J. Agr. Sci. Tech. (2014) Vol. 16: 667-679

Linking Soil Organic Carbon Stocks to Land-use Types in a Mediterranean Agroforestry Landscape

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ABSTRACT

In agroforestry landscapes, land use, and the associated management practices exert strong impacts upon soil organic carbon stocks. Data on the soil organic carbon were collected for different land-use types within a small watershed, El Salado, located in Lanjarón (SE Spain). Eight land-use types namely: farmland planted in olive, almond, and cereals; forest with *Pinus halepensis* Mill. and *Pinus sylvestris* L. stands; shrubland; grassland; as well as abandoned farmland were taken into consideration. Of the land-use types investigated, forest, shrubland, as well as grassland exhibited the highest average soil organic C stocks (100-63 Mg ha^{-1}) in contrast with the abandoned farmland (28 Mg ha^{-1}), with farmland representing a go-between situation (51-49 Mg ha^{-1}). The environmental factors precipitation, temperature, and elevation significantly influenced (P< 0.01) the soil organic C stock, with the contents tending to be higher in mountain soils with respective intermediate values of 600-800 mm, 10-15ºC, and 1,000-1,500 m asl. Thus, the present approach offers a comparison of C-sequestration patterns as related to the land-use types in a Mediterranean agroforestry landscape, where the main challenge is to integrate the forest trees and the crops within their harmonious interacting combinations.

Keywords*:* Land-use change, Lanjarón, Semiarid hillslopes, Soil-organic carbon, SE Spain**.**

INTRODUCTION

An estimation of carbon (C) stocks in soil and in vegetation is essential for a determination of the significance of C allocation in agroforestry landscapes, and as well in improving the understanding of their potential contribution to global C stocks (Calfapietra *et al.,* 2010; Nair *et al.,* 2010). It is also important to evaluate the impact of land-use/land-cover change on the terrestrial C balance, analysing its environmental consequences. Farmland abandonment and the conversion of forests and grasslands into farmland are known to deteriorate soil properties, and especially reduce soil organic matter (Lemenih *et al.,* 2004; Ries and Hirt, 2008). In this sense, a study of the consequences of soil abandonment is very important, as time can play either for or against the trend of soil recovery (Blanco-Canqui and Lal, 2008). In general, when agricultural land is no longer used for cultivation, but allowed to be either reverted to natural vegetation or replanted into perennial vegetation, Soil Organic Carbon (SOC) can

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then accumulate through processes that are contrary to the effects responsible for SOC losses inflicted from when the land was converted from its perennial vegetation (Post and Kwon, 2000). However, in this particular Mediterranean environment, those cultivated fields (usually vineyards and olive trees) are prone to enhance soil degradation processes and cause to be impaired if abandoned at this stage (Dunjo *et al.,* 2003).

The relationship between land-use systems and climate change is fundamental, as these systems sequester atmospheric CO_2 and store the C in soil and as well in plants. Consequently, land-cover dynamics, particularly deforestation, forest fire, as well as abandoned farmlands, have become critical concerns, as the implications for systems involving human livelihoods are immense (Bowen *et al.,* 2007; Durán *et al.,* 2013). In this context, sustainable utilization and conservation of natural resources in Mediterranean agroforestry landscapes is one of the fundamental components of sustainable rural development (Cacho, 2001; Durán *et al.,* 2011).

Also, plant-soil feedback loops influence both plant-community and soil conservation, making researchers increasingly aware of how the aboveground and belowground relationships govern terrestrial-ecosystem processes. According to Bezemer *et al.* (2006), plant-soil feedback mechanisms depend on plant species, functional groups, and site-specific differences in biotic and as well in abiotic chemical characteristics of the soil. On the other hand, climatic factors, especially temperature and precipitation, are the prime determinants of SOC contents (Liu *et al.,* 2011).

Mediterranean agroforestry systems are considered as possessing a higher potential to sequester atmospheric C because of their recognised greater ability to gather and utilize such growth resources as light, nutrients, and water in comparison with single-species crops or grassland systems. As stated by Bolin and Sukumar (2000), land-use change is associated with changes in plant cover and in C stock. Moreover, Senthil *et al.* (2006) reported that the ability to sequester C in the soil is modulated by topography, management practices, initial SOC, soil properties, and as well by parent materials. Therefore, the soil can maintain a potential C-stock equilibrium between C inputs *vs.* losses. However, this balance can be upset by land-use change until a new equilibrium is established within the transformed ecosystem. In this context, many recent studies have demonstrated the strong impact of land-use types on SOC stocks and their fractionation in hilly and semiarid regions (Mokhtari *et al.,* 2012; Ayoubi *et al.,* 2012).

The present work, through an analysis of soil C stocks for the dominant land-cover types in a given land use, contributes knowledge on potential C sequestration, thereby improving the estimation not only of the organic C stock in a Mediterranean agroforestry landscape but also of the potential changes in SOC content, due to different scenarios involving various land-use types, using the example of the Watershed El Salado, Granada (SE Spain).

