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Soil carbon stock in relation to soil properties and landscape position in a forest ecosystem of southern Italy (Calabria region)

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ABSTRACT

Carbon (C) storage in forest soils is of great importance both to forest ecosystems and to reduce the CO_2 in atmosphere. Knowledge of spatial pattern of soil organic carbon (SOC) and the factors influencing it in various soil-landscapes are essential for understanding global C cycle.

The objective of this study was to investigate at profile scale SOC stock in a forested area of southern Italy (Calabria) in relation to soil properties and landscape position. Twenty-eight soil profiles were sampled to cover all soil types and physiographic units of the study area and each horizon was sampled and characterized for its physical-chemical properties (bulk density, texture, pH, SOC, and nitrogen). Moreover, the organic horizon (O) was sampled and SOC concentration was determined. Then, the SOC stock for the organic layer and mineral horizons was calculated.

Soils developed in the study area belong to the Inceptisol and Entisol orders varying from shallow to moderately deep, with chemical and physical characteristics mainly controlled by granitic parent rock. SOC stock for the organic layer varied from 3 Mg ha^{-1} to 6 Mg ha^{-1} whereas for mineral horizons ranged between 20.2 Mg ha^{-1} and 310.9 Mg ha^{-1}.

The results showed a different behaviour of physical-chemical properties and carbon storage for coarse-textured soils and more fine-textured soils. In addition, soil types and topographic features such as slope gradient, slope curvature and landscape position controlled SOC stored in mineral horizons through changes in both in-depth variability of SOC concentration and profile thickness. In particular, higher SOC stocks were recorded in flat areas than on steep slopes, and Inceptisols developed on slopes with concave morphology exhibited higher values than Entisols located on convex slope.

1. Introduction

Forest ecosystems cover large parts of the land surface and play an important role in the terrestrial carbon (C) cycle (Lorenz and Lal, 2010). Particularly, forest ecosystems accumulate organic compounds in vegetation through photosynthesis, and return C to the atmosphere by auto- and heterotrophic respiration, and fix C into stable soil organic carbon (SOC) pools (Post and Kwon, 2000; IPCC, 2003; Pan et al., 2011).

Small variations in SOC can significantly affect the global C cycle, climate change, and soil properties (Lal, 2005; Powlson et al., 2011). There is a clear consensus that sustainable use of forest and soil resources is one of the ways to manage climate change and mitigate global warming. That requires a deeper understanding of the spatial distribution of C storage to support management policies of the forest ecosystems. Consequently, it is crucial quantifying and understanding the spatial variation of soil C stocks in forests, and identifying the environmental factors controlling its dynamics (Batjes, 1996; Six et al., 2002a).

In forest soils, the continuous addition of decaying plant residues to the soil surface and root growth and decay represent the main sources of SOC. The decomposition of the plant litter is one of the main processes of formation and evolution of forest soils showing organic and mineral horizons (O and A horizons) characterized by a high content of humic substances, representing the major components of the global carbon budget (Šnajdr et al., 2008).

Therefore, the amount of SOC is calculated by the net balance between the rate of above and below ground organic matter input and SOC mineralization (Gregorich and Janzen, 1996). Many studies on soil carbon storage have generally focused only on the organic horizons and on the first 20 cm of soil profile (e.g. Yanai et al., 2003; Taylor et al., 2007; Innangi et al., 2015), often neglecting the deeper mineral soil horizons (Diochon et al., 2009). In the last years, several studies have nevertheless highlighted the importance of subsoil in the total SOC storage (Wang et al., 2010), especially in forest ecosystems (e.g. Tarnocai et al., 2009; Rumpel and Kögel-Knabner, 2011; Marty et al., 2015;

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Kirsten et al., 2016). In addition, studying SOC distribution along soil profile is important since content and stability of SOC strongly varies among soil horizons due to changes in soil chemical and/or physical properties (Rumpel and Kögel-Knabner, 2011; Parras-Alcántara et al., 2015).

Several authors highlighted how the amount of SOC stored in soil is not only controlled by organic carbon concentration but also by physical, chemical, and biological soil properties (Six et al., 2002a), among which bulk density, stone content, and soil depth are the most important (Batjes, 1996; IPCC, 2003; Salomé et al., 2010). The variations of chemical-physical properties are greatly influenced by slope morphology and landscape position which affect soil depth, profile development, texture and structure in relation to erosional and depositional processes (Costantini, 1993; Telles et al., 2003; Costantini et al., 2013; Lucà et al., 2014).

At large scale, climate is one of the main factors explaining long term SOC variability due to its influence on forest growth and microbial activity and consequently on litter input and decomposition and loss of C (Bellamy et al., 2005; Lorenz and Lal, 2010; Fantappiè et al., 2011). Even though the rates of these opposing processes had been controversial, the role of temperature and moisture on SOC stock in forest soils, especially in the Mediterranean area, remains certain (Bellamy et al., 2005; Rodeghiero et al., 2011).

At local scale, SOC stocks can vary significantly due to the influence of anthropogenic factors such as land use or management practices (Tan et al., 2004; Lal, 2005; Mou et al., 2005; Von Lützow et al., 2006), as well as environmental factors like parent material, soil properties and topography (e.g. Callesen et al., 2003; García-Pausas et al., 2007; Bruun et al., 2015; Nadeu et al., 2015). In particular, topography has been identified as an important variable for explaining SOC stocks since it influences the distribution of organic matter and soil nutrient (Abrams et al., 1997), the rates of litter decomposition (Sariyildiz et al., 2005), the stability of SOC between landform positions (Chaplot and Poesen, 2012) as results of transport and selectivity of geomorphic processes (Nadeu et al., 2015).

