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Soil carbon stocks and their variability across the woodlands of peninsular Spain

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Abstract

Global warming effects in our ecosystems could be offset by reducing carbon emissions and protecting and increasing carbon stocks. Accurate estimates of carbon stocks and fluxes of soil organic carbon (SOC) are thus needed to asses the impact of climate and land-use change on soil C uptake and soil C emissions to the atmosphere. Here, we present an assessment of SOC stocks in woodlands (forest, shrublands and grasslands) of peninsular Spain based on field measurements in more than 900 soil profiles. Estimations of soil C stocks for the 7 796 306 plots of the Spanish Forest Map (24.3×10^6 ha.) were carried out using a statistical model that included, as explanatory variables, vegetation cover, parent material, soil consistency, mean annual temperature, total annual precipitation and elevation, and the influence of spatial correlation. We present what we believe is the most reliable estimation of current SOC in woodlands of peninsular Spain thus far, based on the considered predictors, the high number of profiles and the validity and refinement of the data layers employed. Mean concentration of SOC was 8.8 $\mathrm{kg\,m^{-2}}$, which is slightly higher than that presented in previous studies. This value corresponds to a total stock of 2574 Tg SOC, which is four times the amount of carbon estimated to be stored in the biomass of Spanish forests. Climate and vegetation cover were the main variables influencing SOC, with important ecological implications for peninsular Spanish ecosystems in the face of global change. The fact that SOC was positively related to annual precipitation and negatively related to mean annual temperature suggests that future climate change may strongly reduce the potential of Spanish soils as carbon sinks. However, this may be mediated by changes in vegetation cover (e.g., by favouring the development of forests associated to higher SOC values) and threatened by perturbations such as fire. The estimations presented here should improve our capacity to respond to global change by carbon stocks conservation and management.

1 Introduction

It is widely accepted that the effects of global warming could be offset by the reduction of carbon emissions and the protection and increase of carbon stocks worldwide (Solomon et al., 2007). Therefore, concerned nations need to assess their stocks and fluxes of carbon, including soil organic carbon (SOC) estimates (Bell and Worrall, 2009). The amount of C in the world's soils represents a large reservoir of about 1500–1600 Pg C (Batjes, 1996; Eswaran et al., 1993). Soils play a crucial role in the global carbon cycle by storing 300 times the annual amount of released carbon from fossil fuel burning (Schulze and Freibauer, 2005). However, this storage capacity is dynamic and depends on land-use changes, land management and environmental changes (Schlesinger, 1995). Studies with accurate assessments of SOC stocks at the country level are critical. These SOC stocks are the necessary baseline for research on the impact of land-use change and climate change on SOC stocks dynamics, and therefore on soil C behaviour and soil C emissions to the atmosphere (Adger and Brown, 1994; Chaplot et al., 2009).

Estimations and studies about SOC at regional and national scales are still scarce and methodologies vary among them (Martin et al., 2011). SOC stocks have been estimated assigning mean SOC values to soil types or land covers and applying them to large scales (e.g. Spain, Rodríguez-Murillo, 2001; Chiti et al., 2012; New Zealand, Coomes et al., 2002; China, Zhou et al., 2003). However, such assessments do not consider the large coefficients of variation in % SOC within a soil or cover type (Liebens and VanMolle, 2003; Davis et al., 2004). Certain studies thus claim that soil series or land-use mean values are not sufficient to correctly assess SOC, and factors such as climate, topography or land management practices should be also considered in the estimations (Krishnan et al., 2007; Bell and Worrall, 2009; Zhang et al., 2011). Spatial modelling approaches can improve SOC stocks estimations, taking into account these factors by projecting statistical associations with real measurements of SOC to the non-sampled territory. Such approaches should provide a continuous and accurate grid map for the whole study area (Razakamanarivo et al., 2011; Zhang et al., 2011; Wiesmeier et al., 2011).

