Solid Earth, 4, 167–177, 2013
www.solid-earth.net/4/167/2013/
doi:10.5194/se-4-167-2013

Solid Earth
Open Access

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

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Received: 27 December 2012 – Published in Solid Earth Discuss.: 22 February 2013
Revised: 20 April 2013 – Accepted: 22 April 2013 – Published: 14 May 2013

Abstract. The agricultural Mediterranean areas are dedicated to arable crops (AC), but in the last decades, a significant number of AC has led to a land use change (LUC) to olive grove (OG) and vineyards (V). 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 horizon thickness, 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 CO_2 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 incorporation of C into carbohydrates (González-Sánchez et al., 2012). Crops capture CO_2 from the atmosphere during photosynthesis into soil organic matter (SOM). Degradation of SOM by microbial processes may be limited by aggregate stability, adsorption by clays or the formation of organo-mineral complexes (Johnson et al., 2007; Lal, 1997). 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 improve soil quality and favor C sequestration into soils.

Carbon sequestration is defined as a net additional transfer of C from atmospheric CO_2 to soils after a change in land management (Powlson et al., 2011). Therefore, C sequestration into soils is one of the most important ecosystem services because of its role in climate regulation (IPCC, 2007). Intensification of agriculture and/or transformation of conventional tillage (CT) practices, 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 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). Climate, use and management are highly influential in the C variability in Spanish soils (Muñoz-Rojas et al., 2012; Rodríguez-Murillo et al., 2001; Ruiz et al., 2012), mainly in semiarid regions, characterized by low levels of SOM content ($\sim 10\,\mathrm{g\,kg^{-1}}$) (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 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 (Zhang et al., 2009).

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 a 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 de 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 studies about the effects of LUC on SOC because the 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 decades, a significant number of arable crops (AC) have been transformed into olive grove cultivations (OG) or vineyards (V) in Montilla-Moriles denomination of origin (D.O.) in Córdoba (South Spain). LUCs in this area have been motivated by subsidies and better olive oil and wine prices.

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

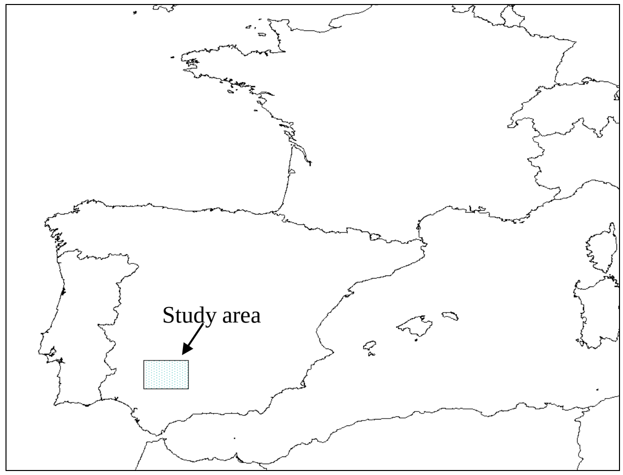

Fig. 1. Study area.

2 Material and methods

2.1 Site description and experimental design

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

The parent material is Triassic gypsiferous marls. The relief is smooth with slopes ranging from 3 % to 8 %. According to IUSS Working Group WRB (2006), the most abundant soils are Luvisol (LV) and Cambisol (CM), locally known as *alberos* and *albarizas*, respectively. Fluvisol (FL), Regosol (RG) and Vertisol (VR) are also present. These substrates correspond to the upper limit of the Pliocene period (Andalusian 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, with very high permeability and high water retention (essential for lands with frequent dry spells).

The Montilla-Moriles D.O. is characterized by cold winters and warm, dry summers with extreme measured temperatures ranging from –2.0° 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 elevation and location.

An unirrigated farm (100 ha) in Montilla-Moriles D.O. cultivated under conventional tillage (CT) was selected for study in 1965. The soil was a Calcic-Chromic Luvisol (LV cc-cr) (classified according to IUSS-ISRIC-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. 2 and 3). In all cases (AC1, AC2, OG and V) were collected soil entire profiles. Table 1 summarizes the land use class and Table 2 summarizes the principal soil properties for the study.

