Impacts of land-use intensity on soil organic carbon content, soil structure and water-holding capacity

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Abstract

The impact of land-use intensity is evaluated through changes in the soil properties in different areas of the traditional central Spanish landscape. Soil organic carbon (SOC) content, bulk density, aggregate stability and water-holding capacity (WHC) in the topsoil of active and abandoned vineyards, livestock routes (LR) and young Quercus afforested areas were analysed. These different types of land use can be interpreted as having a gradient of progressively less impact on soil functions or conservation. As soil use intensity declines, there is an increase in SOC content (from 0.2 to 0.6%), WHC (from 0.2 to 0.3 g H₂O per g soil) and aggregate stability (from 4 to 33 drop impacts). Soils beneath vines have lost their upper horizon (15 cm depth) because of centuries-old tillage management of vineyards. Except for an increase in bulk density (from 1.2 to 1.4 g/cm³), there were no differences in soil characteristics 4 yr after the abandonment of vine management. LR can be considered sustainable uses of land, which preserve or improve soil characteristics, as there were no significant differences between topsoil from LR and that from a 40-yr-old Quercus afforested area. SOC content, one of the main indicators for soil conservation, is considered very low in every case analysed, even in the more conservative uses of land. These data can be useful in understanding the slow rate of recovery of soils, even after long-term cessation of agricultural land use.

Keywords: Livestock routes, abandoned lands, vineyards, soil organic carbon, soil structure, agricultural policies

Introduction

The current situation of degraded agricultural soils in southern Europe is due in part to the variety of agricultural policies implemented in the last 30 yr that have gone through different stages. The first objective of European policies was ‘to increase productivity, by promoting technical progress and ensuring the optimum use of the factors of production, in particular labour’ (Treaty of Rome, 1957). In the nineties, policies focused on the creation of set-aside payments to withdraw land from production; as a consequence, between 10 and 20% of agricultural lands in the Euro-Mediterranean countries were abandoned (Grove & Rackham, 1996). The last ‘single farm payments’ were subject to conditions relating to environment, food safety and animal welfare standards (reforms since 2004–2005). Currently, there is a new proposal to reform the Common Agricultural Policy with three main goals: viable food production, sustainable management of ecosystems and balanced territorial development. To develop this new vision of improving the management of agro-ecosystems, farmers should be involved in preserving environmental landscapes, and policy makers must base their decisions on scientific knowledge. Quantitative information, from both observations and modelling, is needed. Particularly, local data on the current state of soil conservation would provide the information needed to understand how different soil properties change over time and under different land uses, compared with their unaltered original conditions.

As a consequence of these European agricultural policies, countries with semi-arid climates are currently a mosaic of abandoned and used lands, whose detailed conservation
states are usually unknown. The most common types of land uses are tillage-managed and fallow lands. Soil tillage is an intensive use of land that can lead to a loss of productivity in the medium-to-long term depending on fertilizer rates (Marton et al., 2011) and therefore, promote land abandonment (Barbero et al., 2012). There is extensive literature about the impact of tillage on soil structural stability (Abid & Lal, 2009) and its ability to oxidize organic matter (Martínez Mena et al., 2002) rapidly the first years and more slowly thereafter (Balesdent et al., 2000). This literature is generally in good agreement regarding the negative consequences of this practice like the reduction in physical protection of soil organic carbon (SOC) within stable aggregates, and the subsequent exposure of bare soil to rainfall and drying (Balesdent et al., 1998). Particularly, Denef et al. (2007) highlighted the importance of the conservation of soil structure through the protection of microaggregates occluded in macroaggregates as a long-term carbon-stabilization factor in forests or agricultural land with less intensive tillage. A review of the processes through which soil degradation by tillage may affect different environmental aspects – soil organic carbon, soil structure, drainage, water-holding capacity, extreme water logging or drought – can be found in Holland (2004) for different soils and climate conditions in Europe and Lal (2005) for different areas around the world. There is also agreement on the importance of aggregation in facilitating water infiltration; providing adequate habitat space for soil organisms; adequate oxygen supply to roots and soil organisms; and preventing soil erosion (Franzluebbers, 2002). There is no consensus on the impact of tillage on runoff and infiltration of water into the soil; while some authors show that infiltration rate increases (Logsdon et al., 1990; Matula, 2003), others have found that the annual balance is negative (McGarry et al., 2000; Ruiz-Colmenero et al., 2011); climatic conditions and rainfall characteristics may introduce high variability in this issue.