Several variables controlling the spatial distribution of SOC have been identified, including soil type, soil texture, geological substrate, rainfall, temperature, moisture, land cover, historical land use, altitude, slope and management practices (Powers and Schlesinger, 2002; Mueller and Pierce, 2003; Krishnan et al., 2007; Schulp and Veldkamp, 2008; Zhang et al., 2011). From broad Mediterranean estimations to more local studies of Spanish soils, climate and land use are considered the most important factors (Rodríguez-Murillo, 2001; Hontoria et al., 2005; Baritz et al., 2010; Rodeghiero et al., 2011).

The Iberian Peninsula presents a characteristic spatial and temporal variability based upon a diverse geography and a variety of Atlantic and Mediterranean climates. This heterogeneous landscape offers a natural laboratory to understand the factors affecting SOC while assessing overall country stocks. Here we use field measures of more than 900 soil profiles on woodlands of peninsular Spain to build a statistical model of SOC stocks, taking into consideration vegetation cover, climate, soil characteristics and elevation as explanatory variables. The main objectives of the study are (a) to obtain an accurate assessment of SOC stocks of woodlands in Spain and compare these results with previous national and regional estimations and (b) to asses the effects of the main controlling factors of the spatial distribution of SOC, and relate them to the effects of predicted climate and land-use changes in the Iberian Peninsula.

2 Materials and methods

2.1 Study site

The study area comprises peninsular Spain (excluding the Canary and Balearic islands) woodlands (including forests, shrublands and pastures), for a total surface of 24.3 million ha. Croplands were not included in the analyses because their SOC responds to different variables compared to woodlands (Romanyà et al., 2007). The Mediterranean climatic domain, characterized by mild winters and hot and dry summers, covers almost all peninsular Spain except the northwest, represented by the wet and cold temperate-oceanic climatic domain (Capel Molina, 2000). Most soils in the area are typically Mediterranean Cambisols, occurring in the eastern half and on the south and north coasts of Spain. Leptosols appear in most mountainous systems, and Regosols are also present in wide areas of the western half of the country. Finally, Luvisols, in the northern part of the Inner Plateau, and Calcisols, in the Ebro and Segura valleys, are also well represented (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012). According to the Spanish Forest Map (Área de Banco de Datos de la Naturaleza, 2011), the seven most abundant tree species are *Quercus ilex*, *Pinus halepensis*, *P. pinaster*, *P. sylvestris*, *P. nigra*, *Q. pyrenaica* and *Fagus sylvatica*.

2.2 Soil profiles

Information was compiled from the literature (Supplement). Literature search was conducted through a systematic reviewing of soil science Spanish journals (particularly "Anales de Edafología y Agrobiología", but also journals published by the CSIC, the Spanish Council for Scientific Research), Ph.D. theses, reports of the reunions of the Spanish Society of Soil Science, and other similar publications. The initial dataset included nearly 2000 profiles established in non-crop areas of Spain from 1975 to 2007. It should be noted that the objectives of these different surveys and studies were diverse and the location of the soil profiles may not necessarily be representative of the larger region. SOC was estimated in $\text{kg}\,\text{m}^{-2}$ to a maximum depth of 1 m (considering that approximately 75 % of the total SOC stock occurs in the first m depth; Olsson, 2002).

The total amount of C of the i horizon (C_i, in $\text{g}\,\text{m}^{-2}$) is given by

$$\text{C}_i = D_\text{b} \cdot \frac{\text{C}}{100} \cdot 10\,000 \cdot T \cdot \frac{100 - V}{100} \tag{1}$$

where D_b is the bulk density ($\mathrm{g\,cm^{-3}}$), C the concentration of organic carbon (in %), T the thickness of the horizon (in cm) and V the percent of the total volume occupied by stones and gravel.

