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Soil organic carbon stocks assessment in Mediterranean natural areas: A comparison of entire soil profiles and soil control sections

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ABSTRACT

Soil organic carbon (SOC) is an important part of the global carbon (C) cycle. In addition, SOC is a soil property subject to changes and highly variable in space and time. Over time, some researches have analyzed entire soil profile (ESP) by pedogenetic horizons and other researches have analyzed soil control sections (SCS) to different thickness. However, very few studies compare both methods (ESP versus SCS). This research sought to analyze the SOC stock (SOCS) variability using both methods (ESP and SCS) in The Despeñaperros Natural Park, a nature reserve that consists of a 76.8 km^2 forested area in southern Spain. Thirty-four sampling points were selected in the study zone. Each sampling point was analyzed in two different ways, as ESP (by horizons) and as SCS with different depth increments (0–25, 25–50, 50–75 and 75–100 cm). The major goal of this research was to study the SOCS variability at regional scale. The soils investigated in this study included Phaeozems, Cambisols, Regosols and Leptosols. Total SOCS in the Despeñaperros Natural Park was over 28.2% greater when SCS were used compared to ESP, ranging from 0.8144 Tg C (10,604.2 Mg km^{-2}) to 0.6353 Tg C (8272.1 Mg km^{-2}) respectively (1 Tg = 10^{12} g). However, when the topsoil (surface horizon and superficial section control) was analyzed, this difference increased to 59.8% in SCS compared to ESP. The comparison between ESP and SCS showed the effect of mixing pedogenetic horizons when depth increments were analyzed. This indicates an overestimate of T-SOCS when sampling by SCS.

1. Introduction

Soils are the primary terrestrial reservoirs of carbon (C), in fact, more than 71% of the terrestrial organic carbon (OC) pool is found in soils (Lal, 2010). Given the right conditions, soils can store C for thousands of years (Brevik and Homburg, 2004). Even small changes in soil organic carbon stock (SOCS) have the potential to cause relatively large changes in atmospheric CO_2 concentrations, in turn influencing greenhouse gas concentrations. As an important part of the global C cycle, soils can be either a source or sink of CO_2 and CH_4, both of which are important greenhouse gasses (Breuning-Madsen et al., 2009; Brevik, 2012).

The top meter of the world's soils store an estimated 2200 Gt of C (1 Gt = 1 Pg = 10^{15} g), with two-thirds of that stored as soil organic matter (SOM) (Batjes, 1996). This is almost three times more C than is found in the atmosphere. According to Batjes (1996), there is 1462–1545 Pg of soil organic carbon (SOC) to a depth of 1 m in the world's soils, with 684–724 Pg (approximately 50 per cent) in the upper 30 cm. Jobbagy and Jackson (2000) estimate there is 1502 Pg of SOC in the 0–100 cm depth interval, while more recently Köchy et al. (2014) estimated that the top 1 m of the world's soils stored 2476 Pg of SOC. The world's forest ecosystems, which cover 4.1 billion ha (Dixon and Wisniewski, 1995), store the largest share of terrestrial SOCS at about 818 Pg C in the 0–100 cm interval (Jobbagy and Jackson, 2000).

The principal factors that affect to soils' C concentration and to soils' C store are linked to environmental and anthropogenic conditions, including climate (Post et al., 1982); soil mineralogy (Lal, 2009; Wang et al., 2010); landscape (Wilcox et al., 2002); landscape position (Lozano-García and Parras-Alcántara, 2014a,b); slope (Fernández-Romero et al., 2014); latitude (Hobbie et al., 2000); texture and structure (Borchers and Perry, 1992); chemical

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properties (Chandler, 1939); anthropogenic factors (Larionova et al., 2002); soil management (Zinn et al., 2007; Corral-Fernández et al., 2013; Thilde et al., 2013; Cerdá et al., 2014) and natural disturbances such as wind, fire (Novara et al., 2011), drought, insects and diseases (Overby et al., 2003).

Another important issue in the study of SOCS variability is the scale-level factor. Some studies have analyzed the spatial variability of SOCS at the control plot scale (Schöning et al., 2006; Don et al., 2007). Other studies have estimated SOCS variability ranging from field to regional, national, and global scales (Batjes, 2002a; Dixon-Coppage et al., 2005; Hiederer, 2009; Civeira et al., 2012; Köchy et al., 2014).

One of the first publications about the global status of soil carbon was Batjes (1996). This paper was recently reissued in 2014 (Batjes, 2014) and recommends that soil organic and inorganic C contents could be studied on a unit area basis over a specified depth interval. Batjes (2014) also recommends that information on the spatial distribution of soil types, soil C, bulk density (BD), and stoniness should be provided. The development of a standard sampling protocol for assessing SOCS is needed (Lal et al., 2001). Whether sampling is done by depth increment (specific depth) or by genetic horizons is also important for soil assessment (Lal, 2005). With respect to scale of measurement, it is necessary to understand the mechanisms responsible for C stock and fluxes at different scales ranging from molecular to global. Therefore, the choice of sampling methods is important to provide results that are reliable, comparable, and can be extrapolated (Lal, 2005).