Land abandonment is also frequent in southern European landscapes owing to either lack of productivity or to obtain eligibility for environmental aid, particularly in the process of restructuring and converting vineyards.¹ The study of the consequences of soil abandonment is worthy, as time can play for or against the trend of soil recovery (Blanco-Canqui & Lal, 2008) because the gains, losses and interactions between living organisms, soil, organic carbon, water and nutrients depend on the prevalence of degradation processes or recovery processes, which can be ultimately the result of random climatic processes related to the amount, duration and intensity of rainfalls or droughts. Despite a number of studies focusing on the soil cover by re-establishment of vegetation, information is generally lacking on the corresponding changes to soil physical properties (Deuchar et al., 1999).

Another use, which is in decline but is certainly culturally relevant to the Mediterranean landscape, is the reserve of land for the annual migration of livestock for only a few weeks each year, which, therefore, can be considered an extensive use of land. Despite the worldwide presence of livestock routes (LR), also known as drove roads, international studies are difficult to find. Some are related to cultural aspects (Cazorla Montero et al., 2004; Herzog et al., 2005), ecosystem connectivity (Couvreur et al., 2005) and their relationship with biodiversity (Bunce et al., 2004), but, again, none regarding the consequences of this extensive use on soil characteristics.

Discovering how land is conserved under different soil use intensities is the main objective of this study; as it provides information about several soil properties considered by the European Environmental Agency in the improvement of the management of water resources and ecosystems (Jones et al., 2012). The evolution of soil characteristics under different uses over time can be assessed using its soil organic carbon (SOC) incorporation rate and its related ability to hold moisture (Rawls et al., 2003). Both may be considered key factors to reduce the impacts of intense rainfall and droughts, which are projected to become more frequent and severe in future (Solomon et al., 2007).

In this context, this study analyses the status of agricultural soils located in an area in economic decline as an example of degraded agricultural regions of southern Europe. It focuses on three different land uses: (i) intensively cultivated soils, represented by active vineyards; (ii) extensive soil management, represented by the LR; and (iii) abandoned agricultural soils. All of these are compared with a conservative use of soil, represented by nearby young afforested areas. The influence of the land-use intensity on soil characteristics is evaluated through variations in SOC content, structural stability, infiltration rate and water-holding capacity, as compared amongst the above-mentioned land uses. These variables are measured in the top soil layer up to 15 cm, where tillage practices produce dramatic changes in soil organic content (Balesdent et al., 2000; Hernanz et al., 2002) and soil aggregation (Denef et al., 2007).

Materials and methods

Study area

The study area is situated in a section of the traditional LR called Cañada Real Conquense, in central Spain, between Las

¹The implementation of the Common Market Organization led to the application of the abandonment procedure. From 2008/2009 until 2010/11 inclusive, this common market structure allowed wine producers to receive a permanent abandonment premium. The most affected country has been Spain, with an overall reduction close to 50,000 ha (Source: OIV Global Economic Survey. March 2012 http://www.oiv.int/oiv/info/enconjoncture.)

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Pedroñeras (39°27′11″N/2°40′47″W) and Socuéllamos (39°17′ 36″N/2°47′55″W) (Figure 1). This LR consists of a 75 -m-wide corridor that crosses the central Iberian plateau, and it is of particular relevance as it is still used for migratory activities of livestock, including beef cattle, bulls and Merino sheep (Oteros-Rozas et al., 2012). The altitude is between 714 and 677 m.a.s.l., the average annual temperature is 24 °C and the average annual rainfall is ca. 470 mm (Source: National Meteorological Agency, 25 yr data, http://www.aemet.es/).

Figure 2 shows the characteristics of the dominant soil in the study area. Although it cannot be considered an undisturbed native soil, it is located in a place without current signs of agricultural use. As a result of the homogeneous geomorphological characteristics of this area, conformed from a shallow lacustrine carbonate depositional system (Peropadre & Meléndez, 2004), the above-ground horizons described in this pit are expected to be similar to those of the rest of sampling sites. It is a basic soil (pH between 7.4 and 8), classified as a Calcic Luvic (Arenic) (FAO/IUSS/ISRIC, 2006).

