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Controls on soil carbon storage from topography and vegetation in a rocky, semi-arid landscapes

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ABSTRACT

Soil properties can exhibit strong spatial variation, even at the small catchment scale. Especially soil carbon pools in semi-arid, mountainous areas are highly uncertain because bulk density and stoniness are very heterogeneous and rarely measured explicitly. The effect of topographic and vegetation variables, on stoniness, bulk density and soil carbon has been explored in a 2.7 km^2 watershed of Sierra Morena in south Spain. Soil core samples were collected from 67 locations at 6 depths up to 0,3 m. Stoniness and bulk density were measured with standard methods, total organic carbon through elemental analysis. These soil properties were then used to calculate carbon stock and related to solar insolation, elevation, slope, curvature, TWI, TPI, SPI and NDVI. Stone content depends on slope, indicating the importance of water erosion on long-term soil development. Spatial distribution of bulk density was found to be highly random. By means of conventional statistical methods, with the help of a random forest method, solar radiation and NDVI proved to be the key variable controlling soil carbon distribution. Total soil organic carbon stocks were 4.38 kg m^{-2} on average, with stocks about double as high on north versus south-facing slopes. These results confirm the importance of the coupled soil moisture and vegetation dynamics on the carbon balance in semi-arid ecosystems. However, validation of the random forest model showed that the different covariates only explained 18% of the variation in the dataset. Apparently, present-day landscape and vegetation properties are not sufficient to fully explain the full variability in the soil carbon stocks in this complex terrain under natural vegetation. This is attributed to a high spatial variability in bulk density and stoniness, key variables controlling carbon stocks. Future improvement of mechanistic soil formation models could help estimating these soil properties better.

1. Introduction

Within a catchment, topography exerts a first-order control over insolation, water and nutrient fluxes, and vegetation patterns, causing differences between south and north facing slopes (Ivanov et al. 2008, Yetemen et al. 2015a), although this is modulated by aridity as, for instance, reported by Mâren et al. (2015). Vegetation and soil moisture dynamics can be expected to control not only landscape shape but also belowground critical zone architecture and properties, especially soil organic carbon (SOC) stocks. Kunkel et al. (2011) showed how NDVI and potential insolation explained 62% of the variation in SOC stocks in the complex semi-arid Dry Creek Observatory, Idaho. However, in complex, rocky terrain, bulk density (BD) and stoniness (ST), soil properties that are often not explicitly measured, exert an important control over SOC stocks. Schrumpf et al. (2011) concluded that SOC stock errors are more dependent on BD and ST than carbon concentration (C) in rocky terrain. Throop et al. (2012) showed that different methods for taking into account the coarse fragment content can lead to differences of up to 26% in carbon stock. As this information is often difficult to measure, many studies assessing SOC stock variability use indirect methods to estimate the latter two variables, using a constant value for BD and ST values from published data (e.g. Kunkel et al. 2011) or pedotransfer functions (e.g. Bonfatti et al. 2016). While such indirect methods might be a reasonable approximation in simple, agricultural landscapes with low ST, this approach will potentially lead to large errors in complex, stony landscapes. Especially if we are interested in the variables controlling SOC stocks, it is critical to simultaneously assess the spatial variability in C, BD and ST. While C distribution has been linked to vegetation patterns and insolation, as mentioned before, controls over BD and ST are less clear. BD, but especially ST can be expected to vary in response to weathering, transport and biological processes. Geroy et al. (2011) showed how soils in the Dry Creek Observatory,

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Idaho are typically shallower on south compared to north-facing slopes and the latter can store more water from the wet winter. They also found important differences in SOC, ST, and BD, based on 35 surface samples. Anderson et al. (2013) showed how aspect-related differences in temperature modulate frost cracking and regolith production, leading to distinct weathering rates in the Boulder Creek Critical Zone Observatory, Colorado. Hillslope hydrology and chemical weathering rates are also clearly aspect-related (Anderson et al. 2014). Both global and local studies have shown how transport processes and landscape evolution interact with biological processes (Istanbulluoglu and Bras 2006; Yetemen et al. 2015a; Yetemen et al. 2015b).

It is clear that there are important interactions between soil properties, water dynamics, plant growth and carbon dynamics. Many of these interactions are not well quantified yet, especially over longer time scales. If we are to develop mechanistic models of soil formation and landscape evolution (Vanwalleghem et al. 2013; Temme and Vanwalleghem 2016), we need to better understand these interactions and the resulting patterns.

The objectives of this study were: 1) to identify the factors controlling the spatial distribution of carbon concentration, bulk density and stoniness; 2) to use these variables to predict carbon stocks.

