

Impacts of land use change in soil carbon and nitrogen in a Mediterranean agricultural area (Southern Spain)

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Abstract

The agricultural Mediterranean areas are dedicated to arable crops (AC), but in the last decades, a significant number of AC has a land use change (LUC) to olive grove (OG) and vineyards (V) cultivations. A field study was conducted to determine the long-term effects (46 years) 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 (D.O.), 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 stratification ratios (SRs), the effects were opposite; 46 years after LUC increased the SRs (in V and OG) of SOC, TN and C:N ratio.

1 Introduction

Soils play a key role in the carbon (C) geochemical cycle because they can either emit large quantities of CO₂ or on the contrary they can act as a store for C (Smith et al., 2000). Agriculture and forestry can contribute to C sequestration through photosynthesis and the

1 incorporation of C into carbohydrates (González-Sánchez et al., 2012). Crops capture CO₂
2 from the atmosphere during photosynthesis into soil organic matter (SOM). Degradation of
3 SOM by microbial processes may be limited by aggregate stability, adsorption by clays or the
4 formation of organo-mineral complexes (Johnson et al., 2007; Lal, 1997). Soil management is
5 one of the best tools for climate change mitigation and adaptation (Lal et al., 2011). Several
6 authors have proposed introducing soil management techniques that combine a restriction on
7 tillage (Corral-Fernández et al., 2013) and the addition of organic residues (Lozano-García et
8 al., 2011; Lozano-García and Parras-Alcántara 2013) to improve soil quality and favor C
9 sequestration into soils.

10 Carbon sequestration is defined as a net additional transfer of C from atmospheric CO₂ to
11 soils after a change in land management (Powlson et al., 2011). Therefore, C sequestration
12 into soils is one of the most important ecosystem services because of its role in climate
13 regulation (IPCC, 2007). Intensification of agriculture and/or transformation of conventional
14 tillage (CT) practices, may cause enormous losses of soil organic carbon (SOC), thus
15 inducing an increase in soil erosion and a breakage of soil structure (Melero et al., 2009).
16 Land use change (LUC) is considered the second greatest cause of C emissions after fuel
17 consumption (Watson et al., 2000). LUC has contributed to soil degradation and soil loss,
18 leading to a decrease in soil C storage worldwide (Eaton et al., 2008), and even more
19 intensely in the Mediterranean areas during the last few decades (Cerdà et al., 2010). Long-
20 term experimental studies have confirmed that SOC is highly sensitive to LUC (Smith, 2008).
21 Thus, even a relatively small increase or decrease in soil carbon content due to changes in
22 land use or management practices, may result in a significant net exchange of C between the
23 soil C pool and the atmosphere (Houghton, 2003). Recently, it has been shown that soil
24 erosion by water and/or tillage has a significant impact on this large pool of SOC (Lal, 2003;
25 Van Oost et al., 2005; Van Hemelryck et al., 2011).

26 Regional-scale information about C stocks and the relationship between C reservoirs and
27 edaphic factors could be relevant to determine LUC that is of interest in evaluating gains and
28 losses of SOC (Novara et al., 2012). In Spanish soils, climate, use and management are highly
29 influential in the C variability (Muñoz-Rojas et al., 2012; Rodríguez-Murillo et al., 2001;
30 Ruiz et al., 2012), mainly in semiarid regions, characterized by low levels of SOM content
31 (~10 g kg⁻¹) (Acosta-Martínez et al., 2003).

1 The soil C:N ratio is a soil fertility indicator due to the close relationship between SOC and
2 total nitrogen (TN). The soil C:N ratio is often influenced by many factors such as climate
3 (Miller et al., 2004), soil conditions (Ouédraogo et al., 2006; Yamashita et al., 2006),
4 vegetation types (Diekow et al., 2005; Puget and Lal, 2005), and agricultural management
5 practices (Zhang et al., 2009).

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

11 Soil depth has a decisive influence on SOC stocks (Grüneberg et al., 2010). Some authors
12 have evaluated the SOC content in soil surface (restricted to the upper 15-30 or 50 cm), and
13 few studies have included a deeper section of soil cover (Conant and Paustian, 2002),
14 although vertical processes have a significant impact on SOC variability (VandenBygaart,
15 2006). Sombrero and de Benito (2010) noted that to evaluate and compare SOC storage
16 complete profile is necessary. According to Lorenz and Lal (2005) in temperate climates large
17 amounts of SOC may be stored in subsoil horizons below 30 cm deep. This is essential in
18 studies about the effects of LUC on SOC because the SOC can be transported to a deeper soil
19 horizon, contributing to the subsoil C storage (Lorenz and Lal, 2005). Vertical distribution is
20 one of the features of the organic C store that is not clearly understood together with the
21 relationships with climate and vegetation (Jobbágy and Jackson, 2000). In the last decades, a
22 significant number of arable crops (AC) have been transformed into olive grove cultivations
23 (OG) or vineyards (V) in Montilla-Moriles denomination of origin (D.O.) in Cordoba (South
24 Spain). LUCs in this area have been motivated by subsidies and better olive oil and wine
25 prices.

26 Very few reports have compared the effect of transformation from AC to OG and V on SOC
27 and TN storages even on soil quality for long-term in soil entire profiles. In this context, the
28 objectives of this work are (i) to determine the SOC content in the soil; (ii) to study SOC
29 vertical distribution; (iii) to analyze the accumulation and SR of SOC, TN and C:N ratio in
30 Calcic-Chromic Luvisols (LVcc/cr) (IUSS-ISRIC-FAO, 2006) in AC affected by LUC for
31 long-term (46 years) in conventional tillage.

32

1 2 Material and Methods

2 2.1 Site description and experimental design

3 The study area comprises 33607 ha located in Montilla-Moriles D.O., Cordoba (37°38'-29' N;
4 4°45'-31' W, 432 m.a.s.l.) (Fig.1). Montilla is the first production center of Montilla-Moriles
5 wines. This D.O. produced wines with the grapes of the Pedro Ximénez variety.

6 The parent material is Triassic **gypsiferous marls**. The relief is smooth with slopes ranging
7 from 3% to 8%. **According to IUSS Working Group WRB (2006), the most abundant soils are**
8 **Luvisol (LV) and Cambisol (CM), locally known as “alberos and albarizas”. Fluvisol (FL),**
9 **Regosol (RG) and Vertisol are also present.** These **substrates** correspond to the upper limit of
10 the Pliocene period (Andaluciense subperiod), which are characterized by the presence of
11 white marls (argyle-containing limestone) typical of the Guadalquivir basin. These are soft
12 soils owing to the presence of limestone, **with very high permeability and high water retention**
13 **(essential for lands with frequent dry spells).**

14 The Montilla-Moriles D.O. is characterized by cold winters and warm, dry summers with
15 **extreme measured temperatures ranging from -2.0 °C** to 37.8 °C and an average annual
16 rainfall of 602.7 mm. The moisture regime is dry Mediterranean with continental features due
17 to **elevation** and location.

18 An unirrigated farm (100 ha) **in Montilla-Moriles D.O.** cultivated under conventional tillage
19 (CT) was selected for study in 1965. The soil was a Calcic-Chromic Luvisol (LV cc-cr)
20 (classified according to **IUSS-ISRIC-FAO, 2006**). In 1966, the study farm (100 ha) was
21 divided into three plots with three different uses (AC, OG and V respectively). The
22 preliminary analyses were realized in 1965 for AC (AC1), and the second analyses were
23 realized in 2011 for AC (AC2), OG and V. In 2011, 22 samples were collected (7 for AC2, 5
24 for V and 10 for OG) (Fig. 2 and 3). In all cases (AC1, AC2, OG and V) were collected soil
25 entire profiles. Table 1 **Summarizes** the land use class and Table 2 summarize the principal
26 soil properties for the study.