MATERIALS AND METHODS

The Study Area

The study area, a watershed of 669.7 ha named El Salado, situated in the Sierra Nevada Mountains near Lanjarón (province of Granada, SE Spain; Figure 1-A), ranges from 2,374 m to 670 m asl, with an average slope exceeding 20%. The features of the watershed are common of the in Mediterranean mountain zones. Some of the main representative Land-Use Types (LUT) are presented in Figure 1-B. Table 1 provides a brief description of the vegetation species in each unit of land use.

The dominant soil parent material is colluvium and residuum derived from mica schist, while the slopes being composed predominantly of phyllites and mica-schist, with weathered regolith covers of only a few cm depths. These phyllites may have been overlain in places by limestones that have rafted downslope on top of the phyllites. In general, the soils are of loamy, sandy-loam, and silt-loam textures, as classified according to the FAO-WRB (1998) (Figure 1-C).

Table 1. Main plant species on different Land-Use Types (LUTs) of the El Salado watershed in Lanjarón, Granada (SE, Spain).

LUT / location	Dominant land-cover types
Forest *P. halepensis* (36º 56´ N / 3º 30´ W), *P. sylvestris* L. (36º 57´ N / 3º 28´ W)	Areas with Pine stands (*Pinus sylvestris* L., *Pinus halepensis* Mill., *Pinus pinaster* Aiton., *Pinus nigra* J.F.Arnold, *Pinus pinea* L., etc.) that formed nearly closed canopies (60-85%). This category included planted forests, mixed with regenerating indigenous trees and bushes: *Quercus ilex* subsp *ilex* L., *Adenocarpus decorticans* Boiss., *Juniperus oxycedrus* L., *Castanea sativa* Mill., *Salix viminalis* L., *Populus alba* L., *Populus nigra* L., etc.
Rainfed farmland cereals (36º 56´ N / 3º 29´ W), olive and almond (36º 51´ N / 3º 29´ W)	Areas with cultivated crop trees: olive (*Olea europaea* L.), almond (*Prunus dulcis* (Mill.) D.A. Webb,), and grape (*Vitis vinifera* L.). For livestock and wild partridges (hunting) feed, especially annual species of winter wheat (*Triticum aestivum* L.), oat (*Avena sativa* L.), barley (*Hordeum vulgare* L.), legumes (*Lens esculenta* L.), etc..
Shrubland (36º 56´ N / 3º 29´ W)	Areas covered with shrubs, scrubs, and small trees, with little useful wood, mixed with some grasses: *Ulex parviflorus* Pourr., *Genista* sp., *Adenocarpus decorticans* Boiss., *Brachipodium* sp., *Cytisus scoparius* (L.) Link, *Retama sphaerocarpa* (L.) Boiss., *Lavandula pedunculata* (Mill.) Cav., *Bituminaria bituminosa* (L.) Stirton, *Dittrichia viscosa* (L.) Greuter, *Artemisia campestris* L., etc.. Some areas with aromatic and medicinal shrubs especially thyme (*Thymbra capitata* (L.) Cav., *Thymus baeticus* Boiss., *Thymus zygis* Loefl ex L.), sage (*Salvia officinalis* L.), lavender (*Lavandula stoechas* L.), rosemary (*Rosmarinus officinalis* L.), *Santolina* sp., etc..
Grassland/Pasture (36º 56´ N / 3º 29´ W)	Dry grassy areas used for grazing (goat and sheep) dominated by *Poaceae* species and other herbaceous plants (non-woody): *Festuca granatensis* Boiss., *Agrostis* sp., *Jurinea humilis* (Desf.) DC., *Dactylis* sp., *Bromus* sp., etc., annual and perennial forbs (*Stipa tenacissima* L., *Brachypodium* sp., etc.) combined with dwarf shrubs and bare land having either very little or no plant cover (exposed rocks).
Abandoned land (36º 56´ N / 3º 29´ W)	Most of this area is abandoned farmland progressively recolonized with shrubs including herbaceous plants, *Ulex parviflorus* Pourret , *Santolina chamaecyparissus* L., *Stipa tenacissima* L., *Phlomis purpurea* L., *Bromus* sp., *Dactylis glomerata* L., *Thapsia villosa* L., etc.

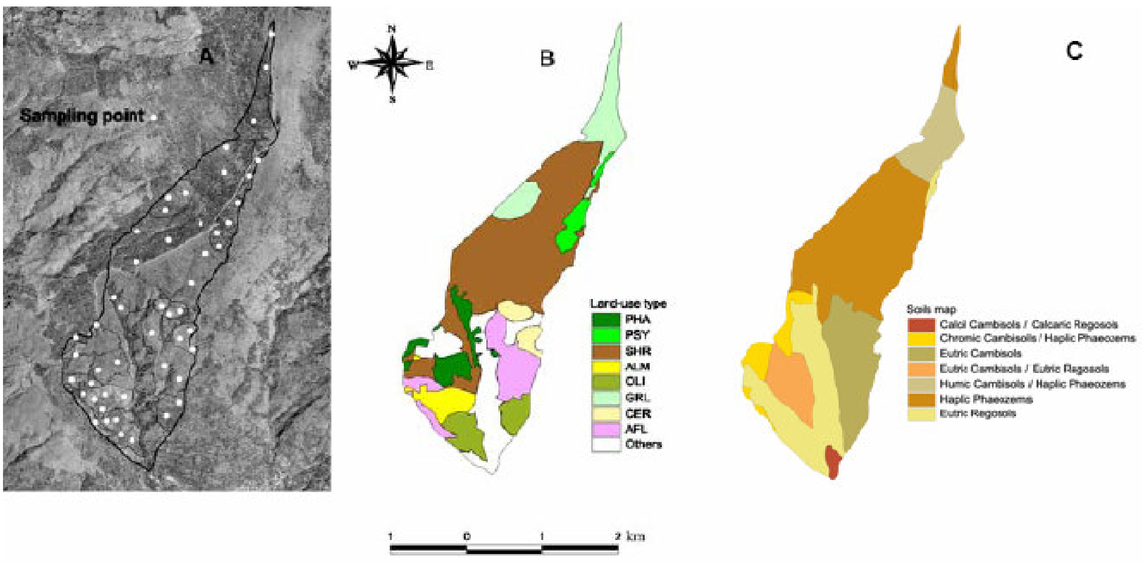

Figure 1. Location of soil sampling sites (A), main LUTs distribution (B), and the soil map (FAO 1998) (C) on different land-use types of the El Salado Watershed in Lanjarón, Granada (SE, Spain). CER: Cereal; GRL: Grassland; OLI: Olive; ALM: Almond; PHA: *Pinus halepensis*; PSY: *Pinus sylvestris*; SHR: Shrub, AFL: Abandoned FarmLand.

The temperature and precipitation datasets in the study area were analysed as annual mean figures of meteorological measurements from weather stations distributed throughout the watershed.

Sampling Design and Data Analysis

Eight LUTs were selected as representatives of the study area and defined according to the scheme shown in Table 2 and in Figure 1-A. Specifically, sampling plots were defined and appointed for each land use namely for olive, almond, *Pinus halepensis* Mill., and *Pinus sylvestris* L. stands. Other plots were laid out for cereals, shrubland, grassland, and as well for abandoned farmlands; these later plots having been left to grow without any human disturbance since 2007, when the farmland was practically abandoned (Table 1).

The soil was sampled (0-25 and 25-50 cm depths) within each selected land-cover type to represent the land use type investigated. For shrubland, grassland, and abandoned farmlands which were the most common LUTs and for those expected to show high variations C, a larger number of subplots (n= 45) was made use of. As for farmland and forests, which were expected to show lower variations in of C level, fewer subplots (n= 20) were take into account.

Soil samples were air-dried before being passed through 2-mm sieves, with crop debris, root material, and stones being removed. The Soil Organic Carbon (SOC), Bulk Density (BD), and soil texture were determined using standard methods (MAPA, 1994). The quantity of SOC stored in the soil was adjusted through soil mass. An estimation of organic C stock at 0.5 m soil depth was made using the following equation:

$$\text{SOC (Mg ha}^{-1}) = A \times BD \times f\,C \times H \qquad (1)$$

Where, *A* is the area (ha); *BD* the Soil Bulk Density (t m^{-3}) at 0.5 m depth; *f* C the fraction of *C*, and while *H* standing for the soil depth (m).

For mapping of the SOC in the watershed, Kriging Interpolation was made use of (Kriging Interpolator 3.2 3D, extension with Arcview 3.2 Spatial Analyst, Nieuwland Automatisering, Wageningen, Netherlands) to interpolate the surface for the Digital Elevation Model (DEM) of 5-m resolution. Also, regression Kriging was chosen to interpolate the data because it is commonly used as an unbiased estimator to minimize error variance.

For an analysis of the effect of environmental factors on organic C stocks, and for an overall estimate of the impact at the watershed level, the elevation, rainfall, and temperature were divided into three categories (< 1,000, 1,000-1,500, and > 1,500 m asl; < 600, 600-800, and > 800 mm; and <10, 10-15 and 15°C, respectively).

Analysis of variance was performed to ascertain whether the land uses differed in C stocks. Differences between individual means were assessed using the Least Significant Difference (LSD) test at $P< 0.05$ in Statgraphics v. 5.1. Finally, the data were

Table 2. General characteristics of land use/land cover studied in the watershed.

Land use/Land cover	Elevation (m asl)	Age (yr)	Stand density[a]	Area (ha)
Farmland/Olive	712-1125	42	144	37.3
Farmland/Almond	885-1120	40	256	24.1
Farmland/Cereals	1260-1390	------	1000000	18.6
Abandoned farmland	827-1326	2-3	------	57.3
Forest/*P. halepensis*	1010-1325	60	1600	35.3
Forest/*P. sylvestris*	1670-2080	60	660	18.1
Shrubland	940-2075	7-15	------	257.2
Grassland	1550-2360	------	------	62.2

[a] Trees and plants per hectare.

treated through parametric correlation analysis to evaluate the relationships (P< 0.01) among climate factors, elevation, and SOC.

RESULTS AND DISCUSSION

Soil Organic Carbon Content in Relation with LUTs

Table 3 shows the organic C content at different soil depths and under different land uses studied, Values are shown to be significantly higher when the land under *P. halepensis* Mill. and *P. sylvestris* L. stands while being decreased with soil depth. Conversely, there was a tendency of increase in SOC content with soil depth in olive, almond, and abandoned farmland. In particular, the SOC content was high in *P. halepensis* Mill. at 0-25 cm of soil depth (more than 50%) in comparison with the other LUTs, especially for almond, olive, and abandoned farmlands. Since plant covers have access to the organic-matter input of C to the soil, the C content is expected to be greater at the soil surface than in deeper layers. In addition, according to Johnson and Curtis (2001), the greater soil C and N stock in the coniferous forests might have resulted from the litterfall, more plentiful under *P. halepensis* Mill. and *P. sylvestris* L. This result agrees with a study by Jeddi and Chaieb (2010), who concluded that forests with *P. halepensis* Mill. improved the soil by increasing organic C, and well by facilitating the colonization and development of understory vegetation. Also, in shrublands dominated by diverse plants, the organic C was presumably high due to the incorporation of decomposing plant litter (Rodríguez *et al.,* 2009). Similar results have been reported by Fu *et al.* (2004), who found the level of organic C content to be lower in farmland than in land rich with native vegetation. In addition, according to Melero *et al.* (2011) the tillage practices used may accelerate the decomposition rate of organic matter, as in monitored farmland plots. According to the results of the observational studies, grassland could be considered an intermediate step between farmland and shrubland, as shown in Figure 2, where plant diversity is shown to increase the short-term

Table 3. Soil organic carbon content, and soil texture in different land-use types.[a]

Land use / land cover	Depth (cm)	SOC ($g\ kg^{-1}$)	BD ($Mg\ m^{-3}$)	Sand	Silt ($g\ kg^{-1}$)	Clay
P. halepensis	0-25	22.91 ± 4.12a	0.91 ± 0.03b	672 ± 22a	173 ± 21b	155 ± 8a
	25-50	20.52 ± 3.43a	0.97 ± 0.07b	640 ± 18a	194 ± 17b	166 ± 10a
P. sylvestris	0-25	17.80 ± 6.11a	1.04 ± 0.04b	540 ± 28b	320 ± 39a	140 ± 8a
	25-50	16.73 ± 9.14ab	1.08 ± 0.02b	552 ± 15b	297 ± 27ab	151 ± 11a
Grassland	0-25	9.60 ± 2.24ab	1.11 ± 0.06b	643 ± 33a	260 ± 42ab	97 ± 18ab
	25-50	9.14 ± 2.34ab	1.10 ± 0.06b	622 ± 39a	255 ± 31ab	123 ± 22a
Shrubland	0-25	13.53 ± 3.22ab	1.12 ± 0.05ab	583 ± 52ab	349 ± 22a	68 ± 18b
	25-50	10.40 ± 1.34ab	1.10 ± 0.03ab	612 ± 11ab	314 ± 18a	74 ± 14b
Cereal	0-25	10.03 ± 2.33ab	1.16 ± 0.06ab	654 ± 24a	250 ± 48ab	96 ± 10ab
	25-50	8.31 ± 8.44ab	1.13 ± 0.09ab	625 ± 28a	271 ± 15ab	104 ± 19a
Olive	0-25	8.54 ± 3.01b	1.19 ± 0.04ab	667 ± 31a	200 ± 17b	133 ± 9a
	25-50	8.94 ± 2.34b	1.17 ± 0.07ab	611 ± 17ab	271 ± 22ab	118 ± 11a
Almond	0-25	8.40 ± 2.23b	1.17 ± 0.04ab	697 ± 65a	215 ± 32b	88 ± 12ab
	25-50	9.22 ± 3.31b	1.20 ± 0.02ab	650 ± 41a	244 ± 19b	106 ± 15a
Abandoned	0-25	6.70 ± 3.44b	1.27 ± 0.05a	705 ± 32a	224 ± 22b	71 ± 21b
	25-50	7.84 ± 3.40b	1.23 ± 0.08a	680 ± 45a	237 ± 18b	83 ± 19ab

[a] Means in the column followed by the same letters are not significantly different at *P*< 0.05 by LSD test; ±Standard deviation; SOC: Soil Organic carbon, BD: Bulk Density.

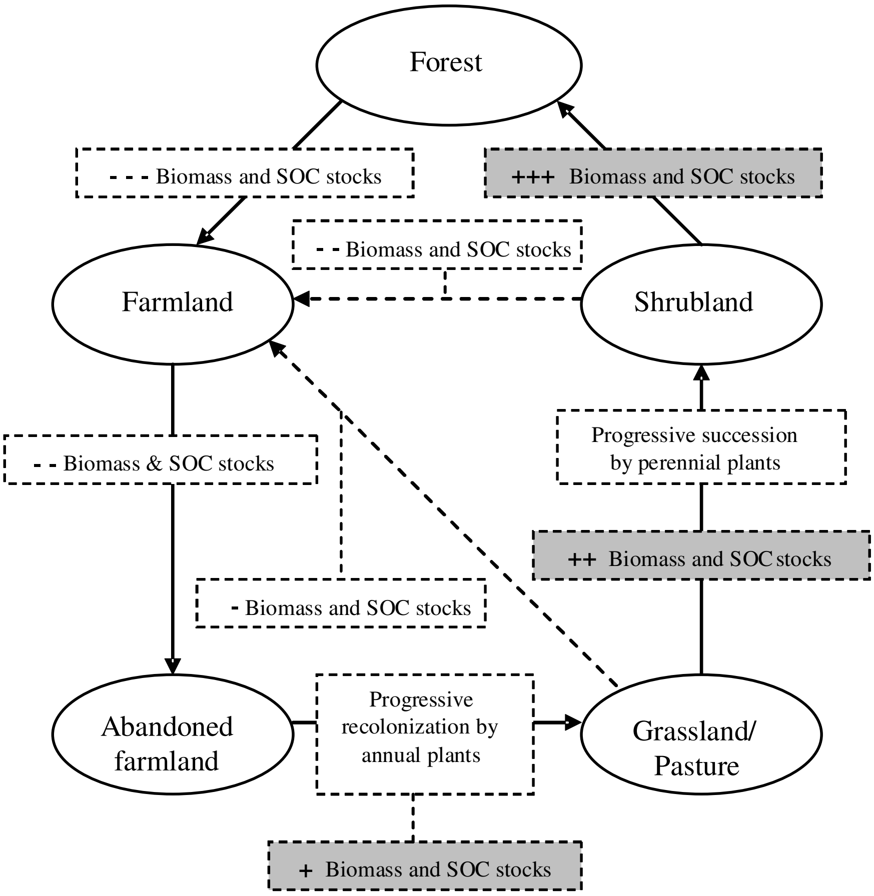

Figure 2. Ongoing processes for vegetation succession and Soil Organic Carbon (SOC) in areas affected by land-use change in different land use types.

soil C content (Steinbeiss *et al.,* 2008).

In relation with soil bulk density, the differences among the LUTs were presumably caused by such soil management practices as the continual farmland tillage, especially in olive and almond plots (Table 3). However, the shrubland and grassland areas registered lower bulk densities, and this trend could be ascribed to the minimal damage to the soil, as the vegetation resulted in a more abundant SOC.

The present study's results reveal differences in relation with soil texture under different LUTs, although it could also be attributed to the inherent characteristics of soil type, and therefore the difference in parent material and soil pedogenesis pathways (within different slope positions under given weather conditions) could be considered as some of the presumably crucial factors. However, Ayoubi *et al.* (2010) reported variations in soil textures among different land uses in soils with similar parent materials at small scales.

The soils planted in *P. halepensis* Mill. carried the highest clay portion, while shrubland, as well as abandoned land the lowest. In this context, at least for the upper soil surface layers, Narain *et al.* (1990) pointed out that deforestation exacerbates soil erosion, leading to selective transport of clay particles. In addition, it is usually linked with the loss of clay particles through a transformation of forest soils into other sorts of land uses, as observed by Hajabbasi *et al.* (1997).

SOC Density and Storage within the Watershed

Table 4 displays the weighted average SOC density for all the LUTs in the study area, and the estimated total C storage in El Salado watershed. The results clearly demonstrate that soils beneath the vegetation with *P. halepensis* Mill., *P. sylvestris* L., and shrubland added fertility where organic C densities were greater (10.03, 8.31, and 7.20 kg m^{-2}, respectively) than the remaining LUTs. In this context, Janssens *et al.* (1999), studying a *P. sylvestris* stand, reported higher values for C stored in soils (11.5 kg m^{-2}) while Pérez *et al.* (2011), examining the soil C stocks of native and afforested arid Mediterranean shrubland, found lower values (3.2 and 1.9 kg m^{-2}, respectively) than those in the present experiment. In addition, the estimated soil C stock in different LUTs are close to those reported by Miralles *et al.* (2009) in mountain agroecosystems of SE Spain: reforested pine forest < 60 years old (*P. halepensis*) of 72.5 Mg ha^{-1}, thickets (shrubland) 64.7 Mg ha^{-1}, and crops (almond, olive, and cereals) 51.8 Mg ha^{-1}.

Grassland significantly ($P< 0.05$) increased organic C stocks as compared with the abandoned farmland conditions, improving soil properties. These changes in soil-surface conditions are presumably related to a contribution of organic C by the leaves and roots of annuals and as well to the perennial species inhabiting the vegetation patches, especially in abandoned farmland areas, where slow and progressive plant succession took place, as depicted in Figure 2.

A comparison of the mean values of the different farmlands (olive, almond, and cereals) shows similarities in the SOC stock (Table 4). Analogous stocks were pointed out by Murillo (2001) for Mediterranean Spain: 5.1 to 5.8 kg C m^{-2} for arable lands, and 3.9 kg C m^{-2} for olive orchards. In addition, similar stocks for French and Italian environments of 4.9 and 5.2 kg C m^{-2} for farmlands were recorded by Martin *et al.* (2011) and Chiti *et al.* (2012), respectively. Consequently, agricultural soils, and especially eroded ones, usually contain lower organic C stocks than their potential capacity, as corroborated by olive, almond, and cereal plots. Thus, the natural and progressive recolonization of abandoned land by spontaneous native species, appropriate soil-management systems in farmland (i.e. non-tillage, reduced tillage, plant strips, etc.), and management of forestland as well as scrubland can augment organic C stocks through C sequestration (Chivenge *et al.,* 2007; Durán *et al.,* 2011) (Figure 2). In Figure 3, the map reveals that the land-use type affected the spatial distribution of SOC within the watershed. The levels of C stocks were dynamic in nature while changes in land use, land-use management, and type of plant cover significantly affected C stocks, causing

Table 4. Soil organic carbon density (content), and its storage at different Land-Use Types.[a]

Land use/Land cover	SOC content (kg m^{-2})	SOC storage (Mg)	TOC storage (%)
Forest/*P. halepensis*	10.03 ± 0.43a	3.52	10.6
Forest/*P. sylvestris*	8.31 ±0.37a	1.51	4.5
Shrubland	7.20 ± 0.78a	18.58	55.8
Grassland	6.34 ± 0.31a	3.93	11.8
Farmland/Olive	5.10 ± 0.76ab	1.89	5.7
Farmland/Almond	4.88 ± 0.69ab	1.18	3.5
Farmland/Cereals	5.29 ± 0.52ab	0.99	3.0
Abandoned farmland	2.80 ± 0.53b	1.71	5.1
Total	------	33.31	100

[a] Different letters in the column are indicative of statistical difference at level 0.05 through LSD test.

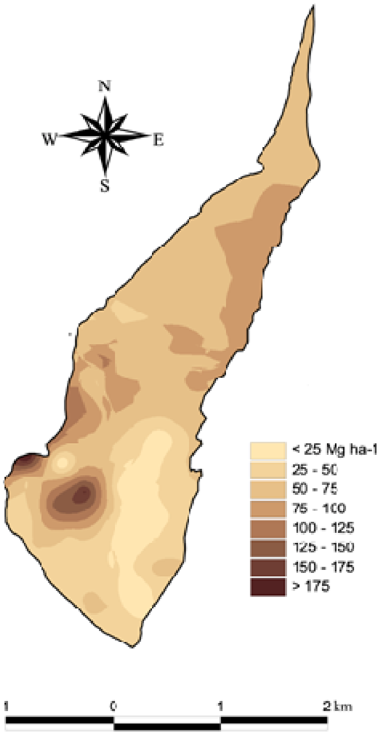

Figure 3. Spatial distribution of soil organic carbon stocks at 0-50 cm of soil depth on different Land-Use Types of the El Salado Watershed in Lanjarón, Granada (SE, Spain).

declination from forest to abandoned farmland.

Effect of Environmental Factors on Organic C Stocks

The mean annual temperature and precipitation were significantly (P< 0.01) correlated with the different elevations monitored in the watershed (r= - 0.97). The effect of elevation on the main climate parameters differed with a positive *vs.* negative association of elevation vs. precipitation (r= 0.98), and elevation *vs.* temperature (r= -0.96), respectively. Since temperatures tend to decline with rises in elevation Leifeld *et al.* (2005), this could have reduced the SOC turnover rates in the study area. In this context, Figure 4A shows SOC content in relation to elevation, registering relatively higher values in areas of intermediate elevations (1,000-1,500 m) than in areas of either higher (> 1,500 m) or lower (< 1,000 m) elevations, with most of the LUTs studied being located within the domain of 1,000-1,500 m. Shrubland, at all elevation intervals, contained almost similar mean SOC contents. *P. halepensis* Mill. and *P. sylvestris* L. stands distributed at elevations of 1,000-1,500 m and > 1,500 m, respectively, showed higher SOC contents than did other LUTs. The grassland was located solely at higher elevations (> 1500 m), where mean SOC values were lower than those under the pine stands but higher than those estimated for farmland and for abandoned farmlands at lower elevations.

On the other hand, Figure 4-B also displays the influence of precipitation on SOC density under LUTs, the types in the present study belonging to the intermediate level of 600-800 mm. Under farmland, precipitation did not strongly influence SOC. However, such agricultural activities in the watershed, as tillage and crop-waste management, accentuated the decline in SOC accumulation. Contrary to the forest, particularly *of Pinus* stands, SOC density was significantly higher in zones with precipitation of 600-800 mm as compared with rainfall of > 800 mm. The high SOC content in shrubland, grassland, and forest under either relatively high or low precipitations could be attributed to slow decomposition of litter. In addition, different responses of LUTs to precipitation could be ascribed to the nature of plant species and assorted complex interactions among them and as well to climate circumstances. In this sense, Figure 4C indicates the influence of temperature on SOC under the LUTs monitored. When a LUT was not considered, SOC density was relatively lower in areas where temperature was > 15ºC than in intermediate (5-15ºC) and cooler areas (< 10ºC). All the LUTs studied had intermediate precipitation (600-800 mm) in the areas with temperatures between 10 and 15ºC. A combination of intermediate temperatures and wetter conditions may lead to better biomass production and potentially higher SOC accumulation. Comparatively,