From the total C in the horizons, the total C in the profile, down to 1 m, is calculated:

$$\mathrm{C} = \left(\sum_{i=1}^{n} \mathrm{C}_i\right) + \mathrm{C}_{n+1}\frac{100 - \mathrm{uL}_{n+1}}{T_{n+1}} \tag{2}$$

where C_i is the total amount of C in the horizons (from 1 to n) whose lower limit is not deeper than 100 cm, C_{n+1} is the total amount of C in the first horizon (if described) whose lower limit is deeper than 100 cm, T_{n+1} the total thickness of this horizon, and uL_{n+1} its upper limit. This last horizon $(n+1)$ is included in the calculation only if its upper limit is < 100 cm deep; it is not included if its upper limit is exactly 100 cm, or deeper.

When the limits of the profile are not indicated, the upper limit of the first horizon having an OC content < 20 % was taken as the zero depth of the profile while we give the last horizon a standard thickness of 20 cm. When the deepest horizons were non-analyzed, %C was estimated by curve-fitting techniques, mostly standard exponential curves (either single or double) and polynomial curves in some cases. From the profiles where experimental numeric data about bulk density was available, we derived empirical relationships to estimate bulk density from total OC in the horizon and (when available) clay content and applied them to the profiles for which bulk density was unknown.

Stoniness was obtained from the following equation (Cabidoche, 1979)

$$V = \frac{R}{D_R}\frac{100}{\frac{R}{D_R} + \frac{100-R}{D_\mathrm{b}}} \tag{3}$$

where R is the weight of coarse materials (gravel and stones), as % of total weight of the horizon, D_R their density (which depended on the kind of parent material), and D_b

the bulk density of the horizon. When the authors give a visual estimation of stones and gravel abundance, it was translated directly to a scale ranging from 0 to 75 % of volume occupied by stones. When no information about the abundance of blocks, stones or gravel was found, we applied the mean V value obtained for profiles over the same type of parent material from which stoniness was available.

Litter layers were not measured in most profiles and therefore were not included in the analyses. It should be noted, however, that this layer comprises a small percent of the total SOC amount (for example, only 2.6 % of total SOC for an assessment of Mediterranean soils; Rodeghiero et al., 2011).

Every profile also contained information about land use, parental material, soil texture and consistency, elevation and slope described in field work (this Supplement has been used as explanatory variables) and one minute geographical coordinates. The geographical scale implies that for a same geographical minute grid it can exist distinct profiles with distinct SOC and distinct explanatory variables. It can cause a large discrepancy and reduces significantly the robustness of the model. For this reason we have filtered the total number of profiles, using only one representative profile for every one minute coordinate (while different subsamples changing the elected profile per coordinate where used to modelling in order to assure no bias was produced by the election). After a more scrupulous analysis of the suitability of the samples, only 942 georeferenced profiles were finally used in the analyses (Fig. 1).

Selected profiles were crossed with layers of environmental variables. The choice of the following explanatory variables is based on the most acknowledged factors from the literature cited in the introduction contributing to the SOC stocks, its availability for every profile, and the accessibility of cartographic information for mapping procedures:

vegetation cover. Indications of each profile were classified based on the Corine Land Cover Map (Table 1) in order to facilitate the later extrapolation over the Spanish Forest Map 1 : 50 000 (MFE50) of the period 1997–2006 (Área de Banco de Datos de la Naturaleza, 2011), which also include the different covers showed in Table 1.

Soil characteristics. Based on geological expert criteria, every soil description, geological class and topoclimatic region were reclassified into three layers of geological information: parent material, texture and consistency (Table 1), in order to facilitate the later extrapolation over the Geological Spanish Map 1 : 1 000 000 (Instituto Tecnológico Geominero de España, 1994).

Elevation and slope. Both variables were extrapolated over the Digital Terrain Model of the period 2004–2008, with a spatial resolution of 25 m × 25 m (Instituto Geográfico Nacional, 2010).

Mean annual temperature and total annual precipitation. For each profile coordinate, both variables were assigned and extrapolated using the Digital Climatic Atlas of the Iberian Peninsula, 200 m × 200 m spatial resolution (Ninyerola et al., 2005).

