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Soil organic carbon distribution in Mediterranean areas under a climate change scenario via multiple linear regression analysis

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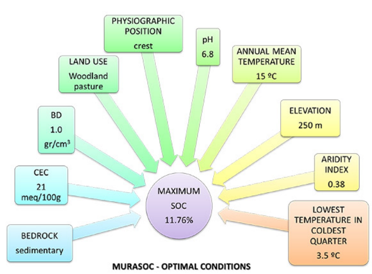
HIGHLIGHTS

- SOC content of topsoil was analyzed to determine the most influential variables.
- Topsoil was considered to analyze the SOC effects under a climate change scenario in Sierra Morena (Mediterranean area).
- Comparing the current and future situations the SOC content in the study area was reduced by 35.4%.
- The method limitations are principally the high spatial variability of the soils and the scale factor.

GRAPHICAL ABSTRACT



MURASOC Multiple Linear Regression Analysis		
BEST CONDITIONS MAXIMUM SOC CONTENT (11.7%)	VARIABLES	ADVERSE CONDITIONS MINIMUM SOC CONTENT (3%)
Sedimentary	BEDROCK	Limestone
21 meq/100g	CEC	6 meq/100g
1.0 gr/cm³	BD	1.5 gr/cm³
6.8	pH	7.4
Woodland pasture	LAND USE - CORINE	Broad-leaved forest
Crest	PHYSIOGRAPHIC POSITION	Valley
250 m.a.s.l.	ELEVATION	750 m
15 ºC	ANNUAL MEAN TEMPERATURE	17.5 ºC
0.38	ARIDITY INDEX	0.55
3.5 ºC	LOWEST TEMPERATURE IN COLDEST QUARTER	1 ºC

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ABSTRACT

Over time, the interest on soil studies has increased due to its role in carbon sequestration in terrestrial ecosystems, which could contribute to decreasing atmospheric CO_2 rates. In many studies, independent variables were related to soil organic carbon (SOC) alone, however, the contribution degree of each variable with the experimentally determined SOC content were not considered.

In this study, samples from 612 soil profiles were obtained in a natural protected (Red Natura 2000) of Sierra Morena (Mediterranean area, South Spain), considering only the topsoil 0–25 cm, for better comparison between results. 24 independent variables were used to define it relationship with SOC content. Subsequently, using a multiple linear regression analysis, the effects of these variables on the SOC correlation was considered. Finally, the best parameters determined with the regression analysis were used in a climatic change scenario. The model indicated that SOC in a future scenario of climate change depends on average temperature of coldest quarter (41.9%), average temperature of warmest quarter (34.5%), annual precipitation (22.2%) and annual average temperature (1.3%). When the current and future situations were compared, the SOC content in the study area was reduced a 35.4%, and a trend towards migration to higher latitude and altitude was observed.

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1. Introduction

According to IPCC (2013), the fossil fuel burning since 1750 until the present has resulted in the emission of 555 Pg C, nevertheless, only 43% (238.7 Pg C) of the emitted C has remained in the atmosphere. Indeed, data reveal that between the years 1750 and 2016 the atmospheric CO_2 concentration increased from 278 to 406.8 ppm respectively (NOAA-ESRL, 2016).

At global level, soils are the largest terrestrial C pool and sink for the atmospheric CO_2 with >71% of the terrestrial organic C pool (Lal, 2010). Furthermore, soil organic carbon (SOC) is one of the most important soil constituents due to its capacity to affect plant growth as energy source and as an essential source for plant nutrients through mineralization processes (Brevik, 2009). However, the SOC storage can be affected by climate conditions, land-use patterns, human activities and policies (Mao et al., 2015). But, one of the foremost characteristics of SOC is that in optimal conditions, soils can store C for thousands of years (Brevik and Homburg, 2004). It is important to highlight that SOC stocks (SOC-S) are influenced by climate conditions through the balance between total C released to the atmosphere in CO_2 and CH_4 forms and the total C amount returned to soils (Brevik, 2012). Recently, some authors have indicated that an increase in global temperature might enhance the release of CO_2 from soils, accelerating global warming (Köchy et al., 2015). Even a reduction of 10% in SOC would be equal to the anthropogenic CO_2 emissions of the last 30 years (Kirschbaum, 2000). Consequently, the potential effects of climate change and other variables such as soil types (Parras-Alcántara et al., 2014), soil properties (Lozano-García et al., 2016a), managements (Fernández-Romero et al., 2016) and land uses (Parras-Alcántara et al., 2013) are necessary to understand SOC dynamics (Christensen et al., 2011). This is a critical role, so that different soil types show different ranges for C sequestration (Parras-Alcántara et al., 2013 and Parras-Alcántara et al., 2015a; Fernández-Romero et al., 2014).

Over time, different simulation models have been developed to predict the SOC content evolution with respect to the future global warming scenarios, e.g. CENTURY (Parton et al., 1987), Roth C (Coleman and Jenkinson, 1999), WinEPIC (Gerik et al., 2006), and CarboSOIL (Muñoz-Rojas et al., 2013). And, in the last years, these models have been used to evaluate SOC and climate change issues in the Mediterranean region (Álvaro-Fuentes and Paustian, 2011; Farina et al., 2011; Francaviglia et al., 2012; Muñoz-Rojas et al., 2015 and Muñoz-Rojas et al., 2017; Lozano-García et al., 2017).

