Geoderma 264 (2016) 117–125

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Assessment of the soil organic carbon stock in Spain

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ARTICLE INFO

Article history:
Received 29 April 2015
Received in revised form 14 October 2015
Accepted 17 October 2015
Available online 24 October 2015

Keywords:
Soil organic carbon
Spanish land use
Spatial variability
Topsoil
Geostatistics

ABSTRACT

Soil organic carbon stock (SOCS) assessments at a national level are essential in the climate change mitigation role. Our study provides the first assessment of the SOC stored in entire Spanish surface soils obtained from one sampling protocol within a regular sampling framework in a short edaphic time. In this study, we analysed topsoil samples (0–30 cm) from 4401 locations. SOC, soil bulk density and stoniness were measured to estimate SOCS. The results showed that half the Spanish areas obtained a SOC value below 1%. There is inherently wide spatial variability in SOC contents in Spain with low SOC concentration levels located in southern areas. The lowest SOC levels were associated with agricultural soils. However, no statistically significant differences were found between forestlands and grasslands. The mean SOCS in the Spanish topsoil layer was 56.57 Mg C ha^{-1} and the total stored in topsoil was 2.8 Pg C. We were surprised to find that our estimates were 40% lower than those known to date for Spain. The results herein highlight the potential land use change for SOC sequestration in Spanish soils. Certain changes in agricultural practises (conservation tillage) or converting some unproductive croplands into grasslands or forestlands can increase carbon sequestration in soils.

1. Introduction

Human activities alter the carbon cycle by adding more CO_2 to the atmosphere and influencing the ability of natural sinks to remove CO_2 from the atmosphere. C accumulates in the atmosphere at a rate of 3.5 Pg C year^{-1} (Pg $= 10^{15}$ g). While phytocoenosis stores C at around 550 Pg, the OC stored in the first metre of soils in most terrestrial ecosystems is about 2–4-fold the quantity found in vegetation (1500 Pg C) (Houghton, 2007; Jobbágy and Jackson, 2000). The residence time of this SOC is also much longer than in biomass, which constitutes an excellent C sink. The SOC parameter is normally employed as an indicator of soil quality (Ruiz Sinoga et al., 2012) and can accumulate in soil for decades. SOC is generally low in most agroecosystems due to soil degradation processes such as erosion, salinisation, and nutrient loss/washings caused by agriculture (Batjes, 2014; Martin et al., 2014). Therefore, it is possible to state that agricultural soils can constitute an excellent C sink, particularly in Mediterranean agroecosystems where C levels are quite low (Rodríguez-Entrena et al., 2014). Based on today's climate change forecasts, Spanish farmlands can act as potential C sinks (Álvaro-Fuentes et al., 2011), although possibilities of soil sequestrating C are limited because it depends on soil management and environmental changes.

In Spain, several studies have reported SOC stocks on a local scale in agricultural (Albaladejo et al., 2013; Álvaro-Fuentes et al., 2008; Muñoz-Rojas et al., 2012), forest and grassland systems (Doblas-Miranda et al., 2013). Nationwide studies have been conducted by analysing the large number of different soil profiles found in the literature (Doblas-Miranda et al., 2013; Rodríguez-Murillo, 2001). However, several limitations exist: these records generally result from observations made with data obtained from various sources; the values obtained in samplings done in different years are mixed; and the data obtained from different approaches have led to wide variations. Some authors (Batjes, 2014; Bernoux et al., 2002; Goidts et al., 2009) have observed striking discrepancies, so it is necessary to obtain data from more homogeneous observations, and also from the sampling type, sampling period and method employed to do calculations (Mishra et al., 2009). In the present work, we assess SOC, bulk density (BD) and stoniness spatial variability as edaphic attributes in Spanish soils.

This paper presents an approach to estimate the carbon stock in Spain using soil quality data (4000 study plots from one sampling protocol in a short edaphic time) and a simple geostatistical technique for evaluation purposes. Our study provides the first assessment of the SOC stored on the entire Spanish surface based on a 10-year study.

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http://dx.doi.org/10.1016/j.geoderma.2015.10.010
0016-7061/

The objectives of this study were to: (1) quantify current SOC and SOCS in Spain; and (2) generate fine-resolution estimates of surface soil SOC stocks.

2. Material and Methods

2.1. Study area and soil sampling

Spain is the second largest country (0.5 mill km^{-2}) in the European Union (EU). Three main climatic zones can be separated in the Iberian Peninsula. The Mediterranean climate predominates in Spain, characterised by dry hot summers and mild moderate rainy winters, and shows local variations on a detailed scale. The oceanic climate is located in northern Spain, while a semiarid climate is located in southeast Spain, especially in the Murcia Region. Spain has wide geologic variability and geological materials are mainly calcareous. The Mediterranean region presents low fertility.

A basic sampling grid was designed in the European ICP-Forest programme (Montoya Moreno and López Arias, 1998). The initial regular 16 × 16 km square grid was projected over Spanish territory to select forest and grassland samples. This initial grid was subdivided to obtain other regular 8 × 8 km square grids in order to select samples in agricultural areas (Rodríguez Martín et al., 2009a,b). The sampling points on each land use type were located using orthophotos (1 m $pixel^{-1}$) and topographic maps on a scale of 1:25,000. Samples were defined as composite samples made up of 4–20 increments collected from the upper 20–30 cm of soil (Martín et al., 2009). Cylinders were also used to determine bulk density (BD). Soil samples (averaging 3 kg) were collected between 1995 and 2007 from 4401 georeferenced localisations (Fig. 1).