2.3 Statistical analyses

Generalized Linear Models (GLMs) were used to predict SOC stocks to 1 m depth. Starting from the saturated model including all variables considered (vegetation cover, parent material, soil texture and consistency, mean annual temperature, total annual precipitation, number of dry months, elevation and slope), the least significant term was removed step-wise until no further reduction in AIC was observed. Geographic coordinates were also included as explanatory variables in the model to account for the effects of spatial autocorrelation. Latitude and longitude were used to model the correlation structure of the errors of the model by using generalized least squares (function gls in library nlme, *R* package). We used a random subsample of 70 % of the soil profiles to fit the model, while the remaining 30 % was used for model validation. The mean R^2 presented here corresponds to the average from 1000 repetitions of the previous process, each time using different random subsamples for model fitting and validation. All statistical analyses were conducted using *R* (2.14).

2.4 Mapping the model output

Extrapolation for the 7 796 306 plots of the Spanish Forest Map was performed using Miramon (v.7.On). A joint resolution of 0.0018° was defined according to the characteristics of each original map in order to avoid loss of information and accuracy. The categorical variables were replaced by dummy variables with the values of either 1 or 0, showing the presence or absence of each category. Finally, the maps of the selected variables in the best model are multiplied to the corresponding regression coefficients to obtain the best modelled SOC stock map. Fore each of the continuous variables, covered ranges (by the profiles) and total ranges (of the total extrapolated map) are indicated in Table 1.

3 Results

3.1 SOC model selection and validation

SOC stocks in the region were strongly related to vegetation cover and soil characteristics but also to climate and elevation (Table 2). The average R^2 for the validation sets was 0.669. The AIC of this model (−787) was clearly lower than the AIC of the same model including spatial coordinates as variables (−859), demonstrating that the spatial autocorrelation of the residuals was unimportant in this case.

The most influential variables were total annual precipitation and mean annual temperature, with a positive and negative effect on the total amount of SOC, respectively (Table 2). Vegetation cover was also important, showing large differences among all categories considered. Mixed broadleaf forests and evergreen woodlands showed the lowest SOC values, whereas the highest values corresponded to deciduous broadleaf forests, mixed forests and grasslands (Table 2). Finally, other significant but less influential variables were elevation (SOC content increasing with altitude), parent material (higher SOC on limestone than on silica) and soil consistency (SOC progressively decreased from firm to loose).

3.2 Amount and distribution of SOC stocks

Predicted SOC stocks in Spain to 1 m depth showed a total of 2574 Tg and a mean value of 8.8 kg m^{-2} ±2.6 S.D., ranging from 2.3 to 23.3 kg m^{-2} (Fig. 2). Larger stocks were located in the north and northwest parts of peninsular Spain, related to mountainous areas and high precipitation rates. Large amounts of SOC were also located in the middle Central and Iberian mountain systems and the southern Betic mountain system. Lower stocks corresponded to Mediterranean Spain (Fig. 3).

4 Discussion

4.1 Amount and distribution of SOC stocks

We believe this estimation of SOC in woodlands of peninsular Spain to be the first based on the quantitative modelling of the main variables affecting soil carbon stocks, including vegetation cover, soil characteristics and climate. The mean value obtained, 8.8 kg of SOC m^{-2}, is lower than the mean value for Spain calculated from the IGBP-DIS database, 23.5 kg m^{-2} (Zinke et al., 1998). However, the very different means obtained from other Mediterranean countries (for example, 12.9 for Italy or 6.21 kg m^{-2} for Greece) and the scarce number of profiles representing the Spanish territory (15) only confirm the need of reassessing soil C on the global level, as current datasets might not be reliable. The SOC values reported here are within the range presented in the baseline map of Europe, 1.3–12.6 kg m^{-2} for the first 20–30 cm of forests' mineral soil (Baritz et al., 2010), while the overall mean is higher than the SOC mean obtained for all the Mediterranean Basin, 5.9 kg m^{-2} (Rodeghiero et al., 2011). It should be noted, however, that the latter value corresponds only to the uppermost 30 cm of mineral soil. The total amount of 2574 Tg SOC estimated in this study represents 3.3 % of the total

SOC of Europe's forests (Jones et al., 2005) and approximately 0.2 % of the total SOC of the world's soils (Batjes, 1996). This quantity, however, is within the range of the annual loss of organic carbon from the world's soils (Buringh, 1984). Moreover, it represents four times the C stocks of the Spanish' forest biomass, estimated at 621 Tg C (Vayreda et al., 2012a).