In this line, the distribution models quantify the probability of dependent variables occurrence based on predictor variables, such as e.g. climate or topographic layers, etc. (Estrada, 2008). The model reliability depends on the predictor variables, that is to say, the environmental variability in the area where the dependent variable is distributed (Soria-Auza et al., 2010). In this sense, Maxent (Phillips et al., 2006) is a modeling software used to predict variables distribution based on the maximum entropy theory. Starting from the idea that the maximum entropy theory is a unified theory that predicts many environmental patterns using different information ranges (Xiao et al., 2015). In this line, Maxent maximize differences in dependent-variables models allowing a comprehensive view of potential distributions (Phillips et al., 2006). Consequently, to apply this model to SOC distribution, is necessary to establish the SOC concentration and the SOC threshold that could affect to soil properties and soil quality, considering that these thresholds can depend on soil type, climatic conditions and land use. In this line authors such Loveland and Webb (2003) proposed a threshold of 2% below which soil quality can be largely decreased, Benito and Díaz-Fierros (1992) suggest in Atlantic grasslands soil threshold of 3% of SOC, and more recently, Spink et al. (2010) states that soil function would not be adversely affected when SOC is above 2%. However, some authors as Gao et al. (2012 and 2013) indicates that an excessive increment in soil C levels could cause damages to ecosystems because other key factor, such as nutrient and water supply, would convert into limiting factors. Therefore, we can use this value (2% of SOC) as the threshold for delimiting the modeling predictions, so that, a 2% of SOC is a critical value to soil function and environmental performance will be adversely affected, and therefore, below which soil is assumed to be in poor condition (Spink et al., 2010).

If current climate trends continue, the global average temperature will increase by 1 to 6 °C in 2100 compared to 1990, and the projected rainfall patterns show seasonal variation across Europe, with wetter winters for northern Europe and dryer summers for southern Europe (IPCC, 2007; Christensen et al., 2011). Accordingly, the response of SOC contents to climate change (changes in the temperatures and rainfall pattern at global scale) could affect to SOC distribution (Brevik et al., 2015). This could be critical in Mediterranean areas that are characterized by seasonal dryness and low SOC (IPCC, 2007; Jones et al., 2005). Therefore, early detection and prediction of these changes in a long term of SOC monitoring are crucial to the effective management of SOC-S to minimize the SOC loss and the reductions in soil fertility (Aguilera et al., 2013).

Consequently, the goals of this study are (i) to model the current SOC content for a geographic area (Sierra Morena - Spain) and (ii) to model SOC suitability-condition under a climate change scenario in protected areas of Sierra Morena – Spain (Mediterranean area).

2. Materials and methods

2.1. Description of the study area

This study was carried out in Sierra Morena (South Spain). It stretches for 450 km from east to west across the south of the Iberian Peninsula, covering an area of 424,000 ha (Fig. 1). This area includes natural protected areas of the Natura 2000 network and zones classified as Special Conservation Areas (SCA) for European Union (European and Spanish legal protection) (Fig. 2). The climate is temperate semi-arid with continental influence. The average annual temperature and precipitation are 16 °C and 600 mm respectively, with warm and dry summers and cold and moist winters. The moisture regime is dry Mediterranean. The parent materials are igneous and metamorphic of the Devonian period, forming underdeveloped soil, with high sand and clay contents due to the weathering of granite, gneiss and quartzite. The relief is smooth and characterized by an undulated topography with slopes ranging from 3 to 8%.

The main vegetal communities of Sierra Morena are non-deciduous forest (evergreen forest) and scrub associated with holm (*Quercus ilex*) and cork oaks (*Quercus suber*). Livestock raising and crops (cereals and olive grove) are important in the foothills (deeper soils) of Sierra Morena (Parras-Alcántara et al., 2014). Most of the study area is used as pasture (34%), coppice (22%) and holm oak forest (21%). Major soils found in the study area are; Acrisols (AC), Antrosols (AN), Arenosols (AR), Cambisols (CM), Fluvisols (FL), Leptosols (LP), Luvisols (LV), Phaeozems (PH) and Regosols (RG) according to IUSS Working Group (IUSS Working Group WRB, 2006) (Table 1). Additional information about the main characteristics of the soils (site, physiographic position, surrounding topography, land use and climate) in the study area can be found in Table 2.

2.2. Soil sampling and analytical methods

Samples from 612 soil profiles were selected in Sierra Morena (South Spain-Mediterranean area) under different land uses according to CORINE Land cover map (Coordination of Information on the Environment, promoted by the European Commission in 1985 for the assessment of environmental quality in Europe) and SIOSE Land cover map (Map of Land Uses and Vegetation Coverages of Andalusia - Land Occupation Information System of Spain at a scale of 1:25.000) classification (Table 2). At each soil sampling point, only the topsoil (0–25 cm) was considered for the study for better comparison of the physical and