**Sampling procedure**

During the spring and summer of 2011, a linear path of 7 km was selected that included three different land uses: (i) intensively cultivated soils, represented by active vineyards; (ii) extensive soil management, represented by the LR; and (iii) abandoned agricultural soils. Each of these was compared with a conservative use of soil, three isolated patches with young *Quercus ilex rotundifolia* (growing since the seventies), to be used as a control treatment. The age of this afforested area was given by the peasants and confirmed using the extrapolation method proposed by Gea et al. (2007) based on the measurement of the trunk diameter at breast height of 100 trees selected randomly from the three forest patches. The time of vineyard abandonment was found to be at least for 4 yr, according to the vine growers.

Ten sampling sites were selected for each land use. One topsoil sample (up to 15 cm depth) was collected at each site, resulting in 10 different plots representing these uses. Because of the scarcity of the control treatment, it was not possible to take 10 different forest samplings but 10 samples

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**Figure 1** Study area location and sampling sites.
were taken from the three different afforested areas described above (Figure 1).

Sample treatment and methods

Every soil sample was air-dried and sieved to a 2 mm diameter; the variables of this study were evaluated using 5 analysis replicates of each of the 10 samples per land use.

Textural analyses were carried out (Bouyoucos, 1936) based on a USDA system (silt from 0.05 to 0.002 mm). Soil pH (1:2.5) was measured by electrometric methods. SOC content was estimated by the loss on ignition method (LOI method, Schulte & Hopkins, 1996), as a strong linear relationship has been demonstrated between LOI and SOC ($R^2$), which ranges from 0.94 to 0.98 (Konen et al., 2002). In this method, the combustion temperature was maintained at 360 °C, avoiding the destruction of any inorganic carbonates that may be present in the sample because of the calcareous nature of the studied soil. Soil bulk density was estimated using the volume of mercury displaced by 2–3-cm-diameter soil clods (Jonston, 1945). The water mass was determined from permanent wilting point to field capacity by rewetting samples of sieved soil (>2 mm). Each sample was carefully submerged in a water tank for 4 h. The samples were then removed, permitting drainage by gravity for 3 h. The gravimetric soil moisture was determined at field capacity (pF 2.54), and at the permanent wilting point (pF 4.2) using a pressure membrane extractor system (Richards, 1941). Finally, the samples were oven-dried at 105 °C for 24 h to obtain the dry weight.

Soil aggregate stability was determined using the water-drop test (Imeson & Vis, 1984). The number of water drops (CND) needed to break down 10 dry macro-aggregates (4–4.8-mm-diameter wire mesh) per sampling site was counted, with 100 replicates per land use.

The infiltration rate was measured using a disc infiltrometer (Perroux & White, 1988). This method was used with one single pressure of 3 cm height in the Mariotte column, equivalent to 0.3 kPa suction; this allowed infiltration through macropores up to 500 µm but not through soil fissures (Greenland, 1977; Reeves et al., 1980).

Data were analysed statistically with the STATISTICA software program. The probability level ($P$-value) at which the null hypothesis was rejected was set at $P < 0.05$. Significant differences between treatments were tested using Tukey HSD or LSD planned comparisons tests whenever the ANOVA was significant. Spearman’s correlations were also carried out to establish relationships between variables.

Results and discussion

The physical and chemical characteristics of soils in the different land uses are stated in Table 1. It was observed that soils that are, or have ever been, intensively managed until 4 yr ago present the same textural class as the $Bt_1$ horizon in the pit of the dominant soil: sandy loam (Figure 2). We attribute this change in cultivated areas to the loss of their topsoil layer because of a centuries-old tradition in soil tillage, which mixed
soil layers at different depths. On the contrary, the upper horizon is preserved on the soils from the afforested area and the LR. In these less intensive soil uses, there are organic inputs from litter or animal faeces, and soils are protected by the permanent spontaneous vegetation cover throughout the year. Significant differences are shown in Figure 3.

A high SOC content in a soil suggests fertility (Sikora & Stott, 1996) and provides soil with buffering capacity, high biodiversity, good structure and effective carbon sequestration, amongst other characteristics. Soils with SOC content below 1% can be considered degraded (Imeson et al., 2006). In this study, SOC content in arable lands was

Table 1 Mean and standard deviation of topsoil variables in the different land uses. The data of the representative soil type correspond to the topsoil of the pit described in the Figure 1. The depth of topsoil layer (Ap) was 15 cm