2.2 Soil sampling and analytical methods

Soil samples were dried at a constant room temperature (25 °C) and sieved (2 mm) to eliminate coarse soil particles. Soil pH was measured in an aqueous soil extract in deionized water (1:2.5 soil:water) (Guitián 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 (USDA, 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 system (USDA, 2004). SOC were determined by wet oxidation with dichromate according to the Walkley and Black system (Walkley and Black, 1934). TN was determined using the Kjeldahl method (Bremner, 1996). The soil C : N ratio was calculated by dividing SOC% by TN%. The SOC stock ($\mathrm{Mg\,ha^{-1}}$) 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 ($\mathrm{Mg\,m^{-3}}$). The TN stock ($\mathrm{Mg\,ha^{-1}}$) 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 Inc. (2004). The statistical significance of the differences in the variables between land use practices was tested using the Anderson–Darling test at each horizon or a combination of horizons for each soil type. Differences with $p<0.05$ were considered statistically significant.

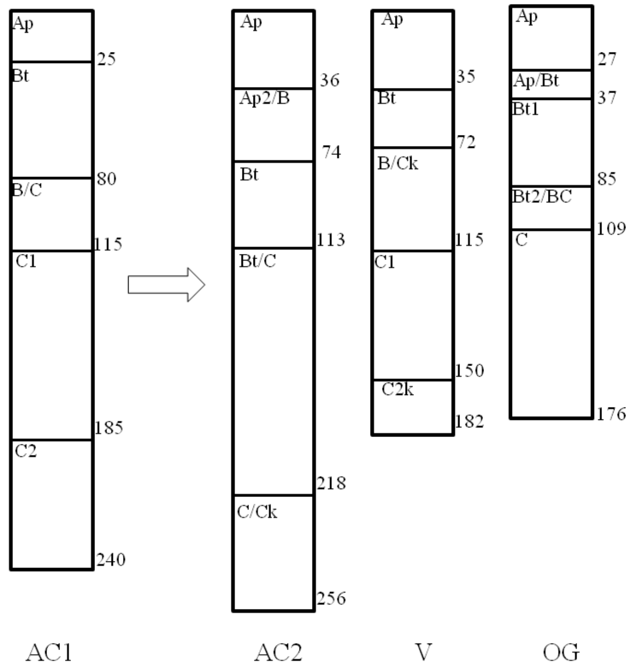

Fig. 2. Soil entire profiles. AC1 (arable crop in 1965), affect by land use conversion (LUC) to AC2 (arable crop), V (vineyard) and OG (olive groves). The LUC was in 1965 (AC1), after 41 years, AC2, V and OG. (Numbers are soil thickness).

3 Results and discussion

3.1 Soil properties

The studied soil is classified as LVcc/cr (IUSS-ISRIC-FAO, 2006). The principal characteristic of these soils is high clay content in the Bt horizon due to migration of clay particles (Table 2). Luvisols are well-developed fertile soils that are suitable for a broad variety of typically Mediterranean uses 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 years) for the same land use (AC1 and AC2), however, during 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 and Fig. 2). This thickness reduction for V and OG was caused by the slope steepness, length, topographic curvature and relative position (different positions in the study farm could be explained in part by these thickness reductions). 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 by associating it with new mechanized equipment (heavy machinery) and water erosion. These causes could be other reasons to justify the thickness reduction in the studied soils.

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	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	tillage	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.

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.

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	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
$n = 5$**	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	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
$n = 7$**	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	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
$n = 5$**	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	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
$n = 10$**	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

*No significant data for Stratification Ratio (SR).
* Size sampling.

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) explain that the low OM values are explained partly by the semiarid Mediterranean conditions, which are accentuated in Europe's southern soils.

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, which is 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, soils present a low OC content due to the high mineralization of the OM and the absence of harvest residues after periods of drought. On the contrary, soils with tree coverage show an increase in C and nitrogen (N) (Albretch and Kandji, 2003); we obtained similar results in topsoil, in V and OG. The SOC found in AC1

