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Land-use change effects on soil quality in Montilla-Moriles DO, Southern Spain

M. Martín-Carrillo, L. Parras-Alcántara, and B. Lozano-García

Department of Agricultural Chemistry and Soil Science, Faculty of Science, Agrifood Campus of International Excellence – ceiA3, University of Cordoba, 14071 Cordoba, Spain

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Correspondence to: L. Parras-Alcántara (qe1paall@uco.es)

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Abstract

The agricultural Mediterranean areas are dedicated to arable crops (AC), but in the last few decades, a significant number of AC has a land use change (LUC) to olive grove cultivations (OG) and vineyards (V). A field study was conducted to determine the long-term effects (46 yr) of LUC (AC by OG and V) and to determine soil organic carbon (SOC), total nitrogen (TN), C:N ratio and their stratification across the soil entire profile, in Montilla-Moriles denomination of origin (DO), in Calcic-Chromic Luvisols (LVcc/cr), an area under semiarid Mediterranean conditions. The experimental design consisted of studying the LUC on one farm between 1965 and 2011. Originally, only AC was farmed in 1965, but OG and V were farmed up to now (2011). This LUC principally affected the thickness horizon, texture, bulk density, pH, organic matter, organic carbon, total nitrogen and C:N ratio. The LUC had a negative impact in the soil, affecting the SOC and TN stocks. The conversion from AC to V and OG involved the loss of the SOC stock (52.7 % and 64.9 % to V and OG respectively) and the loss of the TN stock (42.6 % and 38.1 % to V and OG, respectively). With respect to the soil quality, the effect was opposite; 46 years after LUC improved the soil quality, increasing the stratification ratio (in V and OG) of SOC, TN and C:N ratio.

1 Introduction

The soils play a crucial role in influencing the carbon (C) content of the atmosphere because they can either emit large quantities of CO_2 or on the contrary they can act as a store for C (Smith et al., 2000). Agriculture and forestry can achieve this effect through photosynthesis and the C incorporation into carbohydrates (González-Sánchez et al., 2012). Crops capture CO_2 from the atmosphere during photosynthesis by converting C forms associated with soil organic matter (SOM) for microbial decomposition processes (Johnson et al., 2007). Soil management is one of the best tools for climate change mitigation and adaptation (Lal et al., 2011). Several authors have proposed introducing soil management techniques that combine a restriction on tillage (Corral-Fernández et al., 2013) and the addition of organic residues (Lozano-García et al., 2011; Lozano-García and Parras-Alcántara, 2013) to improving soil properties and diminishing atmospheric CO_2 concentrations.

Carbon sequestration is defined as any increase in the C content of soils after a change in land management (Powlson et al., 2011) and is one of the most important ecosystem services because of its role in climate regulation (IPCC, 2007). Intensive and conventional tillage (CT) may cause enormous losses of soil organic carbon (SOC), thus inducing an increase in soil erosion and a breakage of soil structure (Melero et al., 2009).

Land use change (LUC) is considered the second greatest cause of C emissions after fuel consumption (Watson et al., 2000). LUC has contributed to soil degradation and soil loss, leading to a decrease in soil C storage worldwide (Eaton et al., 2008), and even more intensely in the Mediterranean areas during the last few decades (Cerdà et al., 2010). Long-term experimental studies have confirmed that soil organic carbon (SOC) is highly sensitive to LUC (Smith, 2008). Thus, even a relatively small increase or decrease in soil carbon content due to changes in land use or management practices, may result in a significant net exchange of C between the soil C pool and the atmosphere (Houghton, 2003). Recently, it has been shown that soil erosion by water and/or tillage has a significant impact on this large pool of SOC (Lal, 2003; Van Oost et al., 2005; Van Hemelryck et al., 2011).

Regional-scale information about C stocks and the relationship between C reservoirs and edaphic factors could be relevant to determine LUC that is of interest in evaluating gains and losses of SOC (Novara et al., 2012). In Spanish soils, climate, use and management are highly influential in the C variability, mainly in the dry Mediterranean climate, characterized by a low SOM content (~ 10 g kg^{-1}), which is a weak and degradable structure (Acosta-Martínez et al., 2003).

The soil C:N ratio is a soil fertility indicator due to the close relationship between SOC and total nitrogen (TN). The soil C:N ratio is often influenced by many factors such as

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climate (Miller et al., 2004), soil conditions (Ouédraogo et al., 2006; Yamashita et al., 2006), vegetation types (Diekow et al., 2005; Puget and Lal, 2005), and agricultural management practices (Côté et al., 2000).

The concept of using the stratification ratio (SR) as a soil quality indicator is based on the influence of the SOC surface level in erosion control, water infiltration and nutrient conservation (Franzluebbers, 2002). High SR of SOC and TN pools reflect relatively undisturbed soil with high soil quality of the surface layer. The increase of SR can be related to rate and amount of SOC sequestration (Franzluebbers, 2002).

Soil depth has a decisive influence on SOC stocks (Grüneberg et al., 2010). Some authors have evaluated the SOC content in soil surface (restricted to the upper 15–30 or 50 cm), and few studies have included a deeper section of soil cover (Conant and Paustian, 2002), although vertical processes have a significant impact on SOC variability (VandenBygaart, 2006). Sombrero and Benito (2010) noted that to evaluate and compare SOC storage complete profile is necessary. According to Lorenz and Lal (2005) in temperate climates large amounts of SOC may be stored in subsoil horizons below 30 cm deep. This is essential in LUC because SOC can be transported to a deeper soil horizon, contributing to the subsoil C storage (Lorenz and Lal, 2005). Vertical distribution is one of the features of the organic C store that is not clearly understood together with the relationships with climate and vegetation (Jobbágy and Jackson, 2000). In the last few decades, a significant number of arable crops (AC) have LUC to olive grove cultivations (OG) or vineyards (V) in Montilla-Moriles Denomination of Origin (DO). This LUC has been motivated by subsidies and better olive oil and wine prices.

Very few reports have compared the effect of LUC from AC to OG and V on SOC and TN storages even on soil quality for long-term in soil entire profiles. In this context, the objectives of this work are (i) to determine the SOC content in the soil; (ii) to study its vertical distribution of SOC (entire soil profile by horizons, non-section control); (iii) to analyze the accumulation and SR of SOC, TN and C:N ratio in Calcic-Chromic Luvisols (LVcc/cr) (FAO, 2006) in AC affected by LUC for long-term in conventional tillage.

2 Material and methods

2.1 Site description and experimental design

The study area comprises 33607 ha located in Montilla-Moriles D.O., Cordoba (37°38′–29′ N; 4°45′–31′ W, 432 m a.s.l.). Montilla is the first production center of Montilla-Moriles wines. This DO produced wines with the grapes of the Pedro Ximénez variety.

The parent material is Triassic marl mainly composed by clays, gypsum and salts. The relief is smooth with slopes ranging from 3 % to 8 %. The most abundant soils are Luvisol (LV) and Cambisol (CM), denominated in the study region "alberos and albarizas", although there are Fluvisol (FL), Regosol (RG) and Vertisol (VR) (FAO, 2006). These soils correspond to the upper limit of the Pliocene period (Andaluciense subperiod), which are characterized by the presence of white marls (argyle-containing limestone) typical of the Guadalquivir basin. These are soft soils owing to the presence of limestone, which combines permeability with high water retention. This latter feature is essential for lands with frequent dry spells.