<table>
<thead>
<tr>
<th>Soil variables</th>
<th>Representative soil type (n = 2)</th>
<th>Vineyard (n = 10)</th>
<th>Abandoned (n = 10)</th>
<th>Livestock route (n = 10)</th>
<th>Forest (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Clay</td>
<td>9.3 ± 3.3</td>
<td>14.8 ± 2.1a</td>
<td>14.5 ± 4.3a</td>
<td>9.0 ± 4.6b</td>
<td>9.7 ± 2.4b</td>
</tr>
<tr>
<td>% Silt</td>
<td>6.1 ± 2.0</td>
<td>9.7 ± 2.3a</td>
<td>8.5 ± 2.7a</td>
<td>9.3 ± 2.1a</td>
<td>8.7 ± 1.9a</td>
</tr>
<tr>
<td>% Sand</td>
<td>84.6 ± 4.3</td>
<td>75.5 ± 3.4a</td>
<td>77.0 ± 6.8a</td>
<td>81.7 ± 6.0b</td>
<td>81.6 ± 3.4b</td>
</tr>
</tbody>
</table>

Textural class

<table>
<thead>
<tr>
<th></th>
<th>Loamy sand</th>
<th>Sandy loam</th>
<th>Sandy loam</th>
<th>Loamy sand</th>
<th>Loamy sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH&lt;sub&gt;H2O&lt;/sub&gt;</td>
<td>7.7 ± 0.2</td>
<td>8.2 ± 0.3a</td>
<td>8.1 ± 0.2a</td>
<td>8.0 ± 0.2b</td>
<td>7.4 ± 0.2b</td>
</tr>
<tr>
<td>pH&lt;sub&gt;KCl&lt;/sub&gt;</td>
<td>7.2 ± 0.1</td>
<td>7.5 ± 0.1a</td>
<td>7.3 ± 0.2b</td>
<td>7.4 ± 0.1b</td>
<td>6.8 ± 0.2a</td>
</tr>
<tr>
<td>Bulk density (g/cm³)</td>
<td>1.3 ± 0.1</td>
<td>1.2 ± 0.2a</td>
<td>1.6 ± 0.2b</td>
<td>1.4 ± 0.1c</td>
<td>1.2 ± 0.1a</td>
</tr>
</tbody>
</table>

Different letters indicate significant differences between land uses.

Figure 3 Means and standard deviations of soil organic carbon (SOC) content, aggregate stability (counting number of drops, CND), infiltration rate and gravimetric soil moisture at field capacity in the four different land uses.
below the 1% limit, although this low content can be considered the typical value for these agricultural lands in southern Europe (Zdruli et al., 2004). SOC ranged from 0.2 to 0.3% on the vineyard’s soils (Figure 3), and after 4 yr of abandonment, there was not a significant increase in SOC content; nevertheless, it was higher than 0.5% in the soils from the LR and forests. Other similar topsoils under Mediterranean climatic conditions experienced an increase in SOC content from 0.9 to 1.4% after 15 yr of no tillage (Alvaro-Fuentes et al., 2009).

There is some evidence that abandonment of agricultural land and the subsequent regeneration of scrubland or forests through secondary succession may return C storage to pre-agricultural levels, although the rate of recovery depends on the time under consideration and whether the land was previously used for crops or pasture (Guo & Gifford, 2002).

In this study, when soil is under forests or is extensively used as a LR, the SOC content averages 9.3–11.4 Mg/ha. It is necessary to point that these figures refer to the first 15 cm of soil, to compare them with other values in the literature having different reference depths (usually 1 m), the estimation of SOC distribution found by Jobbágy and Jackson (2000) can be used. These authors analysed the SOC content variations with climate and soil texture at different soil depths using more than 2700 soil profiles in the world. According to their results, the 40% of all SOC content in the top 1 m is contained in the uppermost 20 cm in temperate grasslands and crops; this amount increases up to 48% in temperate evergreen forests. Following these estimates, we could state that the SOC content in the first metre in the afforested or LR soil described in this study would be between 23 and 29 Mg/ha. These values are far from those described for mature forests in the area. For instance, Rodríguez Murillo (2001) reviewed SOC concentration in Spain under the main types of land uses from the topsoil to 75 cm depth and found a very high variability (CV~70%). This author found SOC concentrations in soils under broadleaved forests and bushlands from 94 to 113 Mg/ha. This means that in the forest use after 40 yr the soil has recovered a considerably low amount of SOC. This is not unusual as a wide review carried out in the Mediterranean climate region of Australia shows no evidence of changes in SOC content three decades after afforestation in different soil depths up to 30 cm (Hoogmoed et al., 2012).

