Impact of land use changes and management in soil organic carbon stocks in Andalusia (S Spain)

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Background and objectives

Soils are the largest carbon sinks in terrestrial ecosystems and contain approximately twice the amount of C in the atmosphere and about three times the amount in vegetation. Several experiments on land use change (LUC) have highlighted significant changes in soil organic carbon (SOC). Furthermore, many studies have reported that a substantial amount of carbon can be sequestered through land use changes which might be a critical strategy for reducing atmospheric CO_2 concentrations and contribute to climate change mitigation. In this context, the UNFCCC/Kyoto Protocol recognizes SOC sequestration as a viable mechanism to mitigate CO_2 emissions.

Moreover, carbon sequestration is a natural cost-effective process and has a positive impact on environmental or agricultural qualities and biodiversity. Additionally, modification of land management such as introduction of agricultural practices is a recognized method of carbon sequestration as soil can act as an effective carbon sink offsetting as much as 20% of carbon dioxide emissions annually. Recent studies have estimated SOC stocks at small scale by using national and global soil maps and therefore there are few studies providing regional SOC estimates based on an elevated number of soil profiles. Southern Spain has gone through substantial LUCs with possible consequences for SOC sequestration. This research explores and quantifies the role of soil, land use and land use change as a determinant of the ability of soils to store carbon at a regional scale, where this type of approach is scarcely represented. The Andalusian region was selected as a pilot area, and the impact of land use changes between 1956 and 2007 on SOC stocks was quantified for each land use type. This research is part of a global project for developing a land evaluation tool for assessment of soil capacity for carbon sequestration, as a new component of the MicroLEIS Decision Support System (De la Rosa, et al., 2009). The information generated in this study will be a useful basis for designing sustainable land use and management strategies across Europe.

Methods

Land use change

The land use classification for this study is based on digital spatial databases derived from the Land Cover (LC) maps of 1956 and 2007 (1:25000, minimum map unit 0.5 ha). Land cover classes were reclassified into standard nomenclatures (CORINE Land Cover, CLC) in order to be used through Europe. The methodology applied for the analysis of LU changes consists of generalisation of land cover flow (LCF) at the second data level of CLC. The derivation of the LCFs has been carried out using conversion tables which cluster similar LU/LC changes. In this study, LU/LC changes between 1956 and 2007 have been assessed by comparison of the overlapped LU/LC spatial data layers from 1956 and 2007.

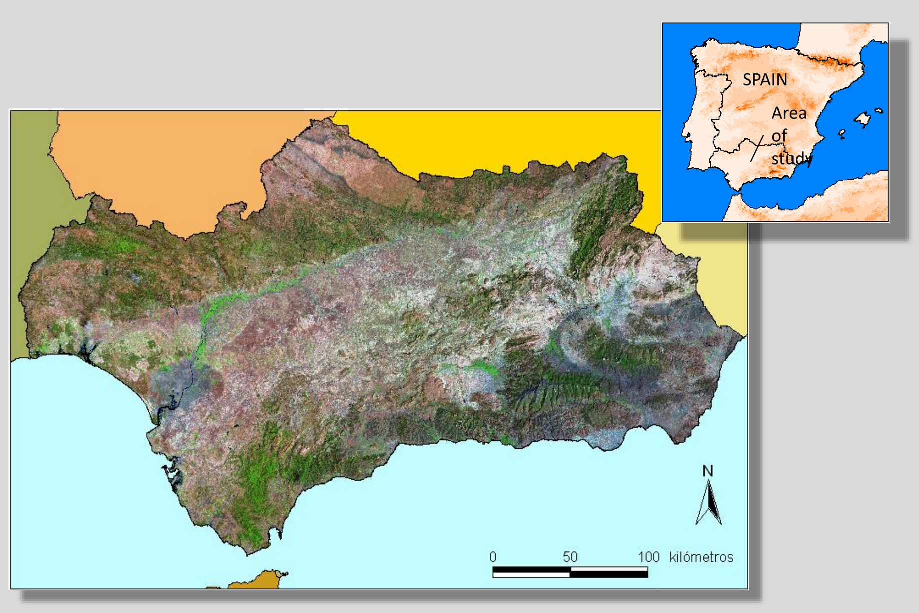

Figure 1, Study area.