27 2.2 Soil sampling and analytical methods

28 **Soil samples were dried at a constant room temperature (25 °C) and sieved (2 mm) to**
29 **eliminate coarse soil particles.** Soil pH was measured in an aqueous soil extract in deionized
30 water (1:2.5 soil:water) (**Gutián** and Carballas, 1976). Prior to determining the particle size

1 distribution, the samples were treated with H₂O₂ (6%) to remove organic matter. The fraction
2 of particles with a diameter greater than 2 mm was determined by wet sieving. Particles
3 measuring < 2 mm were classified according to USDA standards (USDA, 2004). Soil bulk
4 density was measured by the core method (Blake and Hartge, 1986) using a 3.0 cm diameter
5 and 10.0 cm deep core. The distribution of soil particle size was analyzed using the Robinson
6 pipette system (USDA, 2004). SOC were determined by wet oxidation with dichromate
7 according to the Walkley and Black system (Walkley and Black, 1934). TN was determined
8 using the Kjeldahl method (Bremner, 1996). The soil C:N ratio was calculated by dividing
9 SOC % by TN %. The SOC stock (Mg ha⁻¹) was calculated for each horizon according to
10 Wang and Dalal (2006) as follows:

$$11 \text{ SOC stock} = \text{SOC concentration} \times \text{BD} \times d \times (1 - \delta_{2\text{mm}}\%) \times 0.1 \quad (1)$$

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

15 The SRs were calculated from SOC, TN and the C:N ratio data following Franzluebbers
16 (2002). The SR is defined as a soil property on the soil surface divided by the same property
17 at a lower depth. In this study, we defined four SRs ([SR1] for Ap/Ap2-Bt, [SR2] for Ap/Bt-
18 B-Ck, [SR3] for Ap/C-Bt-C and [SR4] for Ap/C2-C-Ck).

19 The statistical analysis was performed using SPSS Inc. (2004). The statistical significance of
20 the differences in the variables between land use practices was tested using the Anderson-
21 Darling test at each horizon or a combination of horizons for each soil type. Differences with
22 $p < 0.05$ were considered statistically significant.

23

24 **3 Results and discussion**

25 **3.1 Soil properties**

26 The studied soil is classified as LVcc/cr (IUSS-ISRIC-FAO, 2006). The principal
27 characteristic of these soils is high clay content in the Bt horizon due to migration of clay
28 particles (Table 2). Luvisols are well-developed fertile soils that are suitable for a broad
29 variety of typically Mediterranean uses such as cereals, fruit trees, olives and vineyards
30 (Zdruli et al., 2011).

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

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

19 **3.2 Soil organic carbon (SOC), Total Nitrogen (TN) and C:N ratio**

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

22 According to the study of Hernanz et al. (2009) on rainfed crops of Mediterranean semiarid
23 regions soils present a low OC content due to the high mineralization of the OM and the
24 absence of harvest residues after periods of drought. On the contrary, soils with the coverage
25 of trees show an increase in C and nitrogen (N) (Albretch and Kandji, 2003); we obtained
26 similar results in topsoil, in V and OG. The SOC found in AC1 was greater ($11.1 \pm 1.2 \text{ g kg}^{-1}$)
27 than that estimated by Don et al. (2007), who established 10 g kg^{-1} for soils with cereal crops
28 in Spain, which must be caused by the accumulation of litter and dead roots in the topsoil.

29 TN and the C:N ratio tended to decrease with depth to the exception of AC2. Sá et al. (2001)
30 observed an increase in the soil C:N ratio in depth (AC2), which may be attributed to high
31 C:N soluble organic compounds leaching into deeper layers (Diekow et al., 2005). For OG,

1 this decrease may be a result of the increased soil clay content with depth (Table 2). Higher
2 clay content is often associated with more decomposed OM with a lower C:N ratio (Puget and
3 Lal 2005; Yamashita et al., 2006). In the case of AC1 and V, crop residues could favour a
4 higher soil C:N ratio (Puget and Lal, 2005). Additionally, residue retention can increase the
5 proportion of SOC (Xu et al., 2011) with a lower decomposition degree and higher C:N ratio
6 (Yamashita et al., 2006). Under AC2 the incorporation of residues into the soil can be
7 uniformly distributed with depths up to 20 cm, or more than 20 cm (Sá and Lal, 2009; Wright
8 et al., 2007). In contrast, under AC1 and V the input of residues is restricted to the topsoil.
9 Consequently, the soil C:N ratio may be stratified to show a declining trend with depths in the
10 upper soil profile. The C:N ratio in the surface soil was higher than in deeper soil horizons,
11 especially in V (12.23:1) and OG (9.44:1), thus indicating high resolution and separation
12 rates. Lal et al. (1995) indicate that C:N ratios are low during resolution and separation times.
13 Brady and Weil (2008) show that C:N ratios varies between 8:1 and 15:1, with an average of
14 12:1.

15 3.3 Soil Organic Carbon (SOC) and Total Nitrogen (TN) stocks

16 The SOC stock for soil groups in Peninsular Spain (Rodríguez-Murillo, 2001) is 66.0 Mg ha⁻¹
17 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
18 respectively; and the SOC stock for Andalucía (Map of SOC content in Andalusia) are 53.2
19 Mg ha⁻¹ and 57.3 Mg ha⁻¹ for LV in arable crop and permanent crops respectively (Muñoz-
20 Rojas et al., 2012). This is in agreement with our results, which show that SOC stock is
21 affected by LUC. The highest SOC was found under AC1 (332.6±28 Mg ha⁻¹) followed by
22 AC2 (229.0±32 Mg ha⁻¹), V (157.2±35 Mg ha⁻¹) and OG (116.7±21 Mg ha⁻¹) (Table 3 and
23 Fig. 4). These differences between SOC stocks for soil groups in Peninsular Spain and
24 Andalusia and the study soils are caused by soil thickness (we used soil complete profile -
25 four or five horizons and Rodriguez-Murillo (2001) used descriptions of soil profiles deeper
26 than 1 m and Muñoz-Rojas et al. (2012b) used control sections at 0-25, 25-50 and 50-75 cm.