In this context, the main objective of the study was to analyse soil carbon stocks at profile scale in a forest ecosystem of southern Italy (Calabria region) in relation to soil properties and landscape attributes. Furthermore, as factors controlling SOC dynamics may vary vertically along the profile, the variation of soil properties with depth was also analyzed. Given that parent material and tree cover do not vary across the study area, the work allowed to constrain the influence of changes in soil chemical-physical properties and topography even within a limited area.

2. Material and methods

2.1. Study area

The study area, large about 33.2 ha, is located within the Biogenetic Natural Reserve "Marchesale" (Calabria region, southern Italy), at 38° 30′ 7″ N to 38° 29′ 31″ N of latitude and 16° 14′ 10″ E to 16° 14′ 42″ E of longitude (Fig. 1a). The study area is covered by a beech forest (*Fagus sylvatica L.*) with sporadic silver fir trees. The elevations range from 1137 to 1212 m a.s.l., whereas slope gradients range between 0 to about 45°, with an average of 11.2°, and the prevalent slope exposures are west and north.

The area has a typical Mediterranean upland climate (*Csb*, sensu Köppen, 1936). Thermo-pluviometric data coming from the station of Mongiana (38°29′55″ N, 16°19′11″E, 921 m a.s.l.) showed an average annual precipitation equal to 1810 mm and an average annual air temperature of 10.7 °C. The average maximum air temperature (summer) is 28.3 °C, whereas the average minimum air temperature (winter) is −3.7 °C. The soil moisture regime is udic and the soil temperature regime is mesic (ARSSA, 2003).

The study area is located within the Serre Massif which represents the central sector of the Calabrian–Peloritan arc (Amodio Morelli et al., 1976), where Hercynian granitoid rocks, mainly represented by granodiorite, locally intruded by pegmatite dikes, crop out. These rocks in outcrop appear intensely fractured and characterized by chemical and/or physical weathering processes, which produced rock fragmentation into large blocks or microgranular disintegration.

The bedrock is locally mantled by thick regolith and/or colluvial deposits (Calcaterra et al., 1996; Conforti et al., 2013). In particular, colluvial deposits with variable thickness can be observed in concave areas and at the foot of the slopes (Fig. 1b).

The geomorphology of the area is characterized by a mountains landscape, generally, with V-shaped valleys, assuming a concave shape when partly filled by colluvial deposits (Fig. 1b). Summit paleosurfaces (Calcaterra and Parise, 2010; Lucà et al., 2011), representing the residual flat or gently-sloping highlands, often bordered by steep slopes and deep incisions also occur (Conforti et al., 2015). In some places, especially on the residual paleosurfaces where the regolith has been removed, subspherical corestones and boulders of unweathered or less weathered rock, have been exhumed and outcrop on the ground surface (e.g. Le Pera and Sorriso-Valvo, 2000; Scarciglia et al., 2005).

2.2. Field survey and soil sampling

Through the interpretation of topographic map at 1:5000 scale and field survey, a detailed geomorphological analysis was performed in order to map the landscape units of the study area. In particular, four landscape units were identified: summit paleosurface, steep slope, gentle slope, and valley floor (Fig. 1c). Moreover, some terrain attributes, such as slope gradient, aspect and curvature, were extracted by a digital elevation model (DEM) with a cell size of 5 m and used as support for landscape unit mapping and pedological survey.

Twenty eight pedons (9 soil profiles and 19 hand auger drilling, using 'Edelman auger') were chosen and described, during summer 2014, trying to cover all landscape units of the study area (Fig. 1c). All soil profiles were dug down to the parent material or Cr horizon, and a detailed field description based on standard international guidelines (FAO, 2006; Schoeneberger et al., 2012) was made. Soils have been collected by pedogenetic horizon instead of control section in order to consider soil natural properties, which would be not reflected by mixing sediments deriving from different horizons (Parras-Alcántara et al., 2015).

Both bulk and undisturbed (core) soil samples were collected in each mineral horizon for laboratory physical and chemical analyses. The Cr horizon was always sampled for a thickness of 20 cm to obtain comparable results in all pedons, also because the auger did not always allow to exceed this depth in the parent material. Undisturbed soil samples were extracted using a stainless steel cylinder of 100 cm^3 in volume, and bulk density (BD) was evaluated by dividing the dry weight of fine earth by the volume of the core, reduced considering the volume of stones if present. BD cores were sampled near the midpoint of each horizon in each profile and at each auger hole.

Moreover, for each soil profile, the entire organic horizon (O) was sampled neglecting sublayers within a frame of 20 cm × 20 cm and SOC and total nitrogen (N) contents were determined.

2.3. Physical and chemical analyses

The collected soil samples from the mineral (80 samples) and organic horizons (28 samples) were first dried for 48 h at 40 °C in a ventilated oven then were gently crushed using pestle and mortar removing the visible roots, and passed through a 2 mm sieve. Particle size distribution was determined by the hydrometer method (Bouyoucos, 1962; Patruno et al., 1997), based on dispersion and sedimentation principles, using sodium hexametaphosphate as a dispersant. The soil particle size distribution (sand, silt and clay)