Soil data

Data from 1736 geo-referenced soil profiles from the SDBm Plus soil database (De la Rosa et al., 2002) and other databases have been used in this research. Soil profile data were re-coded and imported using Paradox format into the SDBm Plus database. Variables used for this study were soil depth (cm), organic carbon content (g 100 g^{-1} soil), sand (%), silt (%) and clay content (%) and bulk density (g cm^{-3}). Soil profiles showed a range of depths, so data were homogenised and re-sampled for 0-25, 25-50 and 50-75 cm. For every soil layer of the soil profile, mean soil organic carbon density (SOCD) for each CLC class was estimated as follows:

$$SOCD = SOC \times BD \times Depth$$

where SOCD is soil organic carbon density (Mg ha^{-1}), SOC is soil organic content (g 100^{-1} g^{-1}), BD is bulk density (g cm^{-3}), and depth is the thickness of the studied layer (cm). Soil carbon stock (SCS) for each CLC class was estimated as:

$$SCS = SOCD \times CLC\ area$$

for 1956 and 2007. Land cover classes in 1956 and 2007 and LCF class were assigned to soil profiles using spatial analysis techniques. Data analysis was performed using SPSS 15 and ArcGIS 9.3 software packs.

Spatial soil data set

Spatial distribution of soil types was extracted from the soil map of Andalusia (CSIC-IARA, 1989) at scale 1:400,000, which contains 2707 polygons classified in 64 soil map units (SMU), according to the legend of the soil map of the world (FAO-UNESCO, 1974).

Results

Cumulative SOC content for 0-25, 25-50 and 50-75 cm layers is shown in Figure 2. Soils with the largest SOC stock are Cambisols (162.66 Tg), Regosols (91.95 Tg) and Vertisols (48.37 Tg). The proportion of SOC in the 0-25 cm layer is on average about 55% (229.69 Tg) of the total SOC stock in the upper 75 cm, around 30% (122.89 Tg) in the 25-50 cm layer and 15% (62.62 Tg) in the deepest layer (50-75 cm). Total stocks per land use class (in absolute terms) are displayed in Figure 3. "Scrub and /or vegetation associations" contain 115.92 Tg C in 22561.98 km^2, "Permanent crops" 94.65 Tg C in 17275.66 km^2, "Arable Land" 84.59 Tg C in 15468.49 km^2 and "Forests" 67.60 Tg C in 15911.37 km^2.

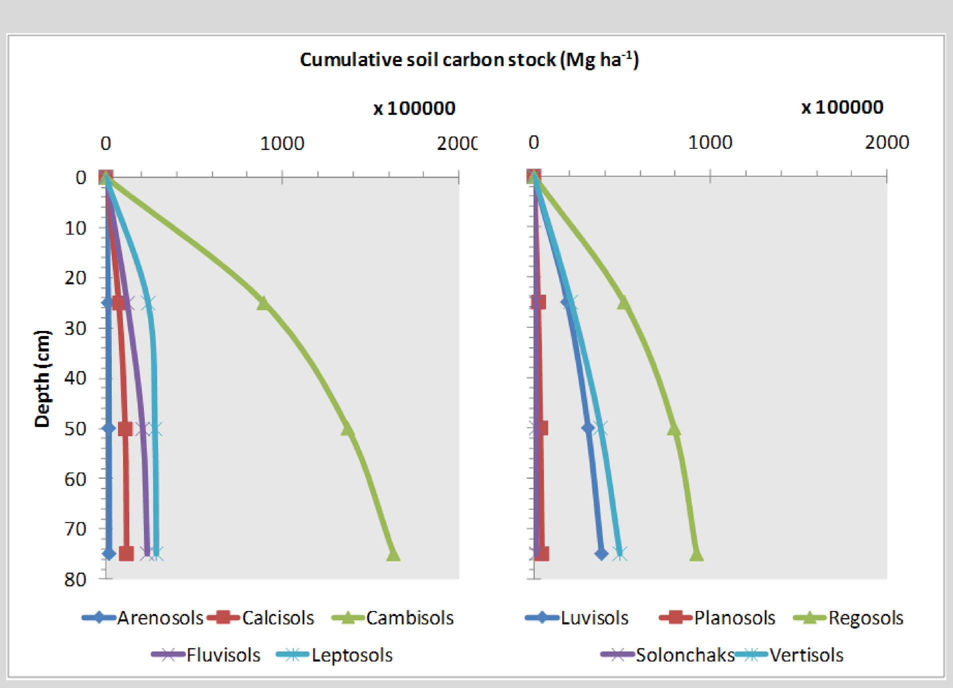

Figure 2. Cumulative average soil carbon stocks for different soil types.