There is a widespread idea that estimates of SOCS can be affected by the sampling approach used. At present, there are different opinions concerning whether SOCS should be inventoried by genetic horizon using an entire soil profile (ESP) approach or using edaphic controls – depth increments within a soil control section (SCS). To date, little work has been done to compare sampling of SOC by horizons using ESP versus SCS at different thicknesses. Such studies have focused on arable land or sometimes on forest soils (Palmer et al., 2002; VandenBygaart et al., 2007; Grüneberg et al., 2010). Previous works recommend studying ESP by genetic or pedogenetic horizons; other researchers recommend SCS by edaphic controls to different thickness, and in each case the benefits of the methodology established was justified. For example, VandenBygaart (2006) recommended ESP for hydromorphic soils, stating that ESP reduced the SOCS variability in the upper 30 cm of ploughed Gleysols. Palmer et al. (2002) indicated that soil horizons can be mixed during SCS sampling but recommended the use of SCS to monitor changes in near surface forest soil OC. In general, the effect of different sampling techniques on the calculation of regional forest SOCS variability is poorly understood. The principal problem is that the experimental design of many soil studies conducted in the past were not focused on soil C monitoring, yet data from those studies is now used in SOC estimation (Baritza et al., 2010).

This study's objectives are (i) quantification of SOC content and SOCS in the Despeñaperros Natural Park – nature reserve (a Mediterranean natural area free of human disturbance), and (ii) to compare the variability of SOC concentrations and SOCS as determined by ESP (by soil horizons) and SCS (edaphic controls by depth increments) for different soil types (Phaeozems, Cambisols, Regosols and Leptosols).

2. Material and methods

2.1. Site characterization

The Despeñaperros nature reserve in Southeast Spain is one of the most pristine natural landscapes in southern Europe (Fig. 1). It is 76.8 km^2 in area and located within the Eastern Sierra Morena between 38°20′ and 38°27′N, 3°27′ and 3°37′W. Winter temperatures are low (−10 °C minimum) while summers are hot (42 °C maximum), with a mean annual temperature of 15 °C. Summers tend to be warm and dry and winters are cold and moist with 800 mm of annual rainfall on average. The climate classifies as temperate semi-arid and the region's altitude introduces a continental influence. Long dry periods that are typical during the hot summers lead to deficits in water of as much as 350 mm, giving the region a dry Mediterranean moisture regime (Parras-Alcántara, 2001).

The topography is mountainous, with a minimum altitude of 540 m in the Despeñaperros River Valley and a maximum altitude of 1250 m on Malabrigo Mountain. Slopes are steep (3%–45%) and slates and quartzites make up the primary parent materials. The most abundant soils in the area are Phaeozems (PH), Cambisols (CM), Regosols (RG) and Leptosols (LP) (Parras-Alcántara, 2001) according to the classification by IUSS Working Group WRB (2006).

The study area is characterized by well-preserved Mediterranean woodlands and scrubland. Forests are dominated by holm, Portuguese, and cork oaks (*Quercus ilex*, *Quercus faginea*, and *Quercus suber*, respectively) while scrublands are dominated by species such as kermes oak (*Quercus coccifera*), strawberry tree (*Arbutus unedo*), mastic (*Pistacia lentiscus*), myrtle (*Myrtus communis*), and narrow-leaved mock privet (*Phillyrea angustifolia*). Formations dominated by laudanum (also known as gum rockrose) (*Cistus ladanifer*) cover a significant part of the area and plantations of stone pine and maritime pine (*Pinus pinea* and *pinaster*) are also common. The main land use is big game hunting, with a variety of deer (*Cervus elaphus*, *Dama dama*, and less frequently *Capreolus capreolus*) and wild boar (*Sus scrofa*) commonly found. Spanish ibex (*Capra pyrenaica*) present very localized populations with only a few individuals, but this nature reserve is home to numerous Iberian wolf (*Canis lupus signatus*), Iberian lynx (*Lynx pardinus*), Spanish imperial eagle (*Aquila adalberti*), Black stork (*Ciconia nigra*), and Black vulture (*Aegypus monachus*) (Parras-Alcántara et al., 2004).

2.2. Soil sampling and analytical methods

Thirty-four sampling points were selected in the Despeñaperros nature reserve (10 in PH, 4 in CM, 10 in RG and 10 in LP) (Table 1) in a random sample design. Each sampling point was analyzed in two different ways, using ESP (by soil horizons) and SCS with different depth increments (0–25, 25–50, 50–75 and 75–100 cm) (Fig. 2). Five laboratory replications were performed for each soil sample.

Soil samples were placed in a room with a constant temperature of 25 °C to dry and coarse particles were removed using a 2 mm sieve with wet sieving. The samples were treated with 6% H_2O_2 before textural analysis to dissolve SOM. The Robinson pipette method was used to determine the distribution of particles <2 mm diameter and texture was classified according to USDA standards (USDA, 2004). The core method of Blake and Hartge (1986) was used to measure soil BD using a core with a diameter of 3.0 cm and length of 10.0 cm. Wet oxidation with dichromate as described by Walkley and Black (1934) was used to determine SOM. SOCS (Mg ha^{-1}) were calculated for each horizon using the method of Wang and Dalal (2006) and IPCC (2003):

$$SOCS = SOC\ concentration \times BD \times d \times (1 - \delta_{2mm}\%) \times 0.1$$

where, d = soil layer thickness (cm), δ_{2mm} = fractional percentage (%) of >2 mm gravel, and BD = bulk density (Mg m^{-3}).

Total SOCS (T-SOCS) (Mg ha^{-1}) was calculated for each ESP and SCS according to IPCC (2003) as follows: