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

V. H. Durán Zuazo1*, C. R. Rodríguez Pleguezuelo2, S. Cuadros Tavira3, and J. R. Francia Martínez4

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, Semi-arid 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 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).

<table>
<thead>
<tr>
<th>LUT / location</th>
<th>Dominant land-cover types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest P. halepensis (36° 56’ N / 3° 30’ W), P. sylvestris L. (36° 57’ N / 3° 28’ W)</td>
<td>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 decorcicans Boiss., Juniperus oxycedrus L., Castanea sativa Mill., Salix viminalis L., Populus alba L., Populus nigra L., etc.</td>
</tr>
<tr>
<td>Rainfed farmland cereals (36° 56’ N / 3° 29’ W), olive and almond (36° 51’ N / 3° 29’ W)</td>
<td>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.</td>
</tr>
<tr>
<td>Shrubland (36° 56’ N / 3° 29’ W)</td>
<td>Areas covered with shrubs, scrubs, and small trees, with little useful wood, mixed with some grasses: Ulex parviflorus Pourr., Genista sp., Adenocarpus decorcicans Boiss., Brachypodium sp., Cytisus scoparius (L.) Link, Retama sphaerocarpa (L.) Boiss., Lavandula pedunculata (Mill.) Cav., Bituminaria bituminosa (L.) Stirt., 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 L. ex L.), sage (Salvia officinalis L.), lavender (Lavandula stoechas L.), rosemary (Rosmarinus officinalis L.), Santolina sp., etc.</td>
</tr>
<tr>
<td>Grassland/Pasture (36° 56’ N / 3° 29’ W)</td>
<td>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).</td>
</tr>
<tr>
<td>Abandoned land (36° 56’ N / 3° 29’ W)</td>
<td>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.</td>
</tr>
</tbody>
</table>

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:

\[
SOC (\text{Mg ha}^{-1}) = A \times BD \times f \times C \times H
\]

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 (KrigingInterpolator 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.

<table>
<thead>
<tr>
<th>Land use/Land cover</th>
<th>Elevation (m asl)</th>
<th>Age (yr)</th>
<th>Stand density(^a)</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmland/Olive</td>
<td>712-1125</td>
<td>42</td>
<td>144</td>
<td>37.3</td>
</tr>
<tr>
<td>Farmland/Almond</td>
<td>885-1120</td>
<td>40</td>
<td>256</td>
<td>24.4</td>
</tr>
<tr>
<td>Farmland/Cereals</td>
<td>1260-1390</td>
<td>--------</td>
<td>1000000</td>
<td>18.6</td>
</tr>
<tr>
<td>Abandoned farmland</td>
<td>827-1326</td>
<td>2-3</td>
<td>--------</td>
<td>57.3</td>
</tr>
<tr>
<td>Forest/P. halepensis</td>
<td>1010-1325</td>
<td>60</td>
<td>1600</td>
<td>35.3</td>
</tr>
<tr>
<td>Forest/P. sylvestris</td>
<td>1670-2080</td>
<td>60</td>
<td>660</td>
<td>18.1</td>
</tr>
<tr>
<td>Shrubland</td>
<td>940-2075</td>
<td>7-15</td>
<td>--------</td>
<td>257.2</td>
</tr>
<tr>
<td>Grassland</td>
<td>1550-2360</td>
<td>--------</td>
<td>--------</td>
<td>62.2</td>
</tr>
</tbody>
</table>

\(^a\) Trees and plants per hectare.
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. 

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

* 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.
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).

Figure 2. Ongoing processes for vegetation succession and Soil Organic Carbon (SOC) in areas affected by land-use change in different land use types.
Table 4. Soil organic carbon density (content), and its storage at different Land-Use Types.

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

Different letters in the column are indicative of statistical difference at level 0.05 through LSD test.
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 CO₂ sequestering as well as to balance CO₂ 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.

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ارتباط ذخیره کربن آلی خاک با انواع کاربری زمین در دامنه کشاورزی - جنگل

و در شرایط مدیرانهای

و. 5. دوران زواتو. ج. ر. فرانسيا مارتينف. ک. ر. ردرگونژ بلوژونلو و س. کوادرس

و تاویرا

چکیده

در دامنه‌های زیر بوشک کشاورزی - جنگل، عوامل کاربری زمین و روش‌های مدیریتی مرتبط با آن تأثیر شدیدی را بر ذخیره کربن آلی در خاک وارد می‌سازد. اطلاعات مربوط به کربن آلی خاک در حالات انواع کاربری زمین در یک حوزه آبیز کوه‌پیک El Salado، در استان یزنهای مورد مطالعه قرار گرفته‌اند. از انواع مورد کاربری زمین مورد مطالعه مورد های جنگل، بوته‌زار و علف زار و علف زار دارای بیشترین حجم و حالت سفید کربن آلی موجود در خاک (18 Mg ha⁻¹) در قیاس با زمین زراعی متروکه (20 Mg ha⁻¹) بوته‌زار.

در حالیکه زمین زراعی وضعیت بینایی‌نی (51-89 Mg ha⁻¹) را نشان می‌داد. عوامل محیطی شامل نیازهای آسیایی در آن بوده که در طول دریا تأثیر معنی‌داری (P<0.01) بر مقدار ذخیره کربن آلی در خاک داشته و این ذخیره کربن در خاک‌های موجود در ارتفاعات با مشخصات 800-1000 میلی‌متر نیازهای طبیعی در آن بوده.

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