Although we believe that the SOC estimations presented here are accurate and reliable, as implied by the relatively high R^2 obtained in the model validation exercise, the following caveats should be made. First, the soil profiles used in the study come from a number of sources and were established for different purposes using distinct methodologies. A specific survey conducted using a common experimental design and methodology would likely improve SOC estimates by reducing unwanted variability among samples. Improving the accuracy and spatial resolution of underlying data layers, particularly the parent material map, would certainly result in greater confidence in the distribution of the stocks and its estimates at the local level. Finally, stocks are dynamic and are known to be influenced by land-use history (Bell and Worrall, 2009). Although including temporal and historical factors pose a challenge to studies at large spatial scales, these factors clearly contribute to the variance in SOC stocks that could not be explained by our model.

There have been two previous attempts to estimate SOC stocks for the whole Iberian Peninsula conducted by Rodríguez-Murillo (2001) and Chiti et al. (2012). However, these two studies used different methodologies. On the one hand, Rodríguez-Murillo (2001) based his approximation on polygons of 10 km^2. He assigned to each polygon the mean SOC of the profiles included in the polygon or the average SOC of the corresponding land use when no profiles were present in the polygon. On the other hand, Chiti et al. (2012) assigned the mean SOC of the profiles included in a forest type-bioclimatic belt. The average SOC stock value obtained by Rodríguez-Murillo (2001) is similar to our estimates: 9.4 kg C m^{-2} in their case (excluding croplands) compared to our value of 8.9 kg C m^{-2}. However, the spatial distribution of the stocks shows striking differences leading to substantial differences at the local scale (for example, SOC stocks proposed by Rodríguez-Murillo in southern mountain systems such as Sierra Nevada are much lower than ours). Although Chiti et al. (2012) do not perform a mapping, the mean SOC value obtained by them, 6.9 kg C m^{-2}, was lower than ours, which could be explained by the absence of grasslands in their calculations. Several reasons support the preferential use of the SOC estimates presented here. First, the extrapolation of data was based on a statistical model that considers several predictors, including discrete and continuous variables, as recommended by numerous studies (Krishnan et al., 2007; Bell and Worrall, 2009; Zhang et al., 2011). Secondly, the spatial data layers of vegetation cover and climatic variables used in the present study are more recent and accurate.

There are also some SOC estimates for smaller areas within Spain, which are generally consistent with – albeit somewhat lower than – the estimates presented here (Fig. 3). For instance, an average of 3.5 kg m^{-2} (to 50 cm depth) was found in the Guadix-Baza Basin, an arid Mediterranean area (Díaz-Hernández et al., 2003); whereas differences in soil depth could explain the lower 6.4 kg m^{-2} (to 30 cm depth) found in an oak stand in NW Spain (Balboa-Murias et al., 2006). In concordance with other studies on SOC distribution (Romanyà et al., 2007), our results showed that lowland Mediterranean soils contain lower quantities of SOC than Atlantic and mountain soils. Forest deforestation would thus result in greater soil C losses in wet continental and mountain areas than in semiarid and lowland Mediterranean areas (Romanyà et al., 2007), particularly considering that the distribution of SOC stocks mimics the spatial patterns of forest biomass in peninsular Spain (Vayreda et al., 2012a).

