil quality of the surface layer, even though SOC quantities may not be high (Franzluebbers, 2002; Corral-Fernández et al., 2013).

The aim of this study is (i) to determine soil quality measured by stratification ratio index of soil organic carbon, nitrogen and C:N ratio under different management practices: conventional tillage and no tillage in olive groves in Mediterranean areas (Andalusia, southern Spain) using entire soil profiles and (ii) to indicate the stratification ratio index limitations.

2. Material and methods

2.1. Study site and experimental design

The study was conducted in Torredelcampo — Jaen (Andalusia, southern Spain) (Fig. 1). The lithological substrate consists on Miocene marl and marlaceous lime. The area has a Mediterranean climate, with three to five months of hot and dry summers (June to September) and moderately wet, cool winters. The mean annual temperature is 17 °C, with a maximum temperature of 40.6 °C (August) and a minimum of −5.2 °C (January). The average precipitation is 645.7 mm/year, and the monthly rainfall ranges from 4.7 mm (July) to 87 mm (February). The studied soils were Cambisols (CM) according to the classification developed by the IUSS Working Group (IUSS-ISRIC-FAO, 2006). These were very similar in their physical-chemical properties, with slight differences with respect to management type, and characterized by gravel content variability (5–22%), silt (44–73%) and clay (19–41%), basic-acid pH (6–8.9) and similar values with respect to bulk density (BD) (1.4 Mg m^{-3})(Fernández-Romero et al., 2014).

The study consisted of studying the effect of five different management practices in unirrigated OG soils (Table 1). All plots had olive trees (*Olea europaea* variety *Picual*), with a tree density of 90 trees ha^{-1} (10 m of separation between trees) with 2–3 trunks each. A mineral fertilizer (Urea, 46% N) was applied in alternate years during winter, just after the harvest, in addition to this, a broad-spectrum herbicide was added in autumn to control weeds under trees in all management systems.

2.2. Sampling and analysis

Soil properties were studied at different depths in the entire profile, horizon by horizon, instead of using soil control sections to reduce the effect of mixing of materials that are not from the same horizons (Parras-Alcántara et al., 2015). Four soil profiles were sampled in each plot. Three replicates for each sampling point were made (5 plots × 4 soil profiles samples in each plot × 3 replications per horizon in the laboratory).

Soil samples were air-dried at constant room temperature (25 °C), and passed through a 2 mm sieve to remove gravels and roots. The analytical methods are described in Table 2.