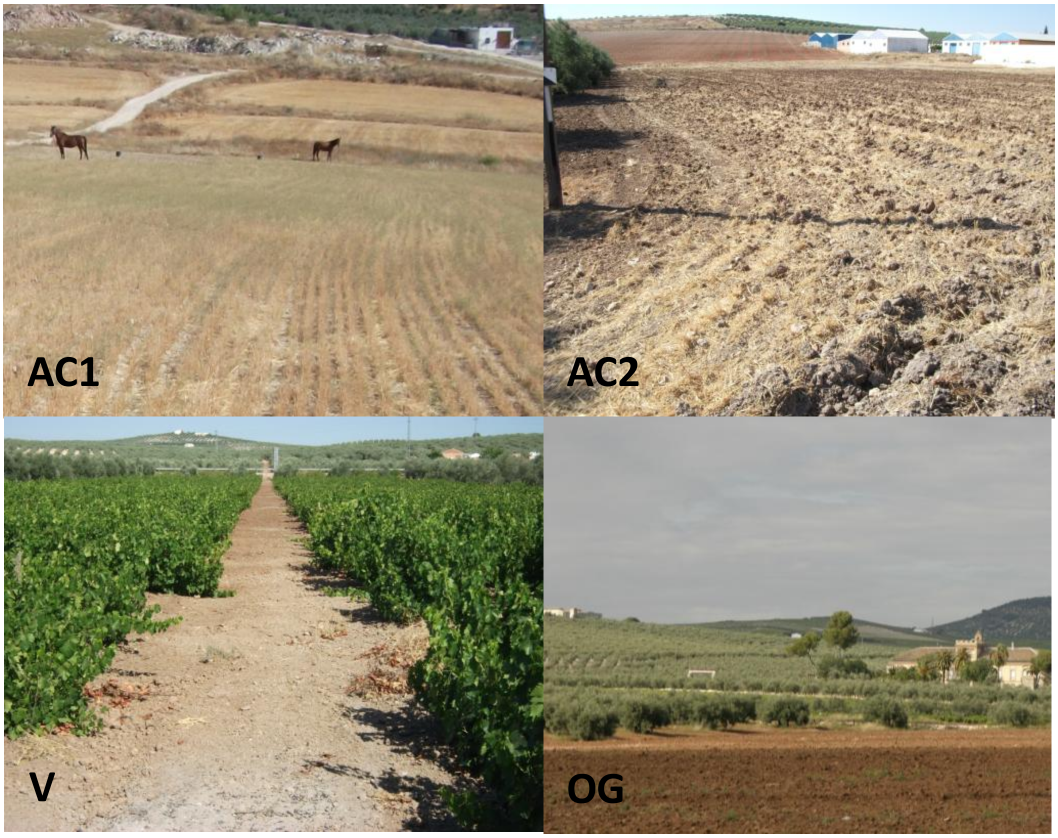

Fig. 3. Montilla-Moriles D.O. (AC1) Arable crop, systems using animal power (plow with mules) with lightweight reversible plows. (AC2) Arable crop, heavy machinery – news mechanized equipment, (V) Vineyard modern, (OG) Olive groves.

was greater ($11.1 \pm 1.2\,g\,kg^{-1}$) 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 in depth (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, 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). In 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 deeper 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 and separation times. Brady and Weil (2008) show that C : N ratios vary 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 (Rodríguez-Murillo, 2001) 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; and the SOC stock for Andalucía (map of SOC 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). This is in agreement with our results, which show that SOC stock is affected by LUC. The highest SOC was found under AC1 ($332.6 \pm 28\,Mg\,ha^{-1}$) followed by AC2 ($229.0 \pm 32\,Mg\,ha^{-1}$), V ($157.2 \pm 35\,Mg\,ha^{-1}$) and OG ($116.7 \pm 21\,Mg\,ha^{-1}$) (Table 3 and Fig. 4). These differences between SOC stocks for soil groups in peninsular Spain and Andalusia and the study soils are caused by soil thickness.

We used complete soil profile for four or five horizons and Rodriguez-Murillo (2001) used descriptions of soil profiles deeper than 1 m and Muñoz-Rojas et al. (2012b) used control sections at 0–25, 25–50 and 50–75 cm.

The total SOC stock for the long term (46 years) was reduced for the LUC (AC1 to V and OG) and tillage (AC1 to AC2) (Table 4). The stored SOC 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 soils included in this research 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, stored SOC was higher in the subsoil (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 other hand, Muñoz-Rojas et al. (2012a) found an increase of SOC for LV (14 %) after conversion from arable land to permanent crops in Andalusia (southern Spain) between 1956 and 2007, 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 into 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 relatively high in areas where the SOC is high, showing a positive C : N relation (Table 3 and Fig. 4). 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; TN decreased when the amount of clay increased. According to the paper by McLauchlan (2006), clay concentration correlated positively with aggregate size and the rate of aggregate accumulation and the potential N mineralization decreases.