4.2 Factors affecting SOC stocks and expectations for the future

The main variables influencing the spatial distribution of SOC were climate and vegetation cover, in concordance with similar studies in the region (Rodríguez-Murillo, 2001; Chiti et al., 2012). However, this result contrasts with the patterns observed for forest biomass stocks, which were mainly determined by forest structural diversity, with a much lower direct effect of climate (Vayreda et al., 2012a). The influence of climate on soil carbon stocks could be related to the role of soil microorganisms in SOC stability, as the soil microflora is highly sensitive to moisture (Coûteaux et al., 1991). Therefore, climate change may play an important role in the degradation of forest soils (Bellamy et al., 2005) and special attention should be paid to carbon stocks in Mediterranean soils (Rodeghiero et al., 2011). The Mediterranean Basin is one of the most prominent worldwide hotspots of climate change (Giorgi, 2006). Most climate models forecast substantial increases in temperature and declines in precipitation (Gao and Giorgi, 2008; Hoerling et al., 2011), which are exactly the most negative expected effects on SOC storage according to our model. In addition, other indirect effect of climate change could affect SOC reserves. First, recent warming includes the reduction of tree-growth rate and associated carbon accumulation (Vayreda et al., 2012b). Second, the general rise in fire risk in the region due to current warming (Moriondo et al., 2006) could aggravate the consequences of climate change on SOC of Mediterranean ecosystems (Rodeghiero et al., 2011). Mountain regions are also supposed to be highly affected by climate change, although the mechanisms and consequences are still less understood (Sjögersten et al., 2011). The observed increase in SOC due to elevation could be related to unfavourable conditions for decomposition (Baritz et al., 2010), which may change with predicted climate conditions. However, future upwards shifts in plant species distribution (Lenoir, 2008) could also change organic inputs and therefore modify SOC in organic layers.

Although climate is unmanageable, vegetation cover also showed an important role affecting soil carbon reserves. Future land use changes in Spain are difficult to predict due to socio-economic constraints (e.g., although urban intensification is predicted to increase in lowlands, an economic crisis could halt this pattern), but recent patterns reveal likely tendencies in terms of vegetation structure, composition and dynamics. Principally, coastal landscapes are suffering increasing anthropogenic impact (Alados et al., 2004) while afforestation of low productive uplands has occurred in the last century due to rural exodus (Hill et al., 2008). Although these novel forests may be essential for the restoration of associated SOC sinks, their relatively unknown structural and functional attributes could be heavily influenced by current impacts under climate change and future fire regimes (Pausas and Fernández-Muñoz, 2012). Management of the type of vegetation cover of such novel forests could thus be a key factor in altering the effects of current global changes, favouring future carbon storage capabilities (Vayreda et al., 2012a). Differences among the types of forest cover, showing the highest SOC mean under broadleaf forests and high and low SOC values for conifers and evergreen forests, respectively, were similar to previous calculations (Chiti et al., 2012). In concordance, promoting the development of mixed forests associated to higher SOC values in more arid areas could be used to maintain SOC stocks under future climatic conditions.

SOC estimations of natural landscape soils of peninsular Spain presented here should help to improve our ability to respond to global changes efficiently by maintaining and increasing carbon reservoirs through land-use management.

Supplementary material related to this article is available online at: http://www.biogeosciences-discuss.net/10/10913/2013/ bgd-10-10913-2013-supplement.pdf.

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Table 1. Variables used in the model. For both categorical variables, vegetation cover (classified following the Corine Land Cover Map) and soil characteristics (based on geologic expert criteria), number of profiles, mean SOC values and the standard deviation of the mean are indicated. For each of the continuous variables, profile ranges, total map ranges and % of the total range covered by the profiles are indicated.