27 The total SOC stock for long term (46 years) was reduced for the LUC (AC1 to V and OG)
28 and tillage (AC1 to AC2) (Table 4). The SOC stored varies within the soil profile, with higher
29 values in Bt horizons for AC1, AC2 and OG, however, in V we found higher SOC in the
30 topsoil. In this line, Novara et al. (2012) for LUC from AC to V obtained similar results and
31 explained that this trend may be due to the mixing of the upper soil layers during soil tillage.
32 SOC stock in the surface horizon in AC1 and AC2 varied from 39.7 Mg ha⁻¹ to 48.9 Mg ha⁻¹

1 respectively. González and Candás (2004) in clayey soils found values near 54 Mg ha⁻¹ in
2 AC. This difference of SOC stock is caused by the texture because soils included in this
3 research were less clayey and sandier (Table 2). According to Burke et al. (1989) and Leifeld
4 et al. (2005), high values of SOC stock in clayey soils are caused by the stabilization
5 mechanisms of the clays in the soil. This effect can be observed in AC1 and OG, which
6 increased the clay content with respect to AC2 and V. By contrast, SOC stored was higher in
7 the subsoil (Bt and Bt/C horizons) in AC1 and AC2, which may be due to the translocation of
8 C in the form of dissolved organic C, soil fauna activity, and/or the effects of deep-rooting
9 crops (Shrestha et al., 2004). On the other hand, Muñoz-Rojas et al. (2012a) found an increase
10 of SOC for LV (14%) after conversion from arable land to permanent crops in Andalusia
11 (southern Spain) between 1956 and 2007, caused by the limited effect that agricultural
12 management in permanent crops has on SOC sequestration (Smith, 2004). Moreover, Vallejo
13 et al. (2003) indicates that the SOC stock is greater in crop pastures, which is an effect that
14 has also been shown by Nair et al. (2009). Both authors also indicate that the potential for C
15 sequestration in grass systems increases because the roots transfer large amounts of C in the
16 soil slowly and contribute to the increase in the underground C content, which accumulates
17 over time, thus indicating that these systems are more effective in C sequestration than other
18 land uses.

19 In our study, TN concentrations are relatively high in areas where the SOC is high, showing a
20 positive C:N relation (Table 3 and Fig. 4). According to this, clay decreases SOC oxidation
21 and could indicate a positive relationship between clay and nitrogen (Sakin et al., 2010).
22 Some studies (Côté et al., 2000) state that the N mineralization decreases when the clay
23 amount increases in the soil. We obtained similar results in LV; TN decreased when the
24 amount of clay increased. According to the paper by McLauchlan (2006), clay concentration
25 correlated positively with aggregate size and the rate of aggregate accumulation and the
26 potential N mineralization decreases.

27 **3.4 The effect of LUC on SOC stock, TN and C:N ratio**

28 A fundamental issue has been to analyze the impact of LUC on SOC stock, TN and C:N ratio.
29 The change from AC1 to AC2 affected the total SOC stock that was reduced 31.2% and the
30 LUC from AC1 to V and OG were reduced 52.7% and 64.9% respectively (Table 2 and Table
31 3). Novara et al. (2012) for LUC from AC to V find an increase of 105%. Guo and Gifford
32 (2002) reported an increase of 18% on SOC stock for LUC from AC to plantation.

1 The loss of SOC stocks was **influenced by management** (Table 1) AC1 had minimum tillage,
2 with higher biomass production of plantations. As a result, the soil was always covered with
3 vegetation, increasing OM stability, which is corroborated by Novara et al. (2012). The
4 lowest SOC stock was in OG that reduced 64.9% with respect to AC1. A similar result was
5 obtained by Rodriguez-Murillo (2001) and Padilla et al. (2010), the first for LUC of bushland
6 to OG and the second for LUC of shrubland to OG. This reduction of SOC stocks from AC1
7 to AC2, V and OG, can be explained by **degraded process (vegetation losses and**
8 **unsustainable soil management) resulting in continuous impoverishment in the OM content**
9 **causing low soil productivity.** The SOC loss in cultivated soils could be due to the OM
10 reduced input, as well as to the reduced physical protection of soil from erosion and the
11 increased decomposition rate as a consequence of tillage (**Jordán et al., 2010**; Moscatelli et al.,
12 2007).

13 The C:N ratio was higher under AC1 than under AC2, V and OG (Table 3 and Fig. 4). This is
14 in line with the results of Blanco-Canqui and Lal (2008) and Lou et al. (2012), which may be
15 explained by the higher contribution of residue input under different tillage.

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

26 Franzluebbers and Arshad (1996) and Melero et al. (2009) suggest that minimum tillage can
27 increase SOC under longer experimental duration. **Our results are in agreement with this**
28 **because in AC1 increased SOC stock and the LUC and tillage for long-term (46 years)**
29 **reduced SOC stock.**

1 **3.5 Stratification of SOC, TN and the C:N ratio**

2 In all cases, the SR of SOC increased in deep with the exception of AC2 (Fig. 5), caused by
3 the low SOC concentration in Ap2/B (transitional horizon between Ap and Bt, caused by the
4 heavy machinery). The SR of SOC for surface to depth [SR1, SR2, SR3 and SR4] increased
5 due to LUC in all situations (AC2, V and OG) (Fig. 5). The LUC apparently improved soil
6 quality because LUC caused alterations in the soil's physical and chemical properties and the
7 soil biotic community (Caravaca et al., 2002), also, the highest carbon content in the top layer
8 is due to carbon input from biomass residue. For degraded soils, the SR of SOC is low and
9 occasionally reaches a value of 2.0 (Franzluebbers, 2002). Other studies have shown that SR
10 ranges from 1.1 to 1.9 for conventional tillage (Franzluebbers, 2002; Franzluebbers et al.,
11 2007; Hernanz et al., 2009; Sá and Lal, 2009). Higher SR of SOC is a consequence of the
12 accumulation of surface SOC due to straw soil surface coverage and root distribution change.

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

24 The higher SRs observed at OG and V, compared to AC1 and A2 was probably due to the
25 presence of a herb layer and the low herbicide applications. The important role of a herb
26 layer, in both protecting soil from the erosion process (Novara et al., 2011) and contributing
27 to SOM content, might explain the similarity among the characteristics of the OG and V.

28 **3.6 Limitations to SRs method**

29 Many authors had applied the SR methodology (Franzluebbers, 2002), in the most cases using
30 control sections (Muñoz-Rojas et al., 2012b), in other cases using soil entire profile (Corral-
31 Fernández et al., 2013). When control sections are used, similar soil thickness can be

1 compared between them, however, if soil entire profile were used especially for to study land
2 uses and/or management changes for long-time, these comparisons can be more complicated.

3 We can observe in this study that the SOC, TN and C:N ratio decreased for LUC and
4 management types (Table 2) by contrast the SRs increased (Fig. 4) when land uses and
5 management changes were applied, this situation may seem contradictory because this
6 decreased of SOC, TN and C:N ratio should involve decreased in SRs index. These
7 contradictories results are due to SR definition (a soil property on the soil surface divided by
8 the same property at a lower depth) for these cases: SOC, TN and C:N ratio.

9 The first consideration to the method is a soil thickness decreased for the LUC from AC1 to V
10 and OG (Table 2 and fig.1), however, the surface horizons thickness increased associated with
11 the news land uses (new mechanized equipment-heavy machinery). The second consideration
12 is caused to a subsurface horizons thickness that decreased in depth; these factors analyzed
13 together explain the SRs increased. The third issue is caused for the LUC for long-term favors
14 the development of news diagnostic horizons, e.g. AC1 [Bt (25-80 cm)], AC2 [Bt (74-113
15 cm) and Bt/C (113-218 cm)] and OG [Bt1 (37-85 cm) and Bt2/BC (85-109 cm)]. If we
16 integrated these horizons, the subsurface horizons thickness increased in depth this new
17 scenario reduced the SRs for LUC.

19 **4 Conclusions**

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

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

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

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6 **References**

7 Acosta-Martínez, V., Klose, S., Zobeck, T.M.: Enzyme activities in semiarid soils under
8 conservation reserve program, native rangeland, and cropland. *J. Plant Nutr. Soil Sci.* 166,
9 699-707, 2003.