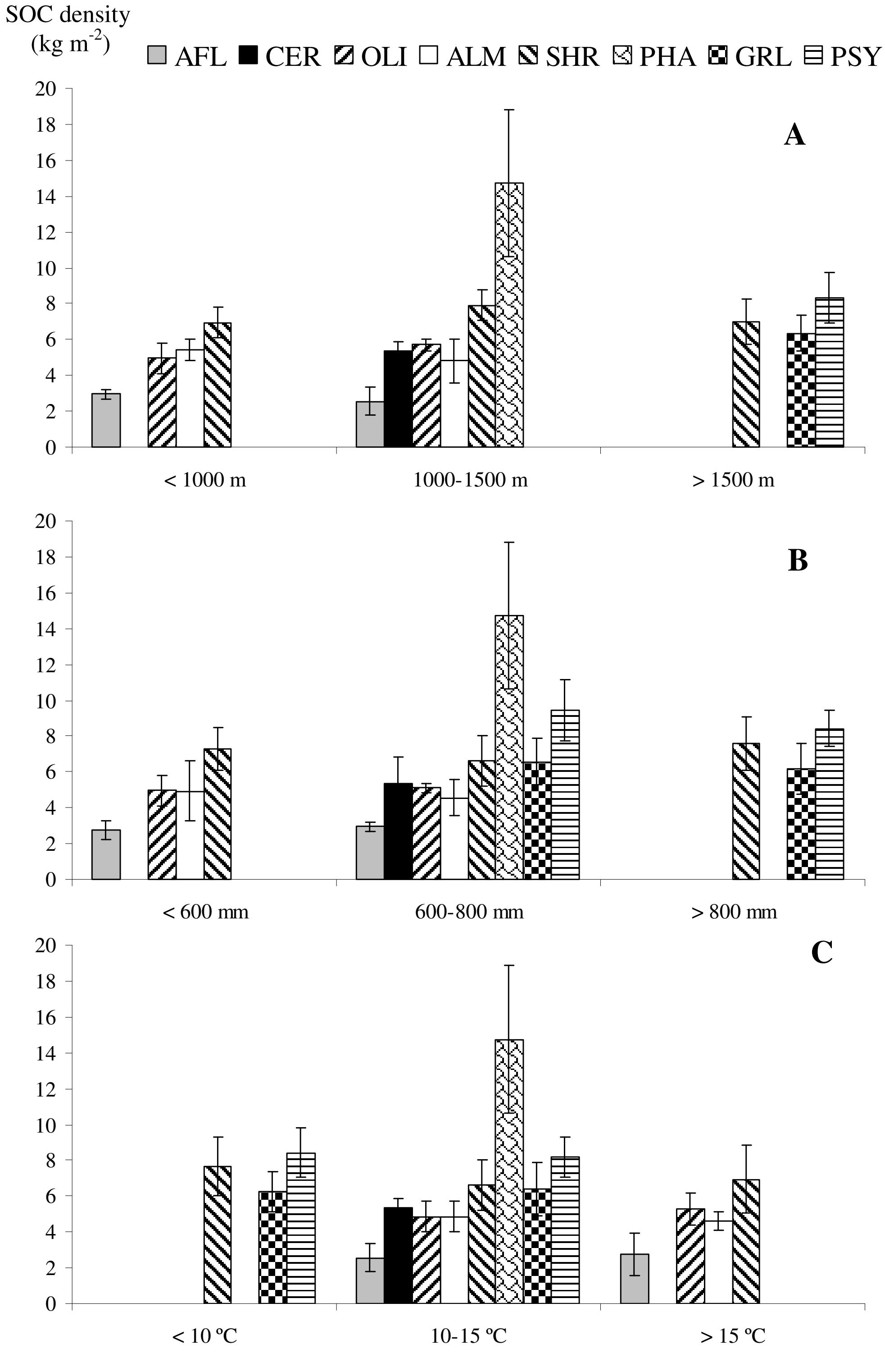

Figure 4. Mean soil organic carbon content at 0-50 cm of soil depth at different elevations (A), precipitation (B), and temperature (C) for different land-use types of the El Salado watershed in Lanjarón, Granada (SE, Spain). CER, cereal; GRL, grassland; OLI, olive; ALM, almond; PHA, *Pinus halepensis*; PSY, *Pinus sylvestris*; SHR, shrub; AFL, Abandoned FarmLand. Vertical bars represent standard deviations.

higher content SOC values in fields with temperatures lower than 10ºC may be ascribed to the slower microbial and chemical breakdown of organic residues.

The influence of temperature on SOC also diverged among the LUTs, being higher under *Pinus* stands and shrubland in all the temperature categories. This trend was consistent with the overall effect of rainfall and temperature on SOC stocks, as mentioned above, suggesting that the factor governing either the presence or absence of forests in these areas was elevation.

However, the impact of environmental factors is complex because of the association between elevation and climatic parameters, where at intermediate elevations the wetter and warmer conditions could encourage biomass production, boosting the organic carbon inputs to the soil. Therefore, these findings suggest that land uses under intermediate climatic and elevation conditions could be considered as potential sinks for the sequestration of the atmospheric C.