The Montilla-Moriles DO is characterized by cold winters and warm, dry summers with temperatures ranging from −2 °C to 37.8 °C and an average annual rainfall of 602.7 mm. The moisture regime is dry Mediterranean with continental features due to altitude and location.

An unirrigated farm (100 ha) of AC cultivated under conventional tillage (CT) was selected for study in 1965. The soil was a Calcic-Chromic Luvisol (LV cc-cr) (FAO, 2006). In 1966, the study farm (100 ha) was divided into three plots with three different uses (AC, OG and V respectively). The preliminary analyses were realized in 1965 for AC (AC1) and the second analyses were realized in 2011 for AC (AC2), OG and V. In 2011, 22 samples were collected (7 for AC2, 5 for V and 10 for OG) (Figs. 1 and 2). In all cases (AC1, AC2, OG and V) were collected soil entire profiles. Table 1 summarizes the land use class and Table 2 summarize the principal soil properties for the study.

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2.2 Soil sampling and analytical methods

The soil samples were air-dried, ground and sieved through a 2-mm sieve. Soil pH was measured in an aqueous soil extract in deionized water (1:2.5 soil:water) (Guitian and Carballas, 1976). Prior to determining the particle size distribution, the samples were treated with H_2O_2 (6 %) to remove organic matter. The fraction of particles with a diameter greater than 2 mm was determined by wet sieving. Particles measuring < 2 mm were classified according to USDA standards (2004). Soil bulk density was measured by the core method (Blake and hartge, 1986) using a 3.0 cm diameter and 10.0 cm deep core. The distribution of soil particle size was analyzed using the Robinson pipette method (USDA, 2004). SOC were determined by wet oxidation with dichromate according to the Walkley and Black system (1934). TN was determined using the Kjeldahl method (Bremner, 1996). The soil C:N ratio was calculated by dividing the SOC concentration by the TN concentration. The SOC stock (Mg ha^{-1}) was calculated for each horizon according to Wang and Dalal (2006) as follows:

$$\text{SOC stock} = \text{SOC concentration} \times \text{BD} \times d \times (1 - \delta_{2\,\text{mm}}\,\%) \times 0.1 \quad (1)$$

where d is the thickness of the soil layer (cm), $\delta_{2\,\text{mm}}$ is the fractional percentage (%) of > 2 mm gravel in the soil, and BD is the bulk density (Mg m^{-3}). The TN stock (Mg ha^{-1}) was also calculated.

The SRs were calculated from SOC, TN and the C:N ratio data following Franzluebbers (2002). The SR is defined as a soil property on the soil surface divided by the same property at a lower depth. In this study, we defined four SRs ([SR1] for Ap/Ap2-Bt, [SR2] for Ap/Bt-B-Ck, [SR3] for Ap/C-Bt-C and [SR4] for Ap/C2-C-Ck).

The statistical analysis was performed using SPSS 13.0 for Windows. The statistical significance of the differences in the variables between land use practices was tested using an Anderson-Darling test at each horizon or a combination of horizons for each soil type. Differences of $p < 0.05$ were considered statistically significant.

3 Results and discussion

3.1 Soil properties

The studied soil; a LVcc/cr (FAO, 2006) was characterized by exhibited differences in some physical and chemical parameters with depth. The principal characteristic of these soils is a high clay content in the subsoil (Bt horizon) compared to the topsoil (caused by clay migration) (Table 2). Luvisols are well-developed fertile soils that are suitable for a broad variety of uses typically Mediterranean such as cereals, fruit trees, olives and vineyards (Zdruli et al., 2011).

With respect to the soil thickness, there were no significant differences ($p < 0.05$) in time (46 yr) for the same land use (AC1 and AC2), however, the LUC from AC1 to V and OG the soil thickness decreased, ranging from 240 cm in AC1 to 182 cm and 176 cm in V and OG respectively (Table 2). This thickness reduction could be caused by the slope steepness, length, topographic curvature and relative position. In this line, McKenzie and Austin (1993) obtained similar results in Australian soils. By contrast, Bakker et al. (2005) in Lesvos-Greece for LUC (AC to V and pastures to OG) between 1956 and 1996 justified this thickness reduction associated with new mechanized equipment (heavy machinery) and water erosion. These causes could be other reasons to justify the thickness reduction in the studied soils.

These soils are characterized by low OM concentrations in depth, especially in V and OG; this can be explained by the soil textures (sandy soils). González and Candás (2004) found that the formation of OM and mineral aggregates diminishes in the surface horizons of sandy soils, thus favoring high levels of transformed OM, which explain the low OM concentrations at greater depths in the soil studied (Table 2). In addition, Gallardo et al. (2000) explains that the low OM values are explained partly by the semiarid Mediterranean conditions, which are accentuated in Europe's southern soils.

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3.2 Soil organic carbon (SOC), Total Nitrogen (TN) and C:N ratio

In all cases (AC1, V and OG), the SOC concentration decreased in depth with the exception of AC2 caused by the high OM concentration in Bt (Table 2).

According to the study of Hernanz et al. (2009) on rainfed crops of Mediterranean semiarid regions; the soil presents a low OC content owing to the high mineralization of the OM and the absence of harvest residues after periods of drought. On the contrary, soils with the coverage of trees show an increase in C and nitrogen (N) (Albretch and Kandji, 2003); we obtained similar results in topsoil, in V and OG. The SOC we found in AC1 was greater (11.1 g kg^{-1}) than that estimated by Don et al. (2007), who established 10 g kg^{-1} for soils with cereal crops in Spain, which must be caused by the accumulation of litter and dead roots in the topsoil.

TN and the C:N ratio tended to decrease with depth with the exception of AC2. Sá et al. (2001) observed an increase in the soil C:N ratio with deep (AC2), which may be attributed to high C:N soluble organic compounds leaching into deeper layers (Diekow et al., 2005). For OG, this decrease may be a result of the increased soil clay content with depth (Table 2). Higher clay content is often associated with more decomposed OM with a lower C:N ratio (Puget and Lal 2005; Yamashita et al., 2006). In the case of AC1 and V, crop residues could favour a higher soil C:N ratio (Puget and Lal, 2005). Additionally, a residue retention can increase the proportion of SOC (Xu et al., 2011) with a lower decomposition degree and higher C:N ratio (Yamashita et al., 2006). Under AC2 the incorporation of residues into the soil can be uniformly distributed with depths up to 20 cm, or more than 20 cm (Sá and Lal, 2009; Wright et al., 2007). By contrast, under AC1 and V the input of residues is restricted to the topsoil. Consequently, the soil C:N ratio may be stratified to show a declining trend with depths in the upper soil profile. The C:N ratio in the surface soil was higher than in the lower soil horizons, especially in V (12.23:1) and OG (9.44:1), thus indicating high resolution and separation rates. Lal et al. (1995) indicate that C:N ratios are low during resolution

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and separation times. Brady and Weil (2008) show that C:N ratios varies between 8:1 and 15:1, with an average of 12:1.

3.3 Soil Organic Carbon (SOC) and Total Nitrogen (TN) stocks

The SOC stock for soil groups in Peninsular Spain (FAO soil map of peninsular Spain) is 66.0 Mg ha^{-1} for LV and soil uses is 50.5 Mg ha^{-1}, 42.5 Mg ha^{-1} and 39.9 Mg ha^{-1} for AC, V and OG respectively (Rodríguez-Murillo, 2001) and the SOC stock for Andalucía (Map of soil organic carbon content in Andalusia) are 53.2 Mg ha^{-1} and 57.3 Mg ha^{-1} for LV in arable crop and permanent crops respectively (Muñoz-Rojas et al., 2012). The SOC stock was affected by LUC; the highest SOC was found under AC1 (332.6 ± 28 Mg ha^{-1}) followed by AC2 (229.0 ± 32 Mg ha^{-1}), V (157.2 ± 35 Mg ha^{-1}) and OG (116.7 ± 21 Mg ha^{-1}) (Fig. 3). These differences between SOC stocks for soil groups in Peninsular Spain and Andalusia and the study soils are caused by soil thickness (we used soil complete profile – four or five horizons and Rodriguez-Murillo (2001) and Muñoz-Rojas et al. (2012b) used two or three horizons by profile – not entire profile).

We can be observed that the LUC (AC1 to V and OG) and tillage (AC1 to AC2), reduced the total SOC stock in the long term (46 yr) (Fig. 3). The SOC stored varies within the soil profile, with higher values in Bt horizons for AC1, AC2 and OG, however, in V we found higher SOC in the topsoil. In this line, Novara et al. (2012) for LUC from AC to V obtained similar results and explained that this trend may be due to the mixing of the upper soil layers during soil tillage. SOC stock in the surface horizon in AC1 and AC2 varied from 39.7 Mg ha^{-1} to 48.9 Mg ha^{-1}, respectively. González and Candás (2004) in clayey soils found values near 54 Mg ha^{-1} in AC. This difference of SOC stock is caused by the texture because our soils were less clayey and sandier (Table 2). According to Burke et al. (1989) and Leifeld et al. (2005), high values of SOC stock in clayey soils are caused by the stabilization mechanisms of the clays in the soil. This effect can be observed in AC1 and OG, which increased the clay content with respect to AC2 and V. By contrast, SOC stored was higher in the subsoil

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(Bt and Bt/C horizons) in AC1 and AC2, which may be due to the translocation of C in the form of dissolved organic C, soil fauna activity, and/or the effects of deep-rooting crops (Shrestha et al., 2004). On the contrary, Muñoz-Rojas et al. (2012a) for LUC (51-yr period) between 1956 and 2007 in Andalusia (conversion of arable crop to permanent crops) found an increase of SOC for LV (14 %), caused by the limited effect that agricultural management in permanent crops has on SOC sequestration (Smith, 2004). Moreover, Vallejo et al. (2003) indicates that the SOC stock is greater in crop pastures, which is an effect that has also been shown by Nair et al. (2009). Both authors also indicate that the potential for C sequestration in grass systems increases because the roots transfer large amounts of C in the soil slowly and contribute to the increase in the underground C content, which accumulates over time, thus indicating that these systems are more effective in C sequestration than other land uses.

In our study, TN concentrations are elevated in areas where the SOC is high, showing a positive C:N relation (Fig. 3). According to this, clay decreases SOC oxidation and could indicate a positive relationship between clay and nitrogen (Sakin et al., 2010). Some studies (Côté et al., 2000) state that the N mineralization decreases when the clay amount increases in the soil. We obtained similar results in LV as TN decreased when the amount of clay increased. McLauchlan (2006) explained that when clay amounts increase in soil, aggregate amounts increase and the potential N mineralization decreases.

3.4 The effect of LUC on SOC stock, TN and C:N ratio

A fundamental issue has been to analyze the LUC influence. The change from AC1 to AC2 affected the SOC stock that was reduced 31.2 % and the LUC from AC1 to V and OG were reduced 52.7 % and 64.9 %, respectively (Fig. 3). Novara et al. (2012) for LUC from AC to V find an increase of 105 %. Guo and Gifford (2002) reported an increase of 18 % on SOC stock for LUC from AC to plantation.

The loss of SOC stock was caused by tillage (Table 1), AC1 had minimum tillage, with higher biomass production of plantations. As a result, the soil was always covered with vegetation, increasing OM stability, which is corroborated by Novara et al. (2012). The lowest SOC stock was in OG that reduced 64.9 % with respect to AC1. A similar result was obtained by Rodriguez-Murillo (2001) and Padilla et al. (2010), the first for LUC of bushland to OG and the second for LUC of shrubland to OG. This reduction of SOC stock from AC1 to AC2, V and OG, can be explained by a degraded process result of the vegetation losses and an unsustainable soil management resulting in continuous impoverishment in the OM content causing low productivity, which derived in unsuitable chemical properties. Moscatelli et al. (2007) indicated that the SOC loss in cultivated soils could be due to the OM reduced input, as well as to the reduced physical protection of soil from erosion and the increased decomposition rate as a consequence of tillage.

The C:N ratio was higher under AC1 than under AC2, V and OG (Fig. 3). This is in line with the results of Blanco-Canqui and Lal (2008) and Lou et al. (2012), which may be explained by the higher contribution of residue input under different tillage.

In OG and V, SOC storage at surface depth (Ap horizon) was high than in the rest of the profile (Fig. 3), West and Post (2002), Puget and Lal (2005), Blanco-Canqui and Lal (2008), argued that SOC stock on surface horizon is greater than in deep due to tillage and in turn increasing the physical protection of native SOC from microbial decomposition. However, AC1 can increase C inputs into surface soil by enhancing crop biomass and in turn residue return. With respect to Bt horizon, this relation was inverse (SOC increased in Bt with respect to Ap horizon). This effect can be explained by soil texture (sandy soils) and tillage, because, native SOC can be reduced on the surface, which may be attributed to soluble organic compounds that can be leaching into deeper layers, increasing the soil aggregates. A similar result was obtained by Diekow et al. (2005).

Franzluebbers and Arshad (1996) and Melero et al. (2009) suggest that minimum tillage can increase SOC under longer experimental duration. We confirmed this because in AC1 increased SOC stock and the LUC and tillage for long-term (40 yr) reduced SOC stock.

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3.5 Stratification of SOC, TN and the C:N ratio

In all cases, the SR of SOC increased in deep with the exception of AC2 (Fig. 4), caused by the low SOC concentration in Ap2/B (transitional horizon between Ap and Bt, caused by the heavy machinery). The SR of SOC for surface to depth [SR1, SR2, SR3 and SR4] increased due to LUC in all situations (AC2, V and OG) (Fig. 4). The LUC improved soil quality because LUC caused alterations in the soil's physical and chemical properties and the soil biotic community (Caravaca et al., 2002). For degraded soils, the SR of SOC is low and occasionally reaches a value of 2.0 (Franzluebbers, 2002). Other studies have shown that SR ranges from 1.1 to 1.9 for conventional tillage (Franzluebbers, 2002; Franzluebbers et al., 2007; Hernanz et al., 2009; Sá and Lal, 2009). Higher SR of SOC is a consequence of the accumulation of surface SOC due to straw soil surface coverage and root distribution change.

The SR of TN showed a similar trend in the SR of SOC. The SR of C:N ratio increased in depth, in AC1 and OG, but had no significant differences with respect to soil use. This can be explained by a higher contribution of residue relative to root inputs leading a higher soil C:N ratio (Puget and Lal, 2005). Under AC1, the residue input could have been concentrated on the surface due to straw soil surface coverage, so the soil C:N ratio was stratified. This slight change in C:N ratio suggests the decomposition degree of SOC decreases toward the surface (Lou et al., 2012). This suggests little effect in the LUC and tillage system on the carbon accumulation in the soil. Balesdent and Balabane (1996) do not find any significant differences in SR, in a Geauga farm (Ohio). In AC2, V and OG had ensured the supply of OM from the surface horizons to a deeper horizon, which suggested an accumulation of carbon in the profile under these systems.

The higher soil quality was OG and V, compared to AC1 and A2 was probably due to the presence of a herb layer and the low herbicide applications. The important role of a herb layer, in both protecting soil from the erosion process (Novara et al., 2011)

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and contributing to SOM content, might explain the similarity among the characteristics of the OG and V.

4 Conclusions

The LUC has a negative impact in the soil, reducing the SOC and TN stocks. The SOC stored varies along the profile, with higher values in the Ap horizon (caused by the mixing of the upper soil layers during soil tillage) and Bt horizons (due to the translocation of C in the form of dissolved organic C, soil fauna activity, and/or the effects of deep-rooting crops). TN concentrations were high in areas where the SOC was high, showing a positive C:N relation.

The reduction of SOC by LUC, can be explained by a degraded process (due to vegetation losses and unsustainable soil management, which result in progressive impoverishment in the SOM content, causing low productivity, which derived in unsuitable chemical properties) and by the reduced input of OM in cultivated soils, which reduced physical protection of soil and increased water erosion. However, with respect to the soil quality, 46 yr of LUC had a positive effect in the soil, increasing the SR (in V and OG) of SOC, TN and C:N ratio, caused by the reduction in depth of the SOC and TN.

In general, the LUC reduces the SOC and TN concentrations and by contrast increases the soil quality (SR). The use of entire profiles is necessary in these soils because in temperate climates, large amounts of SOC, may be stored in subsoil horizons. This is essential in LUC because SOC can be transported to deeper soil horizons, contributing to the subsoil C storage.

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References

Acosta-Martínez, V., Klose, S., and Zobeck, T. M.: Enzime activities in semiarid soils under conservation reserve program, native rangeland, and cropland, J. Soil Sci. Plant Nut., 166, 699–707, 2003.

Albretch, A. and Kandji, S.: Carbon sequestration in tropical agroforestry systems, Agric. Ecosyst. Environ., 99, 15–27, 2003.

Balesdent, J. and Balabane, M.: Major contribution of roots to soil carbon storage inferred from maize cultivated soils, Soil Biol. Biochem., 28, 1261–1263, 1996.

Bakker, M. M., Govers, G., Kosmas, C., Vanacker, V., Oost, K., and Rounsevell, M.: Soil erosion as a driver of land-use change, Agric. Ecosyst. Environ., 105, 467–481, 2005.

Blanco-Canqui, H. and Lal, R.: No-tillage and soil-profile carbon sequestration: an on farm assessment, Soil Sci. Soc. Am. J., 72, 693–701, 2008.

Blake, G. R. and Hartge, K. H.: Bulk density, in: Methods of Soil Analysis: Part 1, Physical and Mineralogical Methods, 2nd Edn., edited by: Klute, A., Am. Soc. Agr., Madison, WI, 363–375, 1986.

Brady, C. and Weil R. R.: The nature and properties of soils. 14th ed. Pearson Prentice Hall, Upper Saddle River, New Jersey Columbus, Ohia, USA, 2008.

Bremner, J. M.: Total nitrogen, in: Methods of Soil Analysis: Chemical Methods, Soil Sci. Soc. Am., edited by: Sparks, D. L., Madison, WI, 1085–1086, 1996.

Burke, I., Yonker, C., Parton, W., Cole, C., Flach, K., and Schimel, D.: Texture, climate, and cultivation effects on soil organic matter content in US grassland soils, Soil Sci. Soc. Am. J., 53, 800–805, 1989.

Caravaca, F., Masciandaro, G., and Ceccanti, B.: Land use in relation to chemical and biochemical properties in semiarid Mediterranean environment, Soil Till. Res., 68, 23–30, 2002.

Cerdà, A., Lavee, H., Romero-Díaz, A., Hooke, J., and Montanarella, L.: Soil erosion and degradation in Mediterranean type ecosystems, Preface. Land Degrad. Dev., 21, 71–74, 2010.

Conant, R. T. and Paustian, K.: Potential soil carbon sequestration in overgrazed grassland ecosystems, Glob. Biogeochem. Cy., 16, 1142–1143, 2002.

Corral-Fernández, R., Parras-Alcántara, L., and Lozano-García, B.: Stratification ratio of soil organic C, N and C:N in Mediterranean evergreen oak woodland with conventional and organic tillage, Agric. Ecosyst. Environ., 164, 252–259, 2013.

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Côté, L., Brown, S., Paré, D., Fyles, J., and Bauhus, J.: Dynamics of carbon and nitrogen mineralization in relation to stand type, stand age and soil texture in the boreal mixedwood, Soil Biol. Biochem., 32, 1079–1090, 2000.

Diekow, J., Mielniczuk, J., Knicker, H., Bayer, C., Dick, D. P., and Kögel-Knabner, I.: Soil C and N stocks as affected by cropping systems and nitrogen fertilisation in a southern Brazil Acrisol managed under no-tillage for 17 years, Soil Till. Res., 81, 87–95, 2005.

Don, A., Schumacher, J., Scherer-Lorenzen, M., Scholten, T., and Schulze, E.: Spatial and vertical variation of soil carbon at two grassland sites. Implications for measuring soil carbon stocks, Geoderma, 141, 272–282, 2007.

Eaton, J. M., McGoff, N. M., Byrne, K. A., Leahy, P., and Kiely, G.: Land cover change and soil organic C stocks in the Republic of Ireland 1851–2000, Clim. Change, 91, 317–334, 2008.

FAO: World reference base for soil resources, World Soil Resources Reports 103, Roma, 2006.

Franzluebbers, A. J.: Soil organic matter stratification ratio as an indicator of soil quality, Soil Till. Res., 66, 95–106, 2002.

Franzluebbers, A. J. and Arshad, M. A.: Soil organic matter pools during early adoption of conservation tillage in northwestern Canada, Soil Sci. Soc. Am. J., 60, 1422–1427, 1996.

Gallardo, A., Rodríguez-Saucedo, J., Covelo, F., and Fernández-Ales, R.: Soil Nitrogen heterogeneity in dehesa ecosystem, Plant Soil, 222, 71–82, 2000.

