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Soil sampling approaches in Mediterranean agro-ecosystems. Influence on soil organic carbon stocks

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ABSTRACT

Studies on the quantities and distribution of soil organic carbon stocks (SOC-S) can help to fill the knowledge gaps in estimating the amount of carbon stored in soils. However, one of the problems of soil organic carbon (SOC) is the high variability in space and time. Over the years, many researchers have studied the soil mainly in two different ways: by pedogenic horizons in entire soil profiles (ESP) or by soil control sections (SCS) with different thicknesses along the profile, and this causes uncertainty in SOC and SOC-S evaluation and assessment.

This study analyzed the differences in the SOC-S in northeastern Sardinia (Italy) in Cambisols, following two soil sampling approaches, ESP by pedogenic horizons and SCS (25 cm thick) on these selected land uses: tilled vineyards, no-till grassed vineyards, and former vineyards naturally re-vegetated after abandonment.

Average data on total SOC-S (T-SOC-S) estimations were 61.5 Mg ha^{-1} and 67.3 Mg ha^{-1} for ESP and SCS respectively, indicating significantly higher estimates of T-SOC-S when sampling by SCS. Consequently, the ESP approach is recommended to evaluate and certify SOC-S, while SCS may be preferred for monitoring and soil management interpretation purposes.

1. Introduction

Carbon (C) sequestration via agricultural soils can potentially contribute to climate change mitigation, if specific measures to limit the increasing atmospheric CO_2 concentrations are implemented (Smith et al., 2008; Whitmore et al., 2014; FAO, 2017a, 2017b). Even if the role of C sequestration to mitigate the climate change is debated (Powlson et al., 2014 and VandenBygaart, 2016), it is widely accepted that sounds management of agricultural soils leads to benefits such as increased soil organic matter (SOM) with consequent potential increased yields, improved water quality as a results of reduced runoff and soil erosion, increased biodiversity, and soil resilience against extreme events such as heavy rainfall and flooding (Stout et al., 2016).

According to the scientific literature (Batjes, 1996; Falkowski et al., 2000; Pacala and Socolow, 2004; Lal, 2008; Schrag, 2007) there are five global C pools: the oceanic pool is the largest, estimated at 38 000 Gt (1 Gt = 10^{15} g); the geological C pool (including fossil fuels) estimated at 4130 Gt; the pedologic pool estimated at 2500 Gt to 1 m depth with two distinct components, SOC estimated at 1550 Gt and soil inorganic carbon at 950 Gt; the atmospheric pool containing 760 Gt of CO_2-C; and the biotic pool estimated at 560 Gt. More recently, Maraseni and Pandey (2014) reported that soil is the largest C pool after the ocean, storing 1580 Gt of organic C and 600 Gt of inorganic C in the top soil meter. Köchy et al. (2015) estimated that the top 1 m of the world's soils stored 2476 Gt of SOC. Therefore, changes in the SOC stock (SOC-S) have profound implications for the mitigation or exacerbation of climate change (Smith et al., 2008).

It is well known that SOC-S is affected by climate conditions, land-use patterns and human activities and policies (Mao et al., 2015). Moreover, SOC varies among environments and management systems, and generally increases with higher mean annual precipitation and lower mean annual temperature, higher clay content, higher crop residue and fertilization input, native vegetation compared to arable crops, conservation tillage compared to conventional tillage, and changes in land use, soil compaction, landscape ecosystems, position and slope (Jenny, 1980; Nichols, 1984; Parton et al., 1987; Burke et al., 1989; Rasmussen and Collins, 1991; Franzluebbers et al., 1998; Schnabel et al., 2001; Brevik et al., 2002; Wilcox et al., 2002; Farina

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et al., 2011; Fernández-Romero et al., 2014; Francaviglia et al., 2014; Lozano-García and Parras-Alcántara, 2014; Parras-Alcántara et al., 2015a).

In recent years, the studies related to SOC and SOC-S have significantly increased given the concern over greenhouse gas emissions. In this sense, many studies point out the need to make a joint effort to homogenize the terminology, the methods to calculate the SOC storage, and even the soil sampling methods (Powlson et al., 2011; Parras-Alcántara et al., 2015c; Lorenz and Lal, 2016). Therefore, the choice of sampling methods is important to provide results that are reliable, comparable and can be extrapolated (Lal, 2005). However, the main problem is that the experimental design of many soil studies was not initially focused on soil C monitoring, and nevertheless data from these studies are presently used in SOC estimations (Baritz et al., 2010). Therefore, different approaches of soil sampling can provide significantly different estimates of SOC-S. Thus, the lack of a common method for soil sampling to certify the changes of SOC-S might be a serious obstacle for the implementation of the Kyoto Protocol in EU (Stolbovoy et al., 2007). In addition, soils are targeted as the major carbon reservoir on Earth in the Paris Climate Agreement signed in 2015 during the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change.

So far, many studies have focused on SOC distribution only in the biologically active layers of topsoil; the IPCC (2006) C accounting method estimates the change on SOC storage for the top 30 cm of a soil profile, and actually limited data are available for SOC-S below this depth (Díaz-Hernández, 2010; Jandl et al., 2014). Moreover, SOC estimates are more uncertain in areas with heterogeneous land uses and pedoclimatic conditions such as Mediterranean and dryland ecosystems, which are more prone to land degradation due to SOC degradation and depletion, and erosive processes (Hoffmann et al., 2012; Muñoz-Rojas et al., 2015).