2. Materials and methods

2.1. Study area

This study was done in the Santa Clotilde Critical Zone Observatory (SC-CZO), located in Southern Spain (Fig. 1A). The outline of the study area corresponds with an experimental farm operated by the University of Cordoba and covers 2.7 km^2. The study area is located within the Martin Gonzalo catchment in Sierra of Cardeña and Montoro Natural Park, placed in the Sierra Morena. This mountainous ridge separates the Spanish Central Plateau and the Betic Depression. The bedrock in this area consists of plutonic rock, microadamellita porphyritic and it is part of the Pedroches Batholith. The predominant soils are Regosols, Leptosols and Cambisols under the FAO-Unesco World Reference Base

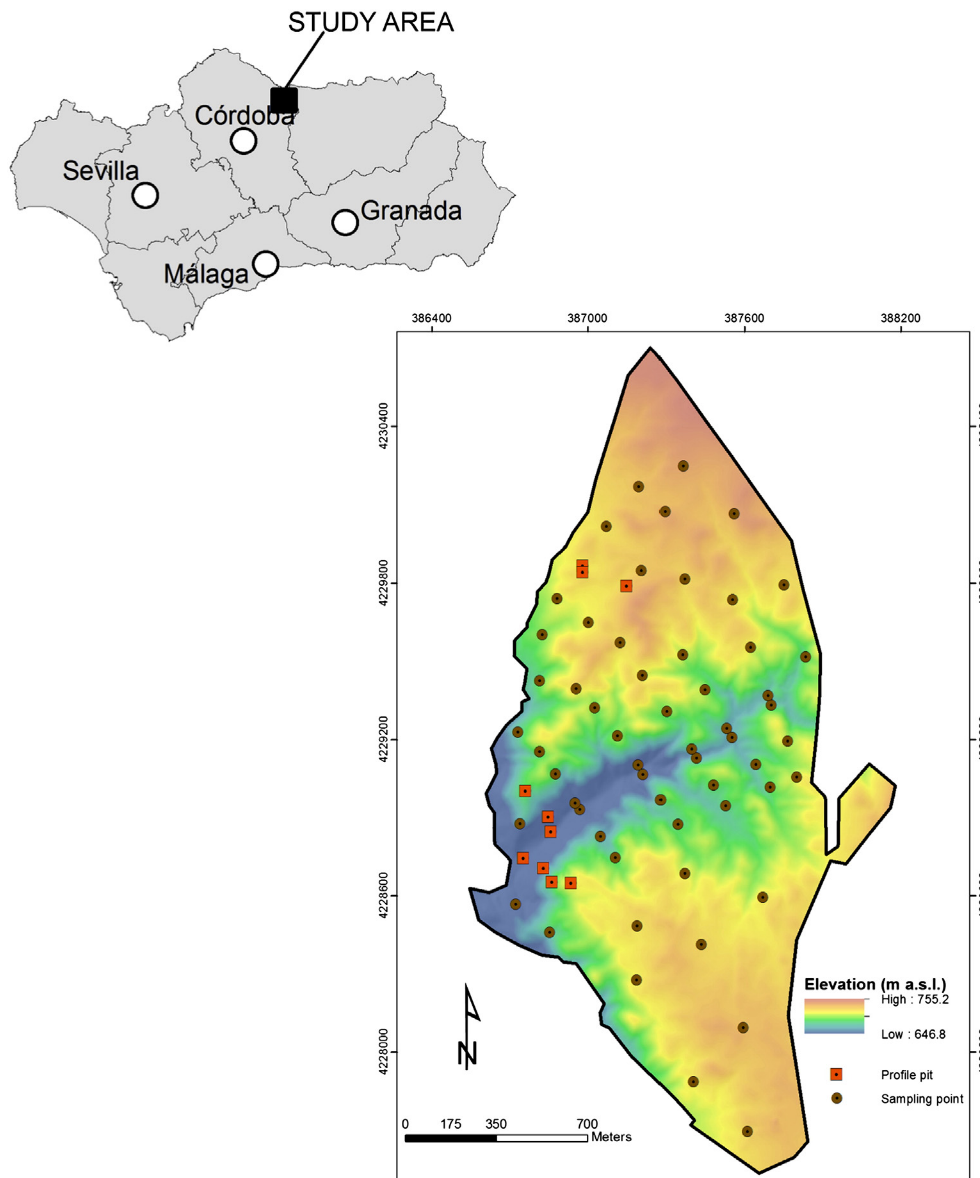

Fig. 1. Location (left), topography (right) of Santa Clotilde Critical Zone Observatory and sampling points within study area.

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