González, J. and Candás, M.: Materia orgánica de suelos bajo encinas. Mineralización de carbono y nitrógeno, Invest. Agrar. Sist. Recur. For., Fuera de serie, 75–83, 2004.

González-Sánchez, E. J., Ordóñez-Fernández, R., Carbonell-Bojollo, R., Veroz-González, O., and Gil-Ribes, J. A.: Meta-analysis on atmospheric carbon capture in Spain through the use of conservation agriculture, Catena, 122, 52–60, 2012.

Grüneberg, E., Schöning, I., Kalko, E. K. V., and Weisser, W. W.: Regional organic carbon stock variability: A comparison between depth increments and soil horizons, Geoderma, 155, 426–433, 2010.

Guitian, F. and Carballas, T.: Técnicas de Análisis de Suelos, Edit. Picro Sacro, Santiago de Compostella, España, 1976.

Guo, L. B. and Gifford, R. M.: Soil carbon stocks and land use change: a meta analysis, Glob. Change Biol., 8, 345–360, 2002.

Hernanz, J. L., Sanchez-Giron, V., and Navarrete, L.: Soil carbon sequestration and stratification in a cereal/leguminous crop rotation with three tillage systems in semiarid conditions, Agric. Ecosyst. Environ., 133, 114–122, 2009.

Houghton, R. A.: Why are estimates of the terrestrial carbon balance so different?, Glob. Change Biol., 9, 500–509, 2003.
IPCC.: Climate change 2007: the physical science basis. Cambridge University Press: Cambridge/New York, NY, 2007.
Jobbágy, E. G. and Jackson, R. B.: The vertical distribution of soil organic carbon and its relation to climate and vegetation, Ecol. Appl., 104, 423–436, 2000.
Johnson, J. M., Franzluebbers, A. J., Lachnicht-Weyers, S., and Reicosky, D. C.: Agricultural opportunities to mitigate greenhouse gas emissions, Environ. Pollut., 150, 107–124, 2007.
Lal, R.: Soil erosion and the global carbon budget, Environ. Internat., 29, 437–450, 2003.
Lal, R., Kimble, J., and Stewart, B. A.: World Soils as a or sink for radio-active gases, in: Soil management and greenhouse effect, edited by: Jorgensen, B. B., Lewis, London, 1–7, 1995.
Lal, R., Delgado, J. A., Groffman, P. M., Millar, N., Dell, C., and Rotz, A.: Management to mitigate and adapt to climate change, J. Soil Water Conserv., 66, 276–285, 2011.
Leifeld, J., Bassin, S., and Fuhrer, J.: Carbon Stocks in Swiss agricultural soils predicted by Land use, Soil characteristics and altitude, Agric. Ecosyst. Environ., 105, 255–266, 2005.
Lorenz, K. and Lal, R.: The depth distribution of organic soil carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons, Adv. Agron., 88, 35–66, 2005.
Lou, Y., Xu, M., Chen, X., He, X., and Zhao, K.: Stratification of soil organic C, N and C:N ratio as affected by conservation tillage in two maize fields of China, Catena, 95, 124–130, 2012.
Lozano-García, B., Parras-Alcántara, L., and Del Toro, M.: The effects of agricultural management with oil mill by-products on surface soil properties, runoff and soil losses in southern Spain, Catena, 85, 187–193, 2011.
Lozano-García, B. and Parras-Alcántara, L.: Short-term effects of olive mill by-products on soil organic carbon, total N, C:N ratio and stratification ratios in a Mediterranean olive grove, Agric. Ecosyst. Environ., 165, 68–73, 2013.
McKenzie, N. J. and Austin, M. P.: A quantitative Australian approach to medium and small scale surveys based on soil stratigraphy and environmental correlation, Geoderma, 57, 329–355, 1993.
McLauchlan, K. K.: Effect of soil texture on soil carbon and nitrogen dynamic after cessation of agriculture, Geoderma, 136, 289–299, 2006.

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5, 163–187, 2013
Land-use change effects on soil quality in Montilla-Moriles DO
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Melero, S., López-Garrido, R., Murillo, J. M., and Moreno, F.: Conservation tillage: Short- and long-term effects on soil carbon fractions and enzymatic activities under Mediterranean conditions, Soil Till. Res., 104, 292–298, 2009.
Miller, A. J., Amundson, R., Burke, I. C., and Yonker, C.: The effect of climate and cultivation on soil organic C and N, Biogeochemistry, 67, 57–72, 2004.
Moscatelli, M. C., Di Tizio, A., Marinari, S., and Grego, S.: Microbial indicators related to soil carbon in Mediterranean land use systems, Soil Till. Res., 97, 51–59, 2007.
Muñoz-Rojas, M., Jordán, A., Zavala, L. M., De la Rosa, D., Abd-Elmabod, S. K., and Anaya-Romero, M.: Impact of land use and land cover changes on organic carbon stocks in Mediterranean soils (1956–2007), Land Degrad. Dev., doi:10.1002/ldr.2194, 2012a.
Muñoz-Rojas, M., Jordán, A., Zavala, L. M., De la Rosa, D., Abd-Elmabod, S. K., and Anaya-Romero, M.: Organic carbon stocks in Mediterranean soil types under different land uses (Southern Spain), Solid Earth, 3, 375–386, 2012b.
Nair, P. K., Kumar, B., and Nair, D.: Agroforestry as a strategy for carbon sequestration, J. Soil Sci. Plant Nut., 172, 10–23, 2009.
Novara, A., Gristina, L., Saladino, S. S., Santoro, A., and Cerdá, A.: Soil erosion assessment on tillage and alternative soil managements in a Sicilian vineyard, Soil Till. Res., 117, 140–147, 2011.
Novara, A., La Mantia, T., Barbera, V., and Gristina, L.: Paired-site approach for studying soil organic carbon dynamics in a Mediterranean semiarid environment, Catena, 89, 1–7, 2012.
Ouédraogo, E., Mando, A., and Stroosnijder, L.: Effects of tillage, organic resources and nitrogen fertiliser on soil carbon dynamics and crop nitrogen uptake in semi-arid West Africa, Soil Till. Res., 91, 57–67, 2006.
Padilla, F. M., Vidal, B., Sánchez, J., and Pugnaire, F. I.: Land-use changes and carbon sequestration through the twentieth century in a Mediterranean mountain ecosystem: implications for land management, J. Environ. Manage., 91, 2688–2695, 2010.
Powlson, D. S., Whitmore, A. P., and Goulding, K. W. T.: Soil C sequestration to mitigate climate change: a critical re-examination to identify the true and the false, Eur. J. Soil Sci., 62, 42–55, 2011.
Puget, P. and Lal, R.: Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use, Soil Till. Res., 80, 201–213, 2005.
Rodríguez-Murillo, J. C.: Organic carbon content under different types of land use and soil in peninsular Spain, Biol. Fertil. Soils, 33, 53–61, 2001.