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

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

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

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

18 Blake, G. R. and Hartge, K. H.: Bulk density, In: Klute, A. (Ed.), *Methods of Soil Analysis:*
19 *Part 1, Physical and Mineralogical Methods*, 2nd ed. American Society of Agronomy,
20 Madison, WI, 1986.

21 Brady, C. and Weil R. R.: *The nature and properties of soils*. 14th ed. Pearson Prentice hall.
22 Upper Saddle River, New Jersey Columbus, Ohio, USA, 2008.

23 Bremner, J.M.: Total nitrogen. In: Sparks, D.L. (Ed), *Methods of Soil Analysis: Chemical*
24 *Methods*. Soil Science Society of America, Madison, WI, pp. 1085-1086, 1996.

25 Burke, I., Yonker, C., Parton, W., Cole, C., Flach, K., Schimel, D.: Texture, climate, and
26 cultivation effects on soil organic matter content in U.S. grassland soils. *Soil Sci. Soc. Am. J.*
27 53, 800-805, 1989.

- 1 Caravaca, F., Masciandaro, G., Ceccanti, B.: Land use in relation to chemical and
2 biochemical properties in semiarid Mediterranean environment. *Soil Till. Res.* 68, 23-30,
3 2002.
- 4 Cerdà, A., Lavee, H., Romero-Díaz, A., Hooke, J., Montanarella, L.: Preface. *Land Degrad.*
5 *Dev.* 21, 71-74, 2010.
- 6 Conant, R.T. and Paustian, K.: Potential soil carbon sequestration in overgrazed grassland
7 ecosystems. *Global Biogeochem. Cy.* 16(4), 90(1-9), 2002.
- 8 Corral-Fernández, R., Parras-Alcántara, L., Lozano-García, B.: Stratification ratio of soil
9 organic C, N and C:N in Mediterranean evergreen oak woodland with conventional and
10 organic tillage. *Agric. Ecosyst. Environ.* 164, 252-259, 2013.
- 11 Côté, L., Brown, S., Paré, D., Fyles, J., Bauhus, J.: Dynamics of carbon and nitrogen
12 mineralization in relation to stand type, stand age and soil texture in the boreal mixedwood.
13 *Soil Biol. Biochem.* 32, 1079-1090, 2000.
- 14 Diekow, J., Mielniczuk, J., Knicker, H., Bayer, C., Dick, D.P., Kögel-Knabner, I.: Soil C and
15 N stocks as affected by cropping systems and nitrogen fertilisation in a southern Brazil
16 Acrisol managed under no-tillage for 17 years. *Soil Till. Res.* 81, 87-95, 2005.
- 17 Don, A., Schumacher, J., Scherer-Lorenzen, M., Scholten, T., Schulze, E.: Spatial and vertical
18 variation of soil carbon at two grassland sites. Implications for measuring soil carbon stocks.
19 *Geoderma* 141, 272-282, 2007.
- 20 Eaton, J.M., McGoff, N.M., Byrne, K.A., Leahy, P., Kiely, G.: Land cover change and soil
21 organic C stocks in the Republic of Ireland 1851-2000. *Climatic Change* 91, 317-334, 2008.
- 22 Franzluebbers, A.J.: Soil organic matter stratification ratio as an indicator of soil quality. *Soil*
23 *Till. Res.* 66, 95-106, 2002.
- 24 Franzluebbers, A.J. and Arshad, M.A.: Soil organic matter pools during early adoption of
25 conservation tillage in northwestern Canada. *Soil Sci. Soc. Am. J.* 60, 1422-1427, 1996.
- 26 Gallardo, A., Rodríguez-Saucedo, J., Covelo, F., Fernández-Ales, R.: Soil Nitrogen
27 heterogeneity in dehesa ecosystem. *Plant Soil* 222, 71-82, 2000.
- 28 González, J. and Candás, M.: Materia orgánica de suelos bajo encinas. Mineralización de
29 carbono y nitrógeno. *Invest. Agrar: Sist Recur For. Fuera de serie*, 75- 83, 2004.

- 1 González-Sánchez, E.J., Ordóñez-Fernández, R., Carbonell-Bojollo, R., Veroz-González, O.,
2 Gil-Ribes, J.A.: Meta-analysis on atmospheric carbon capture in Spain through the use of
3 conservation agriculture. *Catena* 122, 52-60, 2012.
- 4 Grüneberg, E., Schöning, I., Kalko, E.K.V., Weisser, W.W.: Regional organic carbon stock
5 variability: A comparison between depth increments and soil horizons. *Geoderma* 155, 426-
6 433, 2010.
- 7 Guitián, F. and Carballas, T.: *Técnicas de Análisis de Suelos*. Edit. Picro Sacro. Santiago de
8 Compostella. España, 1976.
- 9 Guo, L.B. and Gifford, R.M.: Soil carbon stocks and land use change: a meta analysis. *Glob.*
10 *Change Biol.* 8, 345– 360, 2002.
- 11 Hernanz, J.L., Sanchez-Giron, V., Navarrete, L.: Soil carbon sequestration and stratification
12 in a cereal/leguminous crop rotation with three tillage systems in semiarid conditions. *Agric.*
13 *Ecosyst. Environ.* 133, 114-122, 2009.
- 14 Houghton, R.A.: Why are estimates of the terrestrial carbon balance so different? *Global*
15 *Change Biol.* 9, 500-509, 2003.
- 16 IPCC.: *Climate change 2007: the physical science basis*. Cambridge University Press:
17 Cambridge/New York, NY, 2007.
- 18 IUSS Working Group WRB.: *World reference base for soil resources 2006*. *World Soil*
19 *Resources Reports No. 103*. FAO, Rome.
- 20 Jobbágy, E.G. and Jackson, R.B.: The vertical distribution of soil organic carbon and its
21 relation to climate and vegetation. *Ecol. Appl.* 104, 423-436, 2000.
- 22 Johnson, J.M., Franzluebbers, A.J., Lachnicht-Weyers, S., Reicosky, D.C.: Agricultural
23 opportunities to mitigate greenhouse gas emissions. *Environ. Pollut.* 150, 107–124, 2007.
- 24 Jordán, A., Zavala, L.M., Gil, J.: Effects of mulching on soil physical properties and runoff
25 under semi-arid conditions. *Catena* 81, 77-85, 2010.
- 26 Lal, R.: Residue management, conservation tillage and soil restoration for mitigating
27 greenhouse effect by CO₂-enrichment. *Soil Till. Res.* 43, 81-107, 1997.
- 28 Lal, R.: Soil erosion and the global carbon budget. *Environment International* 29, 437-450,
29 2003.