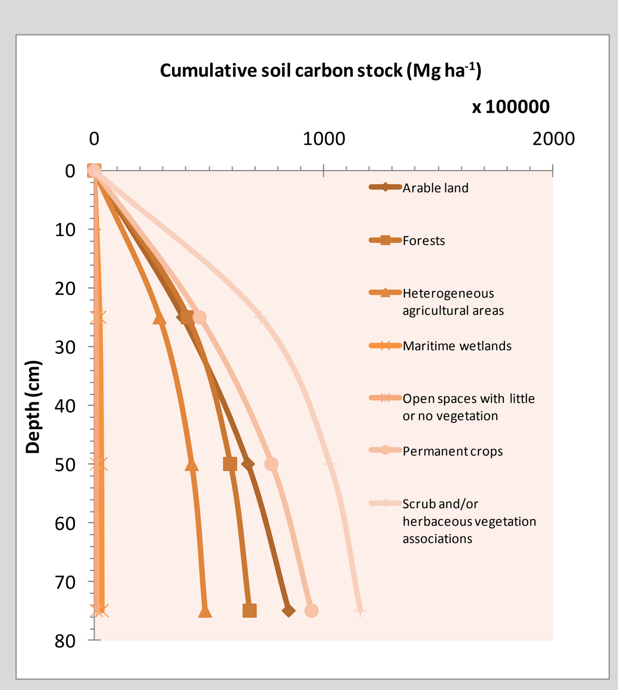

Figure 3. Cumulative average soil carbon stocks for different land use types.

Distribution of SOC (Mg C ha^{-1}) in 1956 and 2007 and SOC sinks/sources are shown in Figure 4. Land use change has an important effect on SOC stocks in the first 75 cm (Table 1). SOC contents increased in areas where land use was changed to "Forest" from "Heterogeneous agricultural areas" (in Regosols) and "Scrub" (in Calcisols). For Cambisols and Luvisols, highest values of SOC content are those for land use changes from "Scrub" to "Permanent crops". In Vertisols, SOC content is increased with changes among agricultural uses ("Arable land" to "Heterogeneous agricultural areas" and "Permanent crops" to "arable land). SOC contents from Arenosols and Leptosols show a decreasing trend when changes are produced after transformation from natural to agricultural areas.