Sá, J. C. M., Cerri, C. C., Dick, W. A., Lal, R., Venske-Filho, S. P., Piccolo, M. C., and Feigl, B. E.: Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a Brazilian Oxisol, Soil Sci. Soc. Am. J., 65, 1486–1499, 2001.
Sá, J. C. M. and Lal, R.: Stratification ratio of soil organic matter pools as an indicator of carbon sequestration in a tillage chronosequence on a Brazilian Oxisol, Soil Till. Res., 103, 46–56, 2009.
Sakin, E., Deliboran, A., Sakin, E. D., and Tutar, E.: Organic and inorganic carbon stock and balance of Adana city soils in Turkey, African J. Agric. Res., 5, 2737–2743, 2010.
Shrestha, B. M., Sitaula, B. K., Singh, B. R., and Bajracharya, R. M.: Soil organic carbon stocks in soil aggregates under different land use systems in Nepal, Nutr. Cycl. Agroecosys., 70, 201–213, 2004.
Smith, P.: C sequestration in croplands: the potential in Europe and the global context, Europ. J. Agronomy, 20, 229–236, 2004.
Smith, P.: Land use change and soil organic carbon dynamics, Nutr. Cycl. Agroecosys., 81, 169–178, 2008.
Smith, P., Powlson, D. S., Smith, J. U., Fullon, P., and Coleman, K.: Meeting Europe's climate change commitments: quantitative estimates of the potential for carbon mitigation by agriculture, Glob. Change Biol., 6, 525–539, 2000.
Sombrero, A. and de Benito, A.: Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon, Spain, Soil Till. Res., 107, 64–70, 2010.
USDA.: Soil survey laboratory methods manual, Soil survey investigation report No. 42, Version 4.0, USDA-NCRS, Lincoln, NE, 2004.
Vallejo, R., Díaz Fierro, F., and De la Rosa, D.: Impactos sobre los recursos edáficos, in: Impactos del cambio climático en España, edited by: MMA, Madrid, 355–397, 2003.
Van Oost, K., Govers, G., Quine, T. A., Heckrath, G., Olesen, J. E., De Gryze, S., and Merckx, R.: Landscape-scale modeling of carbon cycling under the impact of soil redistribution: the role of tillage erosion, Glob. Biogeochem. Cy., 19, GB4014, doi:10.1029/2005GB002471, 2005.
VandenBygaart, A. J.: Monitoring soil organic carbon stock changes in agricultural landscapes: issues and a proposed approach, Can. J. Soil Sci., 86, 451–463, 2006.
Walkley, A. and Black, I. A.: An examination of the Degtjareff method for determining soil O.M. and a proposed modification of the chromic acid titration method, Soil Sci., 37, 29–38, 1934.

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5, 163–187, 2013

Wang, W. J. and Dalal, R. C.: Carbon inventory for a cereal cropping system under contrasting tillage. Nitrogen fertilisation and stubble management practices, Soil Till. Res., 91, 68–74, 2006.

Watson, R. T., Noble, I. R., Bolin, B., Ravindramath, N. H., Verardo, D. J., and Dokken, D. J.: Land-use, Land-use change, and Forestry (A Special Report of the IPCC), Cambridge University Press, Cambridge, 2000.

West, T. O. and Post, W. M.: Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis, Soil Sci. Soc. Am. J., 66, 1930–1946, 2002.

Wright, A. L., Hons, F. M., Lemon, R. G., McFarland, M. L., and Nichols, R. L.: Stratification of nutrients in soil for different tillage regimes and cotton rotations, Soil Till. Res., 96, 19–27, 2007.

Xu, M., Lou, Y., Sun, X., Wang, W., Baniyamuddin, M., and Zhao, K.: Soil organic carbon active fractions as early indicators for total carbon change under straw incorporation, Biol. Fert. Soil., 47, 745–752, 2011.

Yamashita, T., Feiner, H., Bettina, J., Helfrich, M., and Ludwig, B.: Organic matter in density fractions of water-stable aggregates in silty soils: effect of land use, Soil Biol. Biochem., 38, 3222–3234, 2006.

Zdruli, P., Kapur, S., and Çelik, I.: Soils of the Mediterranean Region. Their characteristics, management and sustainable use, in: Sustainable land management learning from the past for the future, edited by: Kapur, S., Eswaran, H., and Blum, W.E.H., Springer-Verlag, Berlin, 125–142, 2011.

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Table 1. Land use categories and class in Montilla-Moriles DO.

Land use	Abbreviation	Year	Characteristics	
Arable crop	AC1	1965	Rudimentary machinery Minimum tillage	Systems using animal power (plow with mules) with lightweight reversible plows. Non-mineral fertilization or pesticides.
Arable crop	AC2	2006	Heavy machinery	Winter crop rotation with annual wheat and barley. Mineral fertilization or pesticides.
Vineyard	V	2006	News mechanized equipment Conventional tillage	Vineyard planted on traditional espalier. Mineral fertilization or pesticides. Three or five chisel passes a year to a depth of 15 to 20 cm from early spring to early autumn.
Olive groves	OG	2006		Annual passes with disk harrow and cultivator in the spring, followed by a tine harrow in the summer. Mineral fertilization, pesticides and weed control with residual herbicides.

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Table 2. Basic physical and chemical properties for Calcic/Chromic Luvisol in Arable land (wheat and barley annual rotation), Vineyard and Olive groves. AC1: Arable crop 1965, AC2: Arable crop 2006, V: Vineyard 2006, OG: Olive groves 2006. Data are means ±SD (n = 5, 7, 5, 10). Hor. = Horizon type. *No significant data for Stratification Ratio (SR).