Variables					
Categorical			*N* of profiles	Mean SOC	SD
Vegetation cover					
Forest	Broadleaf	Evergreen	80	6.54	1.46
		Deciduous	131	11.20	1.88
		Mixed	12	4.26	0.00
	Conifers		215	9.46	2.13
	Mixed		85	9.16	1.03
Shrubland			258	9.37	4.37
Grassland			162	11.22	3.49
Soil characteristics					
Parent material	Limestone		380	8.39	2.41
	Silica		562	10.50	3.59
Texture	Sandy		453	10.46	3.49
	Loam		374	9.05	3.01
	Clay		115	8.29	2.82
Consistency	Firm		596	10.12	3.31
	Friable		161	9.71	3.38
	Loose		185	8.05	2.85
Continuous	Profile range	Total range			Covered %
Mean annual temperature	9.0–18.7 °C	−0.2–19.5 °C			49.7 %
Total annual precipitation	198–2264 mm	0–3182 mm			64.9 %
Elevation	0–3150 m	0–3415 m			92.2 %

Table 2. Coefficients of the linear model used to test the effects of parent material, soil consistency, vegetation cover, elevation, precipitation and temperature on SOC content (3rd root transformed). Intercept refers to the predicted value of the response variable when the different explanatory factors are set to their reference level. Bold values indicate that the correlation coefficient differs significantly from zero ($^a p < 0.05$, $^b p < 0.01$, and $^c p < 0.001$).

			Coefficient	Std.Error	*t* value
Intercept (Limestone, Firm, Evergreen)			2.1132	0.0541	**39.06**^{c}
As factor:	Parent	Silica	−0.0255	0.0114	**−2.23**^{a}
	Consistency	Friable	0.0128	0.0123	1.04
		Loose	−0.0244	0.0124	**−1.97**^{a}
	Vegetation cover	Deciduous	0.1613	0.0205	**7.85**^{c}
		Mixed broadl	−0.2753	0.0495	**−5.56**^{c}
		Conifers	0.1475	0.0186	**7.92**^{c}
		Mixed	0.1610	0.0219	**7.34**^{c}
		Shrubland	0.1395	0.0181	**7.71**^{c}
		Grassland	0.1459	0.0201	**7.26**^{c}
Elevation			0.0001	0.0000	**3.37**^{c}
Precipitation			0.0000	0.0000	**16.16**^{c}
Temperature			−0.0032	0.0003	**−11.53**^{c}

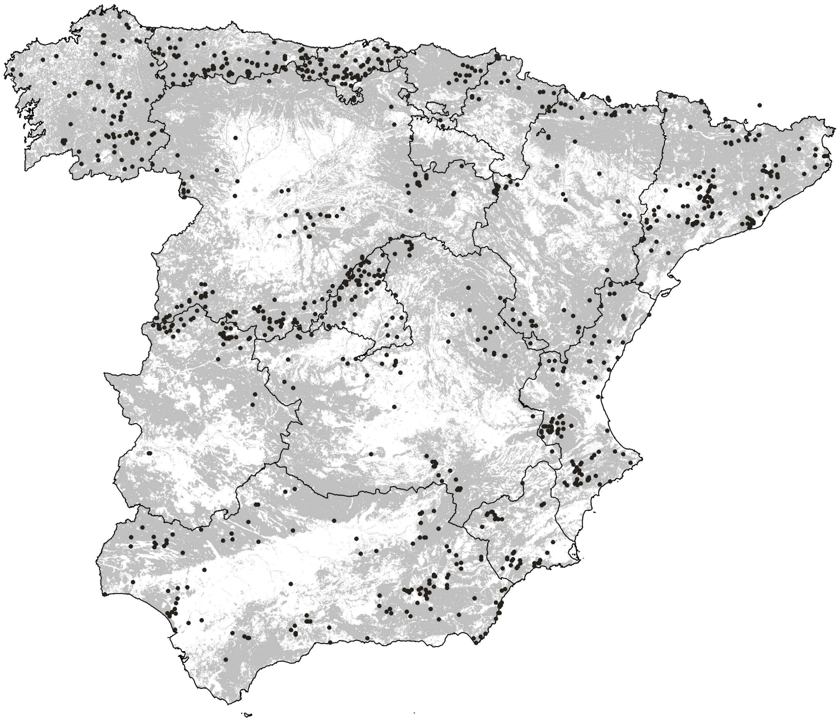

Fig. 1. Location of the 942 profiles established in non crop areas (grey colour) of peninsular Spain and used in the present study.