2.2. Analytical methods and soil organic carbon stock

Soil samples were air-dried and sieved to obtain two samples with rocky fragments of >6 mm, and another sample of between 6 mm and 2 mm to determine coarse fragments (% mineral particles >2 mm in diameter) (Rodríguez Martín et al., 2013). A fine soil sample (<2 mm) was used to determine organic carbon content (SOC). Organic carbon was analysed by oxidising carbon with acidic dichromate (Walkley, 1935). This procedure has been the “reference” method followed to make comparisons with other methods in numerous studies (Schumacher, 2002), and is widely used as it is simple and rapid with minimal equipment requirements (Nelson and Sommers, 1982). BD was measured by the core method according to (Black and Hartge, 1986).

Soil organic carbon stock (SOCS) was computed as the product of three variables, SOC, BD and stoniness, which were regionalised by a

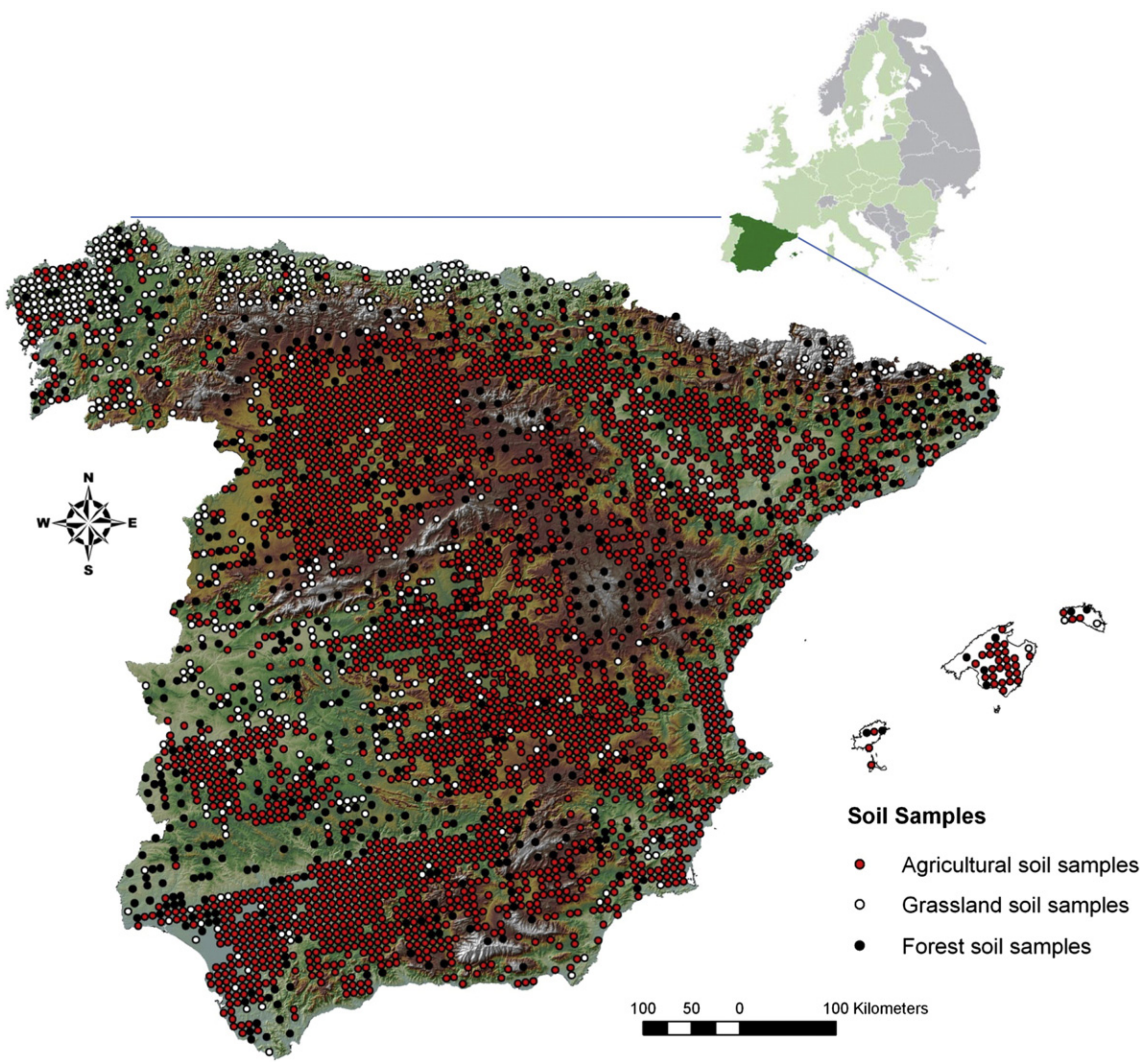

Fig. 1. Map of Spain showing the 4401 samples on a 8 × 8 km square grid in agricultural areas and 16 × 16 km in forests and grasslands.