- 1 Lal, R., Kimble, J., Stewart, B. A.: World Soils as a source or sink for radio-active gases. 1-7 pp,
2 1995. In: Soil management and greenhouse effect, B.B. Jorgensen (Eds.). Lewis, London.
- 3 Lal, R., Delgado, J.A., Groffman, P.M., Millar, N., Dell, C., Rotz, A.: Management to
4 mitigate and adapt to climate change. *J. Soil Water Conserv.* 66 (4), 276–285, 2011.
- 5 Leifeld, J., Bassin, S., Fuhrer, J.: Carbon Stocks in Swiss agricultural soils predicted by Land–
6 use. Soil characteristics and altitude. *Agric. Ecosyst. Environ.* 105, 255-266, 2005.
- 7 Lorenz, K. and Lal, R.: The depth distribution of organic soil carbon in relation to land use
8 and management and the potential of carbon sequestration in subsoil horizons. *Adv. Agron.*
9 88, 35-66, 2005.
- 10 Lou, Y., Xu, M., Chen, X., He, X., Zhao, K.: Stratification of soil organic C, N and C:N ratio
11 as affected by conservation tillage in two maize fields of China. *Catena* 95, 124-130, 2012.
- 12 Lozano-García, B., Parras-Alcántara, L., Del Toro, M.: The effects of agricultural
13 management with oil mill by-products on surface soil properties, runoff and soil losses in
14 southern Spain. *Catena* 85, 187-193, 2011.
- 15 Lozano-García, B. and Parras-Alcántara, L.: Short-term effects of olive mill by-products on
16 soil organic carbon, total N, C:N ratio and stratification ratios in a Mediterranean olive grove.
17 *Agric. Ecosyst. Environ.* 165, 68-73, 2013.
- 18 McKenzie, N.J. and Austin, M.P.: A quantitative Australian approach to medium and small
19 scale surveys based on soil stratigraphy and environmental correlation. *Geoderma* 57, 329–
20 355, 1993.
- 21 McLauchlan, K.K.: Effect of soil texture on soil carbon and nitrogen dynamic after cessation
22 of agriculture. *Geoderma* 136, 289-299, 2006.
- 23 Melero, S., López-Garrido, R., Murillo, J.M., Moreno, F.: Conservation tillage: Short- and
24 long-term effects on soil carbon fractions and enzymatic activities under Mediterranean
25 conditions. *Soil Till. Res.* 104, 292–298, 2009.
- 26 Miller, A.J., Amundson, R., Burke, I.C., Yonker, C.: The effect of climate and cultivation on
27 soil organic C and N. *Biogeochemistry* 67, 57–72, 2004.
- 28 Moscatelli, M.C., Di Tizio, A., Marinari, S., Grego, S.: Microbial indicators related to soil
29 carbon in Mediterranean land use systems. *Soil Till. Res.* 97, 51–59, 2007.

- 1 Muñoz-Rojas, M., Jordán, A., Zavala, L.M., De la Rosa, D., Abd-Elmabod, S.K., Anaya-
2 Romero, M.: Impact of land use and land cover changes on organic carbon stocks in
3 Mediterranean soils (1956-2007). *Land Degrad. Dev.* DOI: 10.1002/ldr.2194, 2012a.
- 4 Muñoz-Rojas, M., Jordán, A., Zavala, L.M., De la Rosa, D., Abd-Elmabod, S.K., Anaya-
5 Romero, M.: Organic carbon stocks in Mediterranean soil types under different land uses
6 (Southern Spain). *Solid Earth*, 3, 375-386, 2012b.
- 7 Nair, P.K., Kumar, B., Nair, D.: Agroforestry as a strategy for carbon sequestration. *J. Soil*
8 *Sci. Plant Nut.* 172, 10-23, 2009.
- 9 Novara, A., Gristina, L., Saladino, S.S., Santoro, A., Cerdá, A.: Soil erosion assessment on
10 tillage and alternative soil managements in a Sicilian vineyard. *Soil Till. Res.* 117, 140–147,
11 2011.
- 12 Novara, A., La Mantia, T., Barbera, V., Gristina, L.: Paired-site approach for studying soil
13 organic carbon dynamics in a Mediterranean semiarid environment. *Catena* 89, 1-7, 2012.
- 14 Ouédraogo, E., Mando, A., Stroosnijder, L.: Effects of tillage, organic resources and nitrogen
15 fertiliser on soil carbon dynamics and crop nitrogen uptake in semi-arid West Africa. *Soil*
16 *Till. Res.* 91, 57–67, 2006.
- 17 Padilla, F.M., Vidal, B., Sánchez, J., Pugnaire, F.I.: Land-use changes and carbon
18 sequestration through the twentieth century in a Mediterranean mountain ecosystem:
19 implications for land management. *J. Environ. Manage.* 91, 2688–2695, 2010.
- 20 Powlson, D.S., Whitmore, A.P., Goulding, K.W.T.: Soil C sequestration to mitigate climate
21 change: a critical re-examination to identify the true and the false. *Eur. J. Soil Sci.* 62, 42-55,
22 2011.
- 23 Puget, P. and Lal, R.: Soil organic carbon and nitrogen in a Mollisol in central Ohio as
24 affected by tillage and land use. *Soil Till. Res.* 80, 201–213, 2005.
- 25 Rodríguez-Murillo, J.C.: Organic carbon content under different types of land use and soil in
26 peninsular Spain. *Biol. Fertil. Soils* 33, 53–61, 2001.
- 27 Ruiz, J.D., Pariente, S., Romero, A., Martínez, J.F.: Variability of relationships between soil
28 organic carbon and some soil properties in Mediterranean rangelands under different climatic
29 conditions (South of Spain). *Catena* 94, 17-25.

- 1 Sá, J.C.M., Cerri, C.C., Dick, W.A., Lal, R., Venske-Filho, S.P., Piccolo, M.C., Feigl, B.E.:
2 Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a
3 Brazilian Oxisol. *Soil Sci. Soc. Am. J.* 65, 1486-1499, 2001.
- 4 Sá, J.C.M. and Lal, R.: Stratification ratio of soil organic matter pools as an indicator of
5 carbon sequestration in a tillage chronosequence on a Brazilian Oxisol. *Soil Till. Res.* 103,
6 46-56, 2009.
- 7 Sakin, E., Deliboran, A., Sakin, E.D. Tutar, E.: Organic and inorganic carbon stock and
8 balance of Adana city soils in Turkey. *African J. Agric. Res.* 5(19), 2737-2743, 2010.
- 9 Shrestha, B.M., Sitaula, B.K., Singh, B.R., Bajracharya, R.M.: Soil organic carbon stocks in
10 soil aggregates under different land use systems in Nepal. *Nutr. Cycl. Agroecosys.* 70, 201–
11 213, 2004.
- 12 Smith, P., Powlson, D.S., Smith, J.U., Fullon, P., Coleman, K.: Meeting Europe's climate
13 change commitments: quantitative estimates of the potential for carbon mitigation by
14 agriculture. *Glob. Change Biol.* 6, 525-539, 2000.
- 15 Smith, P.: C sequestration in croplands: the potential in Europe and the global context. *Europ.*
16 *J. Agronomy* 20, 229-236, 2004.
- 17 Smith, P.: Land use change and soil organic carbon dynamics. *Nutr. Cycl. Agroecosys.* 81,
18 169-178, 2008.
- 19 Sombrero, A. and de Benito, A.: Carbon accumulation in soil. Ten-year study of conservation
20 tillage and crop rotation in a semi-arid area of Castile-Leon, Spain. *Soil Till. Res.* 107, 64–70,
21 2010.
- 22 **SPSS Inc. (2004). SPSS for windows, Version 13.0. Chicago, SPSS Inc.**
- 23 USDA.: Soil survey laboratory methods manual, Soil survey investigation report No. 42.
24 Version 4.0. USDA-NCRS, Lincoln, NE, 2004.
- 25 Vallejo, R., Díaz Fierro, F., De la Rosa, D.: Impactos sobre los recursos edáficos. In *Impactos*
26 *del cambio climático en España*. MMA eds, Madrid, 2003.
- 27 VandenBygaart, A.J.: Monitoring soil organic carbon stock changes in agricultural
28 landscapes: issues and a proposed approach. *Can. J. Soil Sci.*, 86, 451-463, 2006.

