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Conventional tillage vs. organic farming in relation to soil organic carbon stock in olive groves in Mediterranean rangelands (Southern Spain)

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Abstract

Soil organic carbon (SOC) concentration is a soil variable subject to changes. In agricultural soils, the management system is a key factor that influence to these changes. For determine the management system effects on SOC stocks (SOC-S) in olive groves, 114 soil profiles were studied in the Los Pedroches Valley (Mediterranean rangelands – southern Spain) for long-term (20 yr). The management practices were conventional tillage (CT) and organic farming (OF) in four soil types: Cambisols (CM), Regosols (RG), Luvisols (LV) and Leptosols (LP). Soil properties were statistically analyzed by management techniques, soil types and horizons. The principal components analyses identified four factors that explained 65 % of the variance. Also, significant differences ($p < 0.05$) were found between soil types and management techniques. Equally was observed that the management system affected to SOC-S. In addition, the total SOC-S for 20 yr increased in OF with respect to CT by 72 % and 66 % in CM and LV respectively. The SOC showed significant differences for horizons ($p < 0.05$) in relation to the management types. The stratification ratio index of SOC was > 2 in all studied soils. These results indicate high soils quality, and that management practices affect to SOC store in the Los Pedroches Valley.

1 Introduction

Over the centuries, olive grove (OG) has become in the socioeconomic heritage of Mediterranean areas. The olive oil production in Andalusia (Spain) is more than 1.3 million tonnes, constituting 85 % for Spain (MAGRAMA, 2012) and 41 % of worldwide production (IOC, 2012). In Spain, the olive growing surface area is 2.58 million ha, increasing on average by 1–1.5 % per year from 1995 to the present (ESYRCE, 2012). Subsidies and rising price of olive oil have conditioned this growth (Louwagie et al., 2011).

This activity has brought economic benefits to the region, but there have also been adverse effects. Olive production traditionally has been based on low tree density (100 trees ha^{-1}), weeds being controlled by several tillage and tree size limited by pruning (Álvarez et al., 2007). For decades, the management strategy has been conventional tillage (CT), marked by frequent use of the moldboard plow, mineral fertilization and herbicides (Pastor et al., 1997). CT in OG has caused loss of soil quality with significant economic and environmental implications. CT contributed to the nitrogen cycle variation (Fernández-Escobar et al., 2009), water loss by evaporation (Cerdà and Doerr, 2007), destruction of the soil structure (Gómez et al., 2009), loss of soil organic matter (SOM) and nutrients (Paustian et al., 2000) and high erosion rates (Calatrava et al., 2011). The traditional OG has been associated with soil erosion (Castro et al., 2008), bring on pollution of rivers and bodies of water (Colombo et al., 2005), degradation of landscape (Parra-López et al., 2009), affecting to climate change (Rodríguez-Entrena et al., 2012)... among others. Besides, CT reduces soil fertility and OG production, increasing production costs (Calatrava-Leyva et al., 2007), this is particularly aggravated in Mediterranean climatic conditions (Gómez et al., 2009).

Recent studies show that the restriction on tillage (Parras-Alcántara et al., 2013a), and/or the addition of organic residues to soils (Lozano-García et al., 2011; Lozano-García and Parras-Alcántara, 2013a) improve soil quality. Accordingly, organic farming (OF) may be an attractive option for reducing the soil degradation processes (Cerdà et al., 2010; Aranda et al., 2011).

In Mediterranean areas, climate (Wang et al., 2010), land use (Lozano-García and Parras-Alcántara, 2013b), management (Parras-Alcántara et al., 2013b), slope and altitude (Hontoria et al., 2004), tillage intensity and no-till duration (Conant et al., 2007) affecting to soil carbon variability. All these factors, soils management is the best tools for climate change mitigation and adaptation (Lal et al., 2011). Over time, some researchers have studied the relationship between soil management effects in OG and carbon capture and storage in soils as soil organic carbon (SOC) (Parras-Alcántara et al., 2013a and 2013b; Romanya and Rovira, 2011). However, many of these studies have evaluated the SOC content in soil surface, and few studies have included soil deeper sections. In Mediterranean areas, SOC can be stored in deep (below 30 cm in depth). This is important in OF as SOC can be transported to deeper soil horizon, contributing to the subsoil carbon storage (Lorenz and Lal, 2005).

Climatic conditions in Mediterranean areas are limiting factors that affect to accumulation of SOC. Thus, the SOC determination cannot be the best indicator of the improvement caused by management. Under these conditions, it may be more interesting to consider the stratification ratio (SR) index of SOC (Corral-Fernández et al., 2013). The use of SR index, as a soil quality indicator is based on the influence of surface SOC levels on erosion control, water infiltration and nutrient conservation (Franzluebbers, 2002). High SOC and nitrogen (N) SR values reflect undisturbed soil and high soil quality of the surface layer. The SR growth can be related to rate and amount of SOC sequestration. However, ratios < 2 are frequent in degraded soils (Franzluebbers, 2002).

Very limited information is available with respect to OF effects under semi-arid Mediterranean conditions in organic olive groves. Consequently, the goals of this study were; (i) to determine the soil properties that affect to land development in the Los Pedroches Valley (OG in Mediterranean rangelands – southern Spain), (ii) to study the vertical distribution of SOC stock and (iii) to analyze the soil variables that involved in the SR of SOC in OG using traditional and organic management systems in entire profiles.

2 Material and methods

2.1 Study site and management type

The study area is located in Los Pedroches Valley (Cordoba, southern Spain), between 38