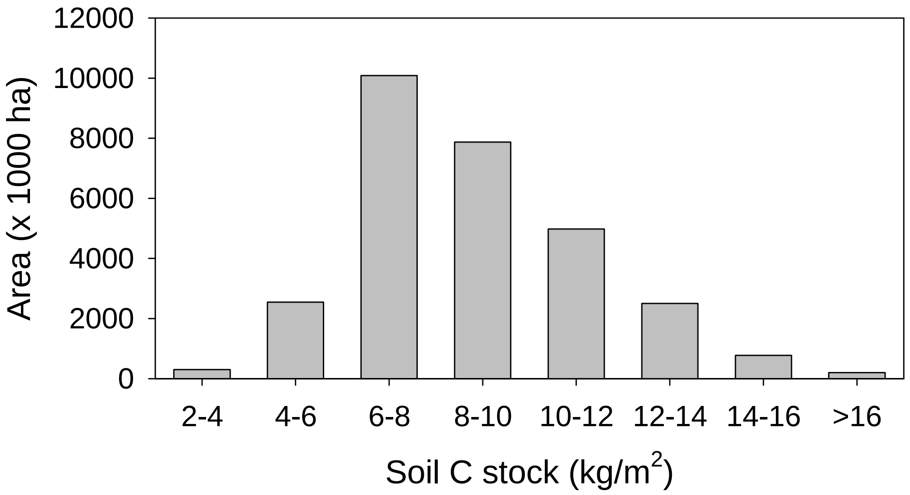

Fig. 2. Distribution histogram of SOC stocks for covered area.

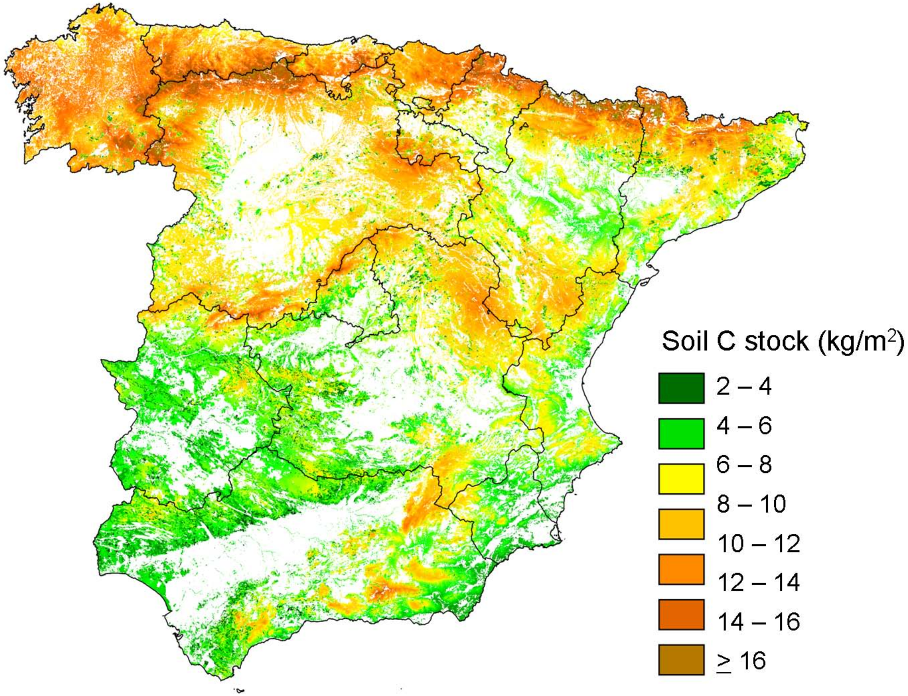

Fig. 3. Map of SOC stocks in natural non crop areas (forests, shrublands and pastures) of peninsular Spain.

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