- 1 Van Oost, K., Govers, G., Quine, T.A., Heckrath, G., Olesen, J.E., De Gryze, S., Merckx, R.:
2 Landscape-scale modeling of carbon cycling under the impact of soil redistribution: the role
3 of tillage erosion. *Global Biogeochem. Cy.* 19: GB4014. DOI. 10.1029/2005GB002471,
4 2005.
- 5 Walkley, A. and Black, I.A.: An examination of the Degtjareff method for determining soil
6 O.M. and a proposed modification of the chromic acid titration method. *Soil Sci.* 37, 29-38,
7 1934.
- 8 Wang, W. J. and Dalal, R.C.: Carbon inventory for a cereal cropping system under contrasting
9 tillage. Nitrogen fertilisation and stubble management practices. *Soil Till. Res.* 91, 68-74,
10 2006.
- 11 Watson, R.T., Noble, I.R., Bolin, B., Ravindramath, N.H., Verardo, D.J., Dokken, D.J.: Land-
12 use, Land-use change, and Forestry (A Special Report of the IPCC). Cambridge University
13 Press, Cambridge, 2000.
- 14 West, T.O. and Post, W.M.: Soil organic carbon sequestration rates by tillage and crop
15 rotation: a global data analysis. *Soil Sci. Soc. Am. J.* 66, 1930–1946, 2002.
- 16 Wright, A.L., Hons, F.M., Lemon, R.G., McFarland, M.L., Nichols, R.L.: Stratification of
17 nutrients in soil for different tillage regimes and cotton rotations. *Soil Till. Res.* 96, 19–27,
18 2007.
- 19 Xu, M., Lou, Y., Sun, X., Wang, W., Baniyamuddin, M., Zhao, K.: Soil organic carbon active
20 fractions as early indicators for total carbon change under straw incorporation. *Biol. Fert. of*
21 *Soils* 47, 745–752, 2011.
- 22 Yamashita, T., Feiner, H., Bettina, J., Helfrich, M., Ludwig, B.: Organic matter in density
23 fractions of water-stable aggregates in silty soils: effect of land use. *Soil Biol. Biochem.* 38,
24 3222–3234, 2006.
- 25 Zhang, T., Wang, Y., Wang, X., Wang, Q., Han, J.: Organic carbon and nitrogen stocks in
26 reed meadow soils converted to alfalfa fields. *Soil Till. Res.* 105, 143-148, 2009.
- 27 Zdruli, P., Kapur, S., Çelik, I.: Soils of the Mediterranean Region. Their characteristics,
28 management and sustainable use. In *Sustainable land management learning from the past for*
29 *the future*, Kapur S, Eswaran H, Blum WEH (eds). Springer-Verlag: Berlin, 2011.

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

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		Winter crop rotation with annual wheat and barley. Mineral fertilization or pesticides
Vineyard	V	2006	Heavy machinery New mechanized equipment	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 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.
Olive groves	OG	2006	Conventional tillage	

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1 Table 2. Basic physical and chemical properties for Calcic/Chromic Luvisol in Arable land
2 (wheat and barley annual rotation), Vineyard and Olive groves. AC1: Arable crop 1965, AC2:
3 Arable crop 2011, V: Vineyard 2011, OG: Olive groves 2011. Data are means \pm SD (n=5, 7,
4 5, 10). Hor. = Horizon type. * No significant data for Stratification Ratio (SR). ** Size
5 sampling.

Soil	Hor.	Depth cm	Thickness cm	Gravel %	Sand %	Silt %	Clay %	Bulk density Mg m ⁻³	pH H ₂ O	OM g kg ⁻¹	SOC g kg ⁻¹	Total SOC g kg ⁻¹	TN g kg ⁻¹	Total TN g kg ⁻¹	C/N
AC1 n=5**	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
	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
AC2 n=7**	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
	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
V n=5**	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
	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
OG n=10**	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
	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

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1 Table 3. Soil Organic Carbon, Total Nitrogen and C:N ratio stock in Calcic/Chromic Luvisol.

2 Data are means \pm SD (n=5, 7, 5, 10). * Size sampling.

Soil	Hor.	SOC Mg ha ⁻¹	Total SOC Mg ha ⁻¹	TN Mg ha ⁻¹	Total TN Mg ha ⁻¹	C/N
AC1 n=5*	Ap	39.7 \pm 2.3		3.18 \pm 0.23		12.47
	Bt	84.9 \pm 3.2		6.31 \pm 0.98		13.47
	B/C	50.9 \pm 2.1	332.6 \pm 28	3.92 \pm 0.65	26.41 \pm 6	12.96
	C1	95.8 \pm 6.2		7.93 \pm 0.95		12.09
	C2	61.3 \pm 3.2		5.07 \pm 0.65		12.07
AC2 n=7*	Ap	48.9 \pm 2.4		7.87 \pm 0.63		7.97
	Ap2/B	34.7 \pm 1.6		4.74 \pm 0.22		7.32
	Bt	42.9 \pm 2.1	229.0 \pm 32	5.46 \pm 0.35	29.73 \pm 8	7.86
	Bt/C	86.4 \pm 3.8		9.57 \pm 0.54		9.03
	C/Ck	16.1 \pm 0.9		2.09 \pm 0.12		7.71
V n=5*	Ap	62.6 \pm 2.3		5.12 \pm 0.36		12.23
	Bt	33.2 \pm 1.4		3.43 \pm 0.42		9.68
	B/Ck	28.6 \pm 2.3	157.2 \pm 35	3.57 \pm 0.38	15.17 \pm 3	8.00
	C1	21.7 \pm 1.2		1.74 \pm 0.24		12.42
	C2k	11.1 \pm 0.7		1.31 \pm 0.09		8.52
OG n=10*	Ap	34.1 \pm 2.1		3.61 \pm 0.65		9.44
	Ap/Bt	9.1 \pm 0.5		1.21 \pm 0.25		7.47
	Bt1	31.6 \pm 2.1	116.7 \pm 21	5.26 \pm 0.32	16.37 \pm 4	6.00
	Bt2/BC	11.6 \pm 1.1		1.66 \pm 0.09		6.98
	C	30.3 \pm 2.7		4.63 \pm 0.23		6.54