With respect to SOC-S estimation, the main points to be considered are the sampling strategy and depth. Batjes (2014) reported SOC stocks according to four depth intervals derived from the FAO-UNESCO soil units (0–30, 0–50, 0–100 and 0–200 cm) and the World Inventory of Soil Emissions database. Some authors applied standard control sections (SCS) at specific depths (Muñoz-Rojas et al., 2012; Muñoz-Rojas et al., 2015; Lozano-García et al., 2016). Other authors investigated the entire soil profile (ESP) method by pedogenic horizons (Parras-Alcántara et al., 2015b), and some researchers use both methodologies simultaneously (Grüneberg et al., 2010; Parras-Alcántara et al. 2015c). In particular, Parras-Alcántara et al. (2015c) showed that samplings by SCS provided higher SOC-S in comparison with ESP method; Grüneberg et al. (2010) obtained similar results but argued that sampling by horizons is beneficial when soil processes in the context of C storage are studied, while the sampling by SCS at depth increments is preferred when changes of SOC-S over time are analyzed. More recently, Rovira et al. (2015) proposed the cumulative coordinates approach (CCA) as an alternative to the IPCC C accounting method. With this approach, soils are sampled to a given depth (30 cm) with a volumetric core sampler that maintains the profile structure, and the obtained core is divided in depth layers; each layer is studied separately for its stone and gravel content, fine earth and coarse organic fragments. CCA provides a better comparison of soil C stocks under different land uses, and allows correcting for the changes in bulk density (BD) due to land use itself, but also to the changes in soil OM content.

Vineyards can account for 41.9 Mg C ha^{-1} in Italy (Chiti et al., 2012), in addition to providing habitat conservation and other ecosystem services (Williams et al., 2011). Moreover, vineyards can sequester atmospheric C, given firstly their long life cycle, which allows them to accumulate C in permanent organs such as trunks, branches, roots and in the soil through rhizodeposition, secondly a low or null soil tillage, which preserves SOM from mineralization, and finally by the frequent presence of herbaceous vegetation in the alleys, which can contribute to the buildup of SOM (Scandellari et al., 2016). For that reason, the SOC and SOC-S correct quantification is essential for evaluating the impact of different agricultural practices and addressing mitigation policy at large scales such as at a country scale.

In this context, the aims of the present study are: i) to compare the soil organic carbon stock determination by using entire soil profile (ESP) and soil control section (SCS) approaches, ii) to choose the best method to be adopted, and iii) to suggest sampling techniques for soil organic carbon estimation and studies.

2. Materials and methods

2.1. Study area

The study site (Fig. 1) is within an area of about 1470 ha in the Berchidda Municipality (Olbia-Tempio, Sardinia, Italy) (40°46′ N; 9°10′ E, mean altitude 285 m a.s.l.). Mean annual rainfall and temperature are 623 mm (range 367–811 mm) and 15.0 °C (13.8–16.4 °C) respectively. According to the updated Köppen-Geiger classification (Kottek et al., 2006), the climate is warm temperate with dry and hot summers (Csa). The area lies within a hilly basin where elevation is in the range 275–340 m a.s.l., and slope ranges from 2–6% to 16–30%. Soils are classified as Typic and Lithic Dystroxerepts and Typic Haploxerepts (Soil Survey Staff, 2014), and Dystric and Eutric Cambisols (IUSS Working Group WRB, 2015), with sandy-loam and loamy-sand texture, as already described in previous papers (Lagomarsino et al., 2011; Francaviglia et al., 2012; Seddaiu et al., 2013; Francaviglia et al., 2014). The lithologic substrate consisted of medium-grained granite, affected by localized presence of veins of quartz and porphyry (Bevivino et al., 2014). The area is characterized by cork oak (*Quercus suber* L.) forest as native vegetation, converted in recent years to managed land with pastures and vineyards; as a consequence, the landscape is very complex and multiple land use/land cover types representing different soil microenvironments occur within close proximity to each other (Lai et al., 2014). To increase soil variability and to compare their effects on SOC and other soil parameters, three land uses with different management schema were selected as examples to apply the soil sampling approaches: Tilled vineyards (Tv), no-till grassed vineyards (Ntgv) and former vineyards (Fv), presently re-vegetated by different natural vegetation covers typical of the Mediterranean basin, such as Scrublands, Mediterranean Maquis, and Helichrysum meadows (Fig. 2 and Table 1).

2.2. Soil sampling, analytical determinations and statistical analysis

Fifteen soil-sampling points were selected to consider local differences due to slope and/or vegetation heterogeneity (Table 2) in a random sample design. Sampling pits were digged with a mini excavator, and samples were taken along the horizons and layers using a hand trowel. Each soil sampling point was analyzed in two different ways, using ESP (by soil genetic horizons) and SCS using soil layers at fixed depth increments (0–25, 25–50, 50–75 and 75–100 cm). Four replicates were collected in Tv, Ntgv, and seven replicates in Fv. In particular, a lower number of samples was collected in the most homogeneous land uses represented by the vineyards (along and between the rows), and a higher number in Fv which was the most heterogeneous land use due to the existence of different conditions of land cover deriving from the heterogeneous natural vegetation.

Soil samples were air-dried, coarse particles were removed using a 2-mm sieve, the gravel (> 2 mm) was determined, and the analyses were made on the < 2 mm soil fraction. Particle-size analysis and soil texture were determined with the wet sieving and sedimentation procedure and the USDA (2004) classification respectively; SOC with the Walkley-Black method (Nelson and Sommers, 1982), soil bulk density (BD) by the core method (Blake and Hartge, 1986) using a cylindrical sampler (diameter 3 cm, length 10 cm) pushed at intermediate depths in the different horizons/layers. Soil cores were dried at 105 °C and