Soil	Hor.	Depth cm	Thickness cm	Gravel %	Sand %	Silt %	Clay %	Bulk density Mg m^{-3}	pH H_2O	OM g kg^{-1}	SOC g kg^{-1}	Total SOC g kg^{-1}	TN g kg^{-1}	Total TN g kg^{-1}	C/N
	Ap	0–25	25 ± 3.1	1.5 ± 0.8*	29.8 ± 2.2	13.3 ± 1.8	56.9 ± 2.9	1.43 ± 0.21	7.1 ± 0.3	19.0 ± 1.1	11.1 ± 1.2		0.89 ± 0.02		12.47
	Bt	25–80	55 ± 4.2	0.9 ± 0.4*	27.1 ± 2.8	10.8 ± 3.4	62.1 ± 2.1	1.53 ± 0.12	7.2 ± 0.7	17.4 ± 1.0	10.1 ± 0.5		0.75 ± 0.06		13.47
AC1 n = 5	B/C	80–115	35 ± 3.3	1.3 ± 0.5*	21.5 ± 2.1	25.7 ± 2.7	52.8 ± 3.1	1.58 ± 0.31	7.7 ± 0.4	15.8 ± 0.7	9.2 ± 0.2	44.9	0.71 ± 0.02	3.55	12.96
	C1	115–185	70 ± 6.3	1.2 ± 0.3*	25.4 ± 3.2	30.7 ± 4.1	43.9 ± 6.2	1.69 ± 0.21	7.6 ± 0.8	13.8 ± 0.6	8.1 ± 0.6		0.67 ± 0.17		12.09
	C2	185–240	55 ± 4.1	2.4 ± 1.1	29.9 ± 5.3	33.6 ± 3.2	36.5 ± 3.9	1.74 ± 0.34	7.7 ± 0.3	11.0 ± 0.8	6.4 ± 0.5		0.53 ± 0.09		12.07
	Ap	0–36	36 ± 2.2	3.3 ± 0.9	32.8 ± 3.1	41.6 ± 3.4	25.6 ± 3.2	1.43 ± 0.16	7.6 ± 0.9	16.2 ± 2.4	9.5 ± 1.2		1.53 ± 0.06		7.97
	Ap2/B	36–74	38 ± 3.5	3.1 ± 0.5	28.5 ± 2.7	32.2 ± 1.7	39.3 ± 2.8	1.45 ± 0.34	7.5 ± 0.4	10.7 ± 1.7	6.3 ± 0.6		0.86 ± 0.03		7.32
AC2 n = 7	Bt	74–113	39 ± 3.6	2.4 ± 1.5	35.1 ± 4.3	28.3 ± 4.2	36.6 ± 4.6	1.43 ± 0.11	7.6 ± 0.6	13.1 ± 0.8	7.7 ± 0.3	31.8	0.98 ± 0.02	3.99	7.86
	Bt/C	113–218	105 ± 6.2	2.3 ± 0.8	29.9 ± 2.6	42.2 ± 4.8	27.9 ± 3.7	1.47 ± 0.36	7.9 ± 0.4	9.5 ± 1.6	5.6 ± 0.5		0.62 ± 0.05		9.03
	C/Ck	218–256	38 ± 2.1	2.9 ± 0.9	45.4 ± 9.8	33.6 ± 2.6	21.0 ± 1.6	1.57 ± 0.48	7.8 ± 0.3	4.6 ± 0.9	2.7 ± 0.5		0.35 ± 0.06		7.71
	Ap	0–35	35 ± 1.8	3.3 ± 1.1	39.3 ± 3.4	46.4 ± 3.1	14.3 ± 2.1	1.42 ± 0.31	8.1 ± 0.7	21.6 ± 1.2	12.6 ± 0.9		1.03 ± 0.05		12.23
	Bt	35–72	37 ± 2.9	3.0 ± 0.9	42.0 ± 2.7	34.0 ± 2.9	24.0 ± 3.1	1.47 ± 0.26	8.1 ± 0.2	10.5 ± 0.6	6.1 ± 0.5		0.63 ± 0.03		9.68
V n = 5	B/Ck	72–115	43 ± 6.5	1.8 ± 0.6*	40.5 ± 5.1	40.1 ± 3.9	19.4 ± 2.3	1.51 ± 0.21	8.3 ± 0.6	7.5 ± 0.3	4.4 ± 0.2	29.5	0.55 ± 0.01	2.81	8.00
	C1	115–150	35 ± 2.4	1.4 ± 0.3*	43.4 ± 4.8	33.8 ± 4.5	22.8 ± 3.9	1.51 ± 0.14	8.3 ± 0.8	7.0 ± 0.6	4.1 ± 0.4		0.33 ± 0.06		12.42
	C2k	150–182	32 ± 3.2	2.3 ± 0.7	30.6 ± 3.7	41.6 ± 5.7	27.8 ± 3.4	1.51 ± 0.22	8.4 ± 0.1	3.9 ± 0.4	2.3 ± 0.3		0.27 ± 0.03		8.52
	Ap	0–27	27 ± 3.9	2.3 ± 0.3	29.4 ± 2.4	14.9 ± 6.7	38.5 ± 1.2	1.25 ± 0.24	7.9 ± 0.5	17.3 ± 2.4	10.1 ± 1.1		1.07 ± 0.06		9.44
	Ap/Bt	27-37	10 ± 1.2	1.5 ± 0.5*	32.1 ± 3.7	34.7 ± 2.5	33.2 ± 2.5	1.39 ± 0.32	7.9 ± 0.7	11.1 ± 1.7	6.5 ± 0.6		0.87 ± 0.03		7.47
OG n = 10	Bt1	37–85	48 ± 9.4	0.7 ± 0.4*	30.1 ± 6.2	26.4 ± 4.6	45.3 ± 6.3	1.29 ± 0.12	8.0 ± 0.6	8.7 ± 0.2	5.1 ± 0.5	28.8	0.85 ± 0.04	3.84	6.00
	Bt2/BC	85–109	24 ± 2.6	1.1 ± 0.3*	22.2 ± 5.4	31.3 ± 5.4	46.5 ± 6.1	1.31 ± 0.17	8.0 ± 0.1	6.3 ± 0.6	3.7 ± 0.6		0.53 ± 0.07		6.98
	C	109–176	67 ± 4.2	1.2 ± 0.4*	29.1 ± 3.6	32.8 ± 3.8	38.1 ± 3.4	1.33 ± 0.21	8.1 ± 0.1	5.7 ± 0.3	3.4 ± 0.4		0.52 ± 0.06		6.54

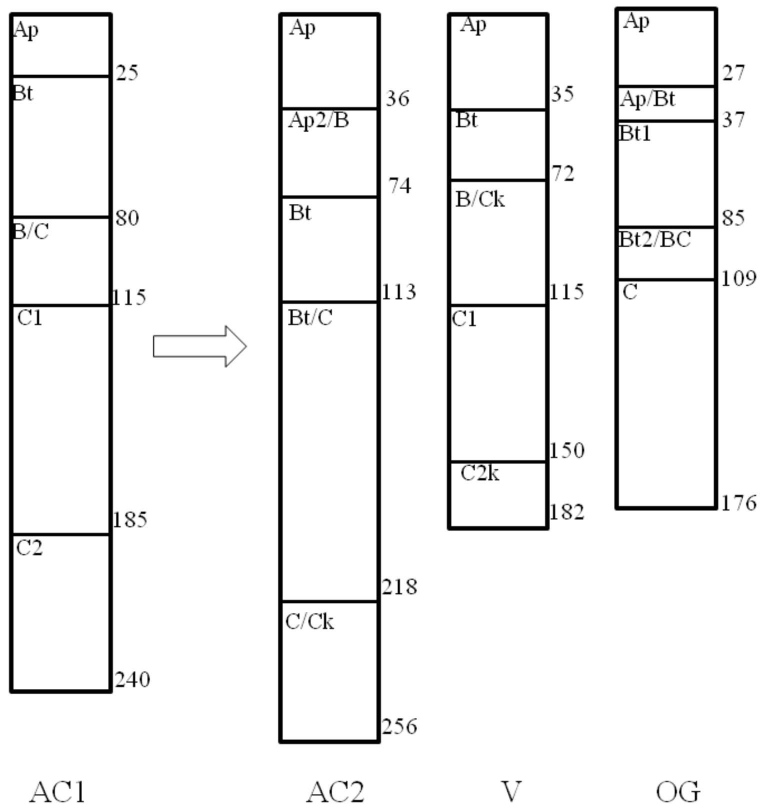

Fig. 1. Soil entire profiles. AC1 (arable crop in 1965), affect by land use conversion (LUC) to AC2 (arable crop), V (vineyard) and OG (olive groves). The LUC was in 1965 (AC1), after the 41 yr, AC2, V and OG. (Numbers are soil thickness).