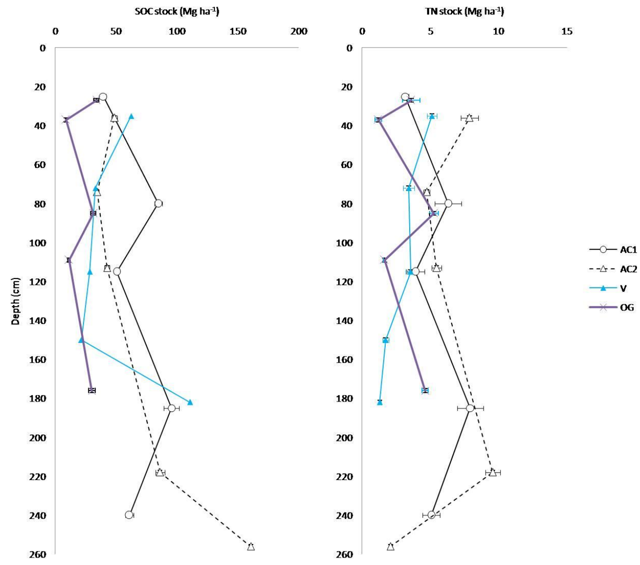

Fig. 4. Depth distribution of SOC stock and TN stock under arable crop (AC1), arable crop (AC2), vineyard (V) and olive groves (OG). Data are means ± SD ($n^* = 5, 7, 5, 10$). * Sampling size.

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

A fundamental issue has been to analyze the impact of LUC on SOC stock, TN and C : N ratio. The change from AC1 to AC2 affected the total SOC stock reduced 31.2 % and the LUC from AC1 to V and OG reduced 52.7 % and 64.9 %, respectively (Table 2 and Table 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 stocks was influenced by management and (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 stocks from AC1 to AC2, V and OG, can be explained by a degraded process (vegetation losses and unsustainable soil management) resulting in continuous impoverishment in the OM content causing low soil productivity. 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 (Jordán et al., 2010; Moscatelli et al., 2007).

The C : N ratio was higher under AC1 than under AC2, V and OG (Table 3 and Fig. 4). 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.

Table 3. Soil organic carbon, total nitrogen and C : N ratio stock in Calcic/Chromic Luvisol. Data are means ±SD ($n = 5, 7, 5, 10$).

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

* Size sampling.

In OG and V, SOC storage at surface depth (Ap horizon) was higher 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. Our results are in agreement with this because in AC1 increased SOC stock and the LUC and tillage for the long term (46 years) reduced SOC stock.

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

In all cases, the SR of SOC increased with depth with the exception of AC2 (Fig. 5), 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. 5). The LUC apparently improved soil quality because LUC caused alterations in the soil's physical and chemical properties and the soil biotic community (Caravaca et al., 2002), also, the highest carbon content in the top layer is due to carbon input from biomass residue. 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

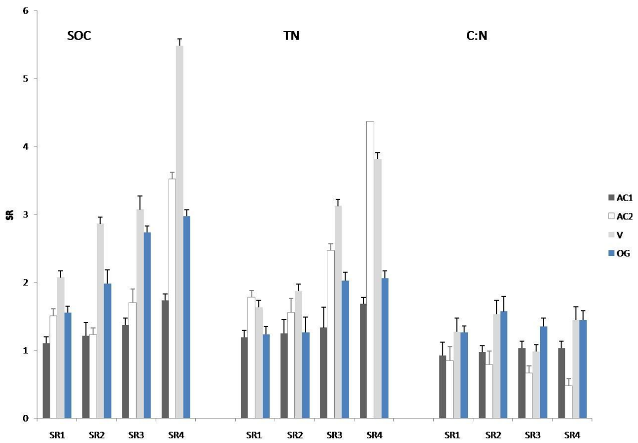

Fig. 5. Stratification ratios (SR) of SOC concentrations, TN concentrations and C : N ratios under arable crop (AC1), arable crop (AC2), vineyard (V) and olive groves (OG). Data are means ± SD ($n^* = 5, 7, 5, 10$). * Sampling size.

surface horizons to a deeper horizon, which suggested an accumulation of carbon in the profile under these systems.

The higher SRs observed at 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) and contributing to SOM content, might explain the similarity among the characteristics of the OG and V.

3.6 Limitations to SRs method

Many authors had applied the SR methodology (Franzluebbers, 2002), in most cases using control sections (Muñoz-Rojas et al., 2012b), in other cases using the entire soil profile (Corral-Fernández et al., 2013). When control sections are used, similar soil thickness can be compared between them, however, if the entire soil profile were used especially to study land uses and/or management changes for a long time, these comparisons can be more complicated.

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

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

4 Conclusions

The LUC has a negative impact on the soil, reducing the SOC and TN stocks. The stored SOC 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 SRs, 46 years 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 SRs index. 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.

Acknowledgements. The authors wishes to thank the two anonymous referees an the editor for their helpful comments.

Edited by: A. Cerdà

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