The results of this study also show that intensive use of land (vineyards, active or abandoned) maintains SOC content at rates of ca. 2.3 and 4.6 Mg/ha, respectively. These contents are also low compared with the SOC concentrations in soils under vineyards and olive groves recorded by Rodríguez Murillo (2001), which were 43 ± 29 and 40 ± 28 Mg C per ha, respectively. Regarding these differences, it is worth to mention that when different carbon stocks are compared, it is necessary to take into account bulk density variation and depth because if the compared volumes are too shallow, ploughed-SOC storage can be underestimated (Balesdent et al., 2000). In any case, these figures confirm the critical threshold for SOC content in topsoils of southern Europe; as stated by Zdruli et al. (2004), up to 74% of topsoil (0–30 cm depth) shows <2% of organic carbon.

In short, after 40 yr of Quercus tree cover, the calculated recovery of SOC can be as low as 0.15 Mg/ha/y. The low rates of SOC recovery found in this study are because of a low net primary productivity in these degraded soils that may be caused by their low organic matter content, water imbalance and frequent droughts. The literature shows a wide range of variability in the results of the impact of afforestation on soil carbon and the corresponding sequestration rates. This is the consequence of different methods, soil depths, vegetation, climate, soil type and previous land use. Examples of relative gains of 0.6 Mg C per ha per yr can be found in humid oak forests after 80 yr of afforestation (Jenkinson, 1971), also moderate gains of 0.3 Mg C per ha per yr in forest or woody vegetation establishment after some period of agricultural use (Post & Kwon, 2000). There are also low increases such as 0.016 Mg C per ha per yr in some cases in a review of more than 200 afforested sites around the world (Paul et al., 2002), and even decreases by ~0.09 Mg C per ha per yr in warm temperate areas after grazing exclusion and growing of shrub oaks (Brejda, 1997). In a recent meta-analysis reviewing 25 studies in different scenarios in Mediterranean climates, Hoogmoed et al. (2012) found no evidence for substantial changes in soil carbon, across three decades of afforestation.

Changes in SOC are also slow after abandonment of vineyards. Novara et al. (2013) estimated that 40–60 yr are necessary to multiply the SOC content by 1.5–1.6 on semi-arid abandoned vineyards in the first 15 cm of soil depth. Following this trend, much more time would be needed to achieve soil carbon stocks of undisturbed native forest within this phytoclimatic environment, which are reported in the literature ranging from 6.5 to 9.9% SOC in the topsoil at 0–10 cm soil depth (Fernández-Ondoño et al., 2010).

The aggregate resistance to drop impacts (CND, Figure 3) is a good indicator of soil structural stability. Figure 3 shows the structural stability of topsoil samples of intensively cultivated soils, both in the past (abandoned) or current (active vineyards). Soil disruption after tillage does impact aggregate stability in active vineyards; while aggregates broke up after receiving an average of only four drop impacts (CND = 4.3 ± 1.7, n = 100), the situation improved significantly in the abandoned vineyards, where it took up to nine impacts (9.4 ± 8.7) to achieve the total destruction of the aggregate. Although these soils have not yet regained their structural stability, the higher variability may indicate a trend of recovery in some places. Soil aggregate stability increased in the LR, a land use that can be observed as having an intermediate level of human impact, because CND is three times as high when compared with active tillage in vineyards.
(13.7 ± 7.5). The afforested cover is clearly a positive use to preserve or improve soil structure, as its aggregates needed 33 drops for total decay (32.9 ± 20.3). Figure 4 clearly shows the differences between treatments considering the percentage of survival aggregates in the four land uses.

In this study, 4 yr may be a sufficient time lapse to perceive signs of soil structure recovery. Goulet et al. (2004) reported a period of 9 yr of soil cover to observe such changes. Marques et al. (2009) did not find structural changes after 2 yr of cover crops in vineyards, although in that study the CND index was higher (eight drops). All these figures are in the range of those observed along a catena of soils and vegetation in a semi-arid environment (<300 mm/y annual rainfall), as Cantón et al. (2009) found an average CND between 13 and 55.

Soil structure variations have been frequently found as the cause of infiltration variability (Valentin & Bresson, 1992), particularly in vineyards (Leonard & Andrieux, 1998). Soil infiltration rates in limestone are highly variable in Mediterranean environments (Calvo-Cases et al., 2003), and it is not uncommon to find <15 mm/h infiltration rates (Cerdà, 1997; Martínez-Mena et al., 1998; Chamizo et al., 2012).