The results of the correlation analysis revealed that SOC was in significant relationships ($P< 0.01$) with elevation ($r= 0.59$), temperature ($r= -0.60$), and precipitation ($r= 0.61$). In total, the relationship of SOC *vs.* elevation was also investigated, and positive correlations found, in agreement with Mendoza *et al.* (2003). Furthermore, the increasing trend of SOC with rainfall, in the study area, could be attributed to the joint interactions with temperature and the level of net primary production in controlling the overall soil C stocks along such an elevational gradient. Finally, for the study area, a typical decline in vegetation was noted across elevational strata and within locations, grassland being the dominant LUT.

CONCLUSIONS

Land-use change from forest to abandoned farmland significantly reduced the organic C accumulation in the soil. The results of the present study provide insight into the potential benefits of forest and shrubland to act as C sinks, indicating that, when agricultural practices are stopped, the abandoned farmlands are led to a shift in vegetation composition in the sense that grass species are replaced by shrub-dominated communities. Such shifts boost the capability of the atmospheric C to be fixed in these types of ecosystems. Consequently, the potential of forestry and shrubland in C sequestration should be considered for appropriate management in order to maximize CO_2 sequestering as well as to balance CO_2 emissions. In particular, the present results suggest that *Pinus* stands are effective in sequestering the organic C in soils, explaining the predominance of climate over vegetation in influencing the organic C stock at higher elevations, and of vegetation type as well as physiographic situation at lower elevations within the watershed. In addition, land uses under intermediate weather and elevation conditions could be regarded as potential sinks for the sequestration of the atmospheric C.

The positive relationship found between elevation and SOC stocks in the present study implies that a proportion of the shift in the level of SOC is explained by the climate, or is due to the influence of predominant vegetation and plant species related to an elevational gradient. Thus, a knowledge of soil C stocks and the effects of environmental factors on them are critical, both from the perspective of C budgets and the corresponding Mediterranean agroforestry management.

ACKNOWLEDGEMENTS

Part of this study that leads to this publication was sponsored by the research project “Conservation agriculture techniques in rainfed-tree crops and Mediterranean climate: implications for sustainable productivity, erosion control, and improvement of soil quality and biodiversity” (RTA2011-00007-00-00) granted by INIA, Spain and cofinanced by FEDER funds (European Union).

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ارتباط ذخیرهٔ کربن آلی خاک با انواع کاربری زمین در دامنه‌ی کشاورزی – جنگلی و در شرایط مدیترانه‌ای

و. ه. دوران زوازو، ج. ر. فرانسیا مارتینزف، ک. ر. ردریگوئزپلگوزوئلو و س. کوادرس و تاویرا

چکیده

در دامنه‌های زیر پوشش کشاورزی – جنگل، عوامل کاربری زمین و روشهای مدیریتی مرتبط با آن تأثیر شدیدی را بر ذخیرهٔ کربن آلی در خاک وارد می‌سازد. اطلاعات مربوط بـه کـربن آلـی خـاک در حالات انواع کاربری زمین در یک حوزهٔ آبریز کوچک El Salado در Lanjaron (جنوب شـرقی اسپانیا) جمع‌آوری شدند. هشت نوع کاربری زمین عبارت از : ۱- کشت زیتون ۲- کشت بادام ۳- زمین زیـر کشـت غـلات، ۴- جنگـل کـاج *Pinus halepensis Mill* ۵- جنگـل کـاج *Pinus silvestris* L. ۶- بوته زار ۷- علف زار و ۸- زمین زراعی متروکه مورد مداقه قرار گرفتند. از انواع موارد کاربری زمین مورد مطالعه موردهای جنگل، بوته‌زار و علف زار دارای بیشترین حد متوسط کربن آلی موجود در خاک (۶۳–۱۰۰ $Mg\ ha^{-1}$) در قیاس با زمین زراعـی متروکـه (۲۸ $Mg\ ha^{-1}$) بودنـد، در حالیکه زمین زراعی وضـعیت بینـابینی (۴۹–۵۱ $Mg\ ha^{-1}$) را نشـان مـی‌داد. عوامـل محیطـی شـامل نزولات آسمانی، دما و ارتفاع از سطح دریا تأثیر معنی‌داری ($P<$ ۰/۰۱) بر مقدار ذخیـرهٔ کـربن آلـی در خاک داشتند و این ذخیرهٔ کربن در خاکهـای موجـود در ارتفاعـات بـا مشخصـات ۶۰۰ – ۸۰۰ میلیمتـر نزولات، دمای ۱۰–۱۵$^{\circ}$C و ۱۰۰۰–۱۵۰۰ متر بالاتر از سطح دریـا دارای مقـادیر زیـادتری بـود. بنـابراین رویکرد حاضر مقایسه‌ای را در رابطه با زمینه‌های جدائی و تجمع کربن آلی در خاک (با توجه بـه انـواع کاربری زمین) در یک دامنه کشاورزی – جنگلی مدیترانه‌ای ارائه می‌دهد. چالش اساسی در ایـن رابطـه عبارتست از فراهم آوردن نوعی تجمع از درخت همراه با محصولات زراعی که در ترکیبی هم آهنـگ و در تعامل مطلوب با یکدیگر قرار گیرند.