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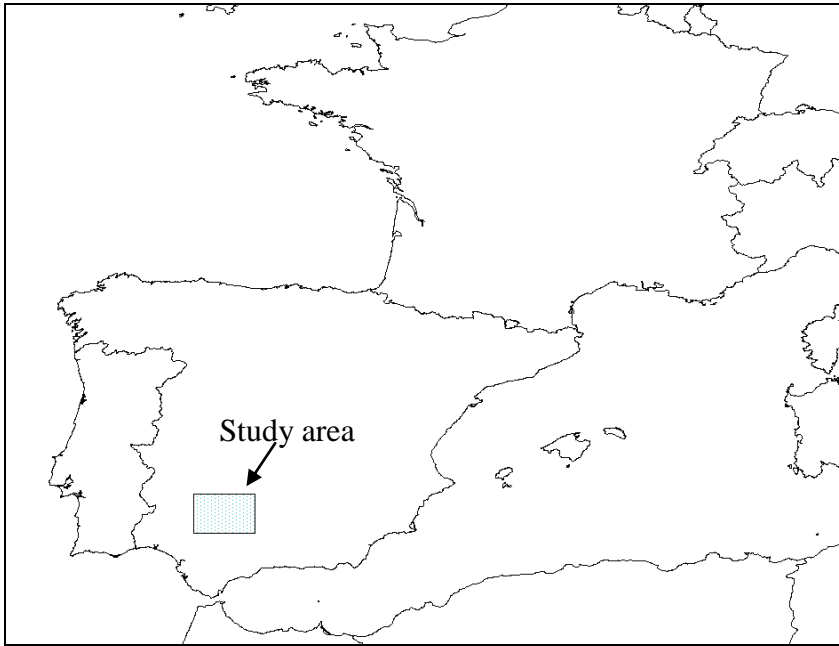
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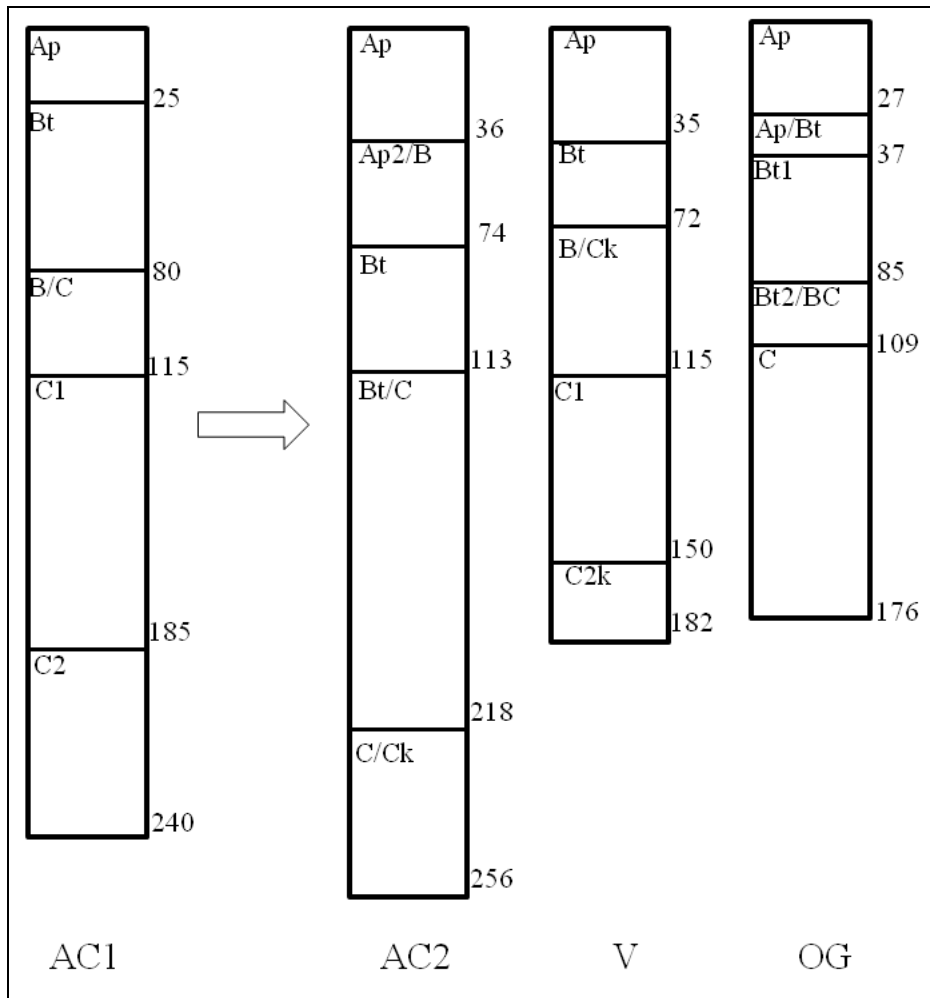
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3 Figure 1. Study area.

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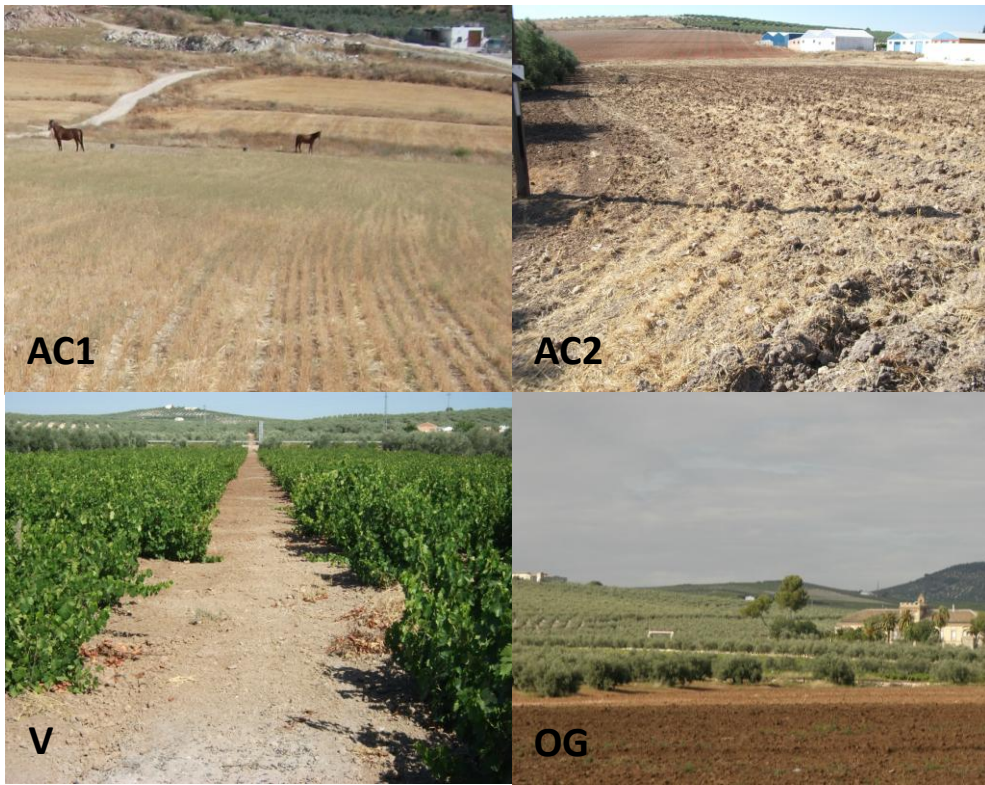


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2 Figure 2. Soil entire profiles. AC1 (arable crop in 1965), affect by land use conversion (LUC)
 3 to AC2 (arable crop), V (vineyard) and OG (olive groves). The LUC was in 1965 (AC1), after
 4 the 41 years, AC2, V and OG. (Numbers are soil thickness).