Figure 5 shows the infiltration rates in the different land uses, each of which was carried out during the summer under dry soil conditions. Soils used for vineyards showed higher infiltration rates as a result of recent tillage, which was more evident in the first minutes of the process; soil infiltration through macropores is four times higher than in the other land uses (from 60 to 80 mm/h), with stabilization taking place at 35 mm/h. The abandonment of vineyards cut the infiltration rate by half; it began with 30 mm/h and stabilized at 17 mm/h. Although we expected to find higher infiltration rates in the less intensive uses, we found lower values. Arguably, in an intact forest soil, there is a well-developed plant cover and root system providing a diverse soil porous structure with large and continuous pores, which facilitate water transport through the soil, even though they constitute only a very small fraction of the total porosity (Cameira et al., 2003). The afforested area and the LR, which are considered less intensive use of land, showed an infiltration rate beginning with 20–25 mm/h and stabilized at 7–11 mm/h, as evidenced by the curve, which was elongated and showed little variation with time, these values are close to those found in the above-mentioned literature in similar uses in Mediterranean environments.

The history of tillage in vineyards has lead to an increase in soil porosity that eventually increases infiltration rates. Nevertheless, it is worth to mention that after a period of time, depending on meteorological conditions, the lack of plant or residue cover in tilled soil exposed to high intensity rainfall often results in poor aggregation, compaction, crusting and decrease in infiltration (Franzluebbers, 2002).

In this study, there is no relationship between soil structure and infiltration rate. Higher infiltration rate is not always an indicator of soil conservation. Soil permeability is closely related to the pore space, which in turn depends on the bulk density, and we found significant differences in this variable due more to variations in pore space than to differences in soil texture. The lower values found in afforested soils and vineyards (1.2 g/cm³) may be because of different causes, in the forests because of an increase in SOC content and root systems and in the active vineyard because of recent tillage. Tillage operations are very frequent in this region, with the resulting lower bulk density being only temporary (Franzluebbers, 2002). In fact, tillage may lead to further compaction when soil is no longer used, as it is
shown in the bulk density value in the abandoned lands (1.6 g/cm³). The compaction observed in the soils of the LR (1.4 g/cm³) is arguably because of the passage of livestock and people.

The gravimetric soil moisture is generally assumed to be independent of bulk density and to be mainly related to texture. The different topsoil textures in this study could explain the variations of water content. We expected to find higher soil moisture in sandy loam textures (vineyards) than in loamy sand textures (afforested land and LR). To the contrary, gravimetric soil moisture at field capacity was higher in loamy sand textures (Figure 3; $F = 3.6; P < 0.05$). Moreover, the available water in these different land uses soil moisture between field capacity, and permanent wilting point in sieved soils (<2 mm; mean ± standard deviation) was 18 ± 6.5% for vineyards, 16 ± 2.34% in soils after abandonment, 22 ± 7% in the LR and 23 ± 8% in the afforested soil. These differences may be attributed to the higher SOC content ($\rho = 0.6; P < 0.02$) and better structure ($\rho = 0.5; P < 0.04$) in the more conservative uses. The benefit of this improvement in soil water retention is particularly important in the foreseeable scenario of global warming and evapotranspiration increase in Mediterranean areas (Calanca et al., 2006).

Conclusions

Soils subjected to intensive land use, in the present or recent past, are affected in their physical and chemical characteristics. Both soil uses operational and recently abandoned vineyards lost their topsoil layer. These soils show a decrease of 43% in their organic carbon when compared with afforested soils after 40 yr of Quercus tree cover. Consequently, they also manifested less aggregate structural stability and less water-holding capacity. The latter variables are conserved in less intensive soil uses, such as livestock routes, which may be because of the constant inputs from cattle. There are very few available studies that compare different land uses to evaluate how intensive or extensive uses introduce differences in soil properties. This lack of information is even more noticeable when addressing livestock routes. Nevertheless, these long paths could act as a spatial reference to evaluate the conservation or degradation status of the surrounding soils.

More than 4 yr are necessary to observe signs of recovery in these soils after the cessation of tillage. Forty years later, the afforested land shows some improvement in soil conditions, but this soil is still very different from undisturbed soils under native forests described in the literature beneath these climatic conditions. These results are especially important in the semi-arid Spanish landscape, which is dominated by intensive land use and a remarkably low content of soil organic matter.

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