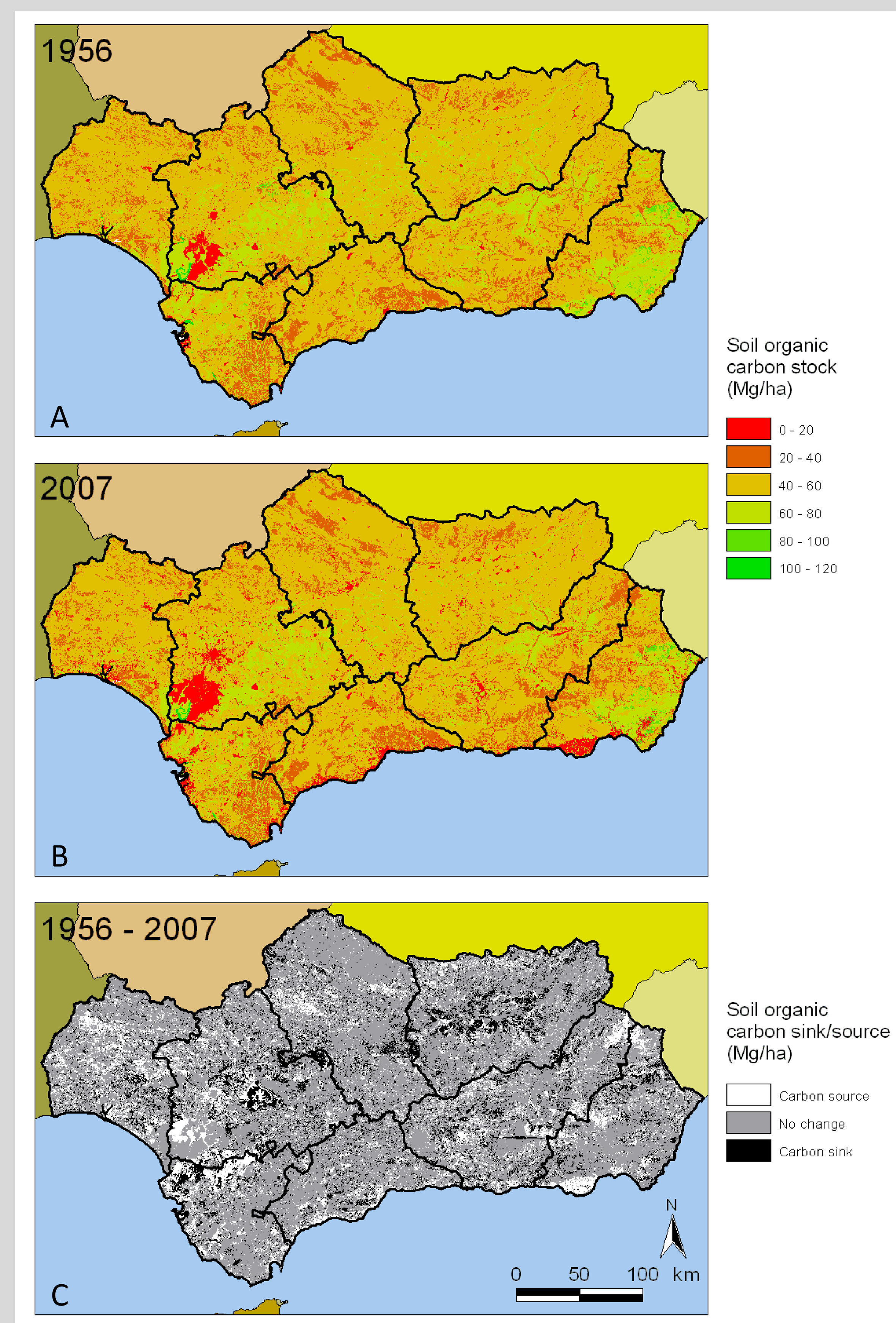

Figure 4. Soil organic carbon stocks in Andalusia in 1956 (A) and 2007 (B), and soil organic carbon sink and source areas between 1956 and 2007 (C).

Table 1. Soil organic carbon stocks (Mg/ha) for each land use change and soil type between 1956 and 2007. Key: SOC in 2007 / SOC in 1956.

Land use change	Soil type							
	Arenosol	Calcisol	Cambisol	Fluvisol	Leptosol	Luvisol	Regosol	Vertisol
Arable to Permanent	14,4 / 39,2	53,5 / 70,1	51,8 / 44,0	-	34,3 / 65.1	64,8 / 56,6	68,3 / 62,5	64,8 / 73,0
Arable to Heterogeneous	56,1 / 39,2	70,4 / 70,1	49,3 / 44,0	76,2 / -	44,4 / 65.1	11,5 / 56,6	55,3 / 62,5	70,0 / 73,0
Arable to Scrub	-	81,0 / 70,1	41,2 / 44,0	53,4 / -	47,7 / 65.1	69,7 / 56,6	84,8 / 62,5	17,0 / 73,0
Permanent to Arable	37,1 / 29,1	61,1 / 64,5	66,2 / 56,4	49,2 / 10,6	34,9 / 35.4	46,1 / 59,9	54,7 / 57,8	71,8 / 58,7
Heterogeneous to Forest	24,2 / 44,0	55,7 / 79,5	7,2 / 22,0	8,8 / 31,8	10,1 / 21.3	-	117,1 / 42,4	-
Forest to Heterogeneous agricultural areas	92,2 / 36,2	92,4 / 69,3	5,9 / 61,9	-	41,8 / 39.2	12,7 / 55,7	11,5 / 60,7	-
Forest to Scrub	17,1 / 36,2	-	30,1 / 61,9	51,1 / 41,7	-	-	31,8 / 60,7	-
Scrub to Arable	18,5 / 49,0	17,8 / 86,5	-	39,7 / 79,9	-	33,4 / 96,7	48,0 / 63,0	-
Scrub to Permanent crops	22,7 / 49,0	-	101,9 / 34,8	-	21,9 / 45.7	97,3 / 96,7	45,4 / 63,0	-
Scrub to Heterogeneous	5,5 / 49,0	-	48,5 / 34,8	96,8 / 79,9	23,9 / 45.7	41,4 / 96,7	46,1 / 63,0	-
Scrub to Forest	43,8 / 49,0	126,1 / 86,5	43,4 / 34,8	9,2 / 79,9	46,0 / 45.7	86,3 / 96,7	45,1 / 63,0	-

Conclusions

An analysis of LU/LC change dynamics between 1956 and 2007 in southern Spain and its effects on SOC stocks has been carried out in this research. Our results confirm the strong relationship between LU/CC and soil organic carbon stocks. LU/LC changes can intensely affect SOC stocks. A decrease in SOC stock is observed in most cases after conversion from forest to scrub, what often means increased CO_2 flux, and different trends are observed after conversion to heterogeneous agricultural areas. Data show that after transformations from forest or scrub uses to other land use types, most soils in southern Spain become a new source of carbon. Appropriate soil and LU/LC management, restoration of forests and afforestation could be an important step to increase carbon sequestration in the study area. These previous studies will constitute a basis for carbon sequestration modelling and analysis of potential scenarios.

Acknowledgements

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