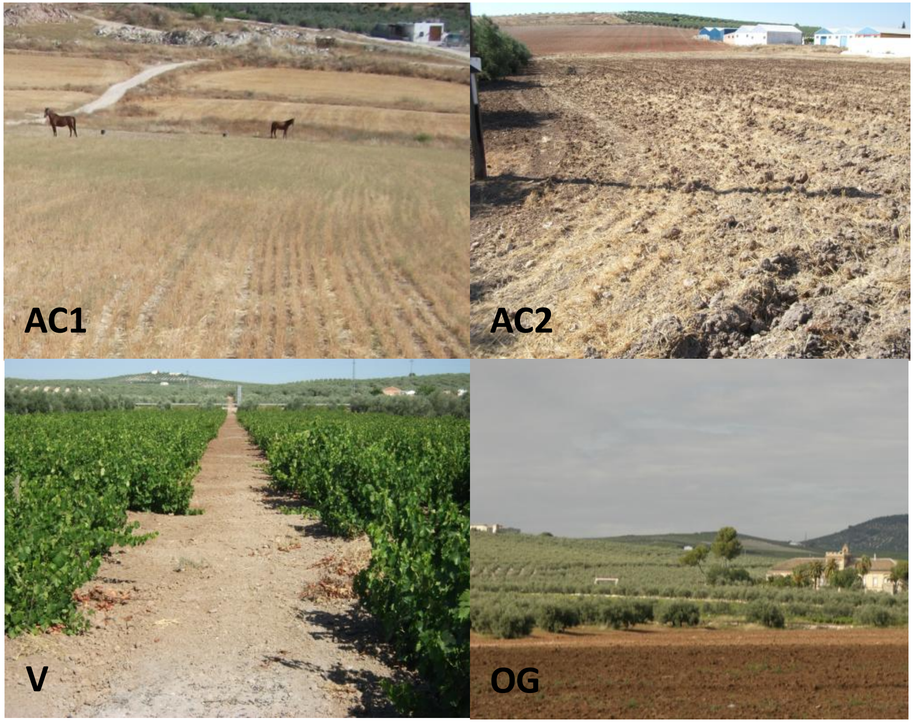

Fig. 2. Montilla-Moriles DO (AC1) Arable crop, systems using animal power (plow with mules) with lightweight reversible plows. (AC2) Arable crop, heavy machinery – news mechanized equipment. (V) Vineyard modern. (OG) Olive groves.

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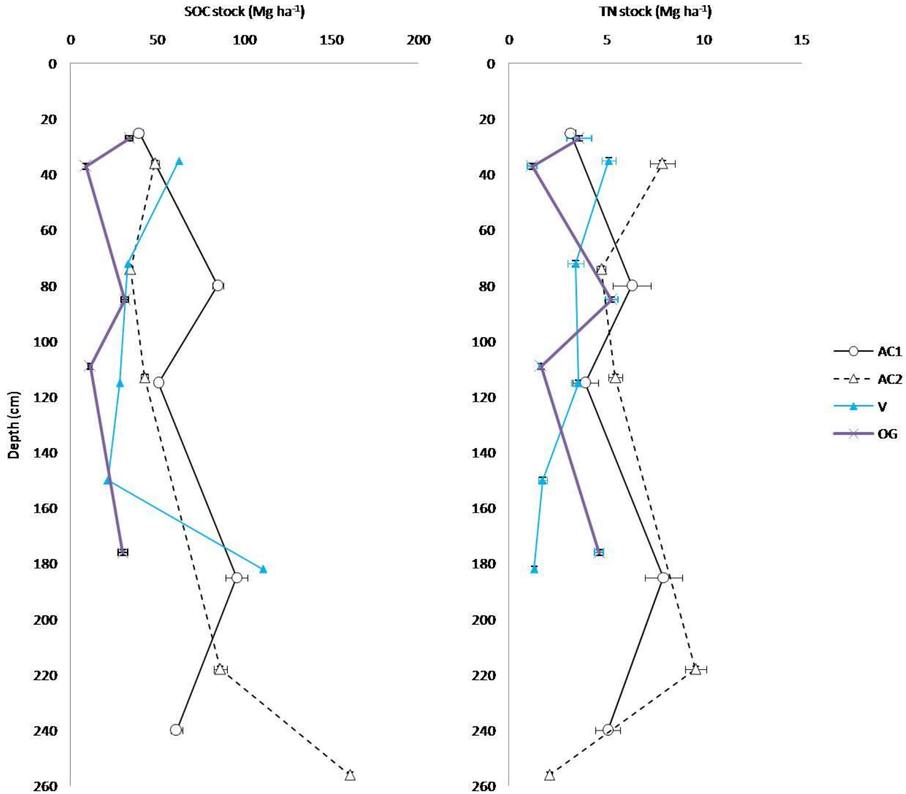

Fig. 3. Depth distribution of SOC stock and TN stock under arable crop (AC1), arable crop (AC2), Vineyard (V) and Olive groves (OG). Data are means ±SD ($n = 5, 7, 5, 10$).

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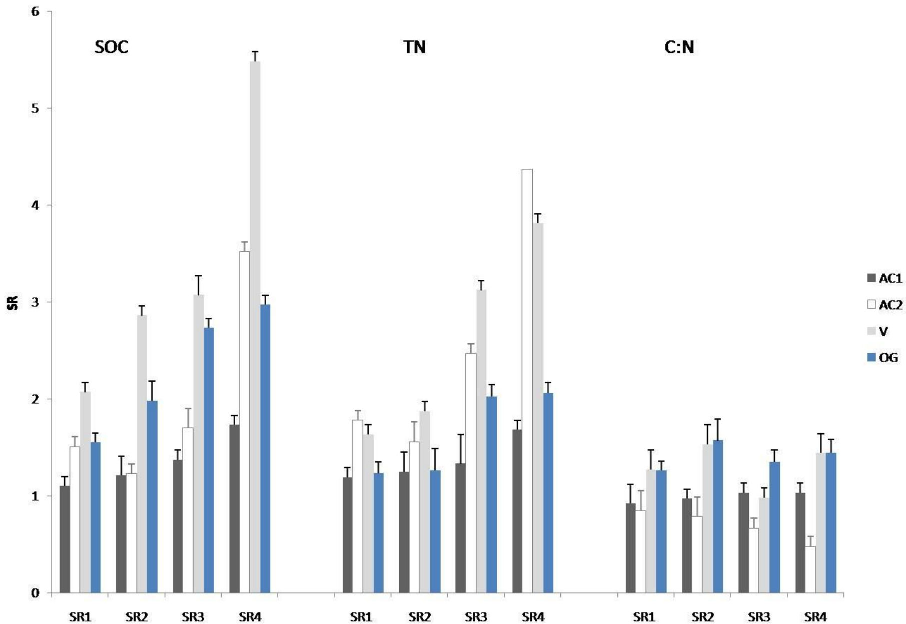

Fig. 4. Stratification ratios (SR) of SOC concentrations, TN concentrations and C:N ratios under arable crop (AC1), arable crop (AC2), Vineyard (V) and Olive groves (OG). Data are means ±SD ($n = 5, 7, 5, 10$).

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