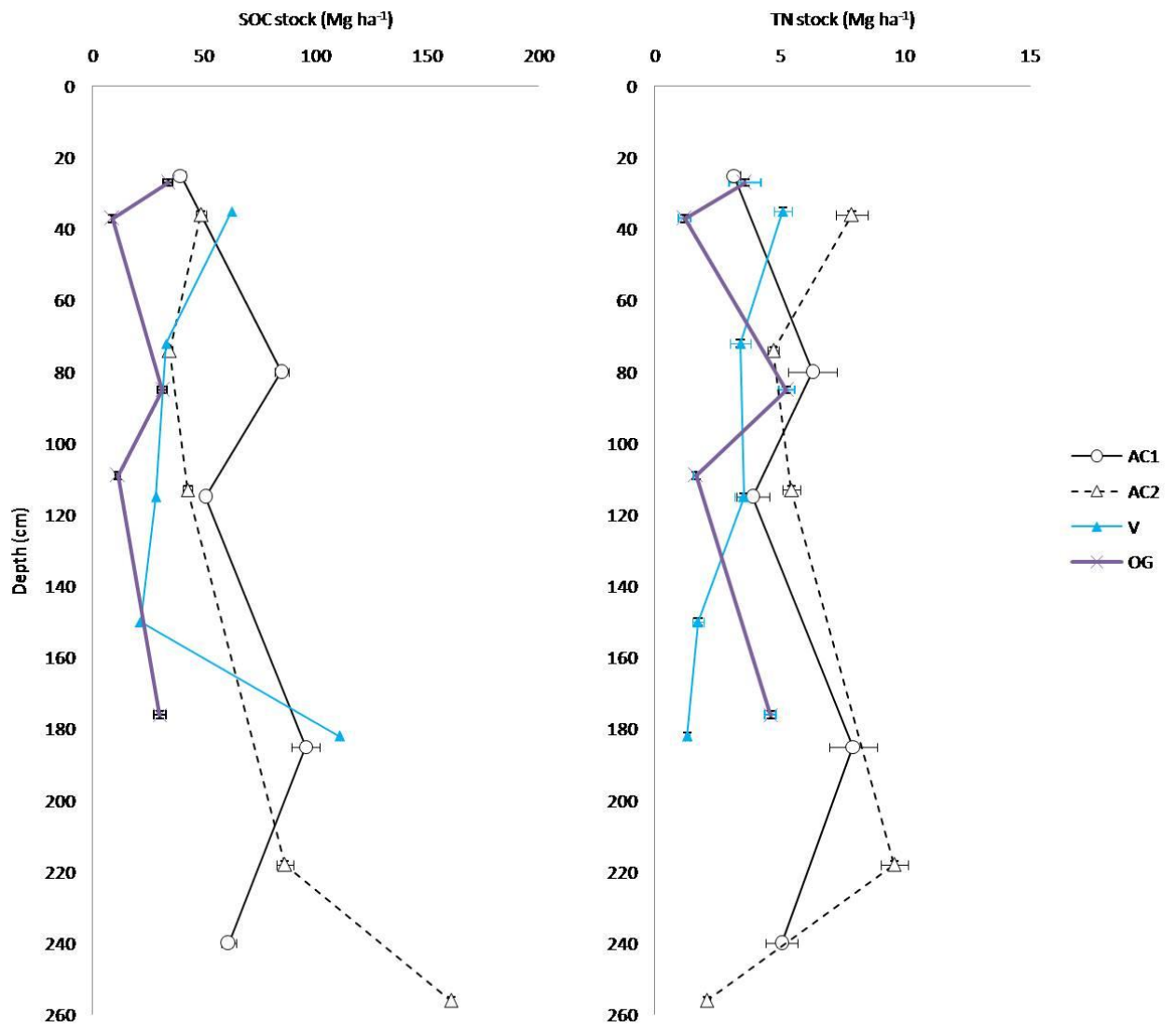
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13 Figure 3. Montilla-Moriles D.O. (AC1) Arable crop, systems using animal power (plow with
14 mules) with lightweight reversible plows. (AC2) Arable crop, heavy machinery - news
15 mechanized equipment. (V) Vineyard modern. (OG) Olive groves.
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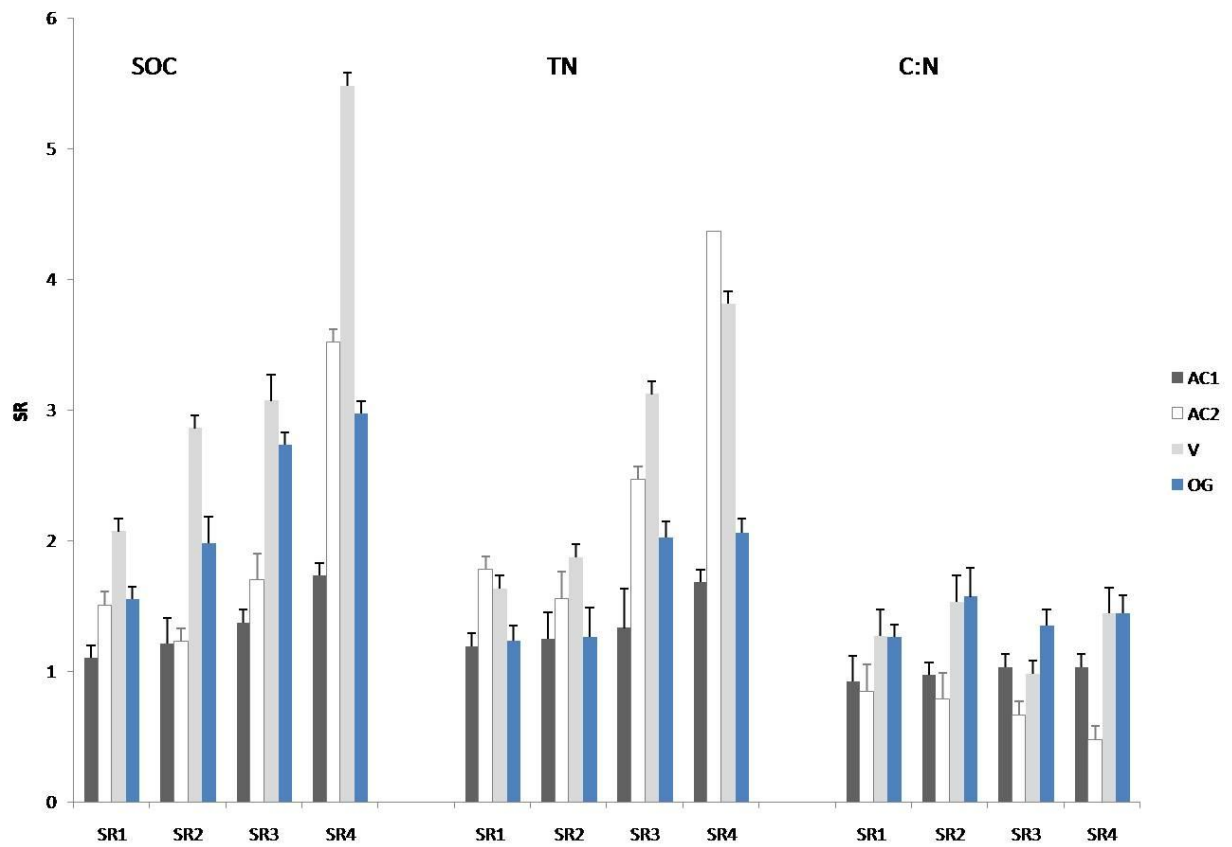
3 Figure 4. Depth distribution of SOC stock and TN stock under arable crop (AC1), arable crop
4 (AC2), Vineyard (V) and Olive groves (OG). Data are means \pm SD ($n^* = 5, 7, 5, 10$). *
5 Sampling size.

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2 Figure 5. Stratification ratios (SR) of SOC concentrations, TN concentrations and C:N ratios
 3 under arable crop (AC1), arable crop (AC2), Vineyard (V) and Olive groves (OG). Data are
 4 means \pm SD ($n^* = 5, 7, 5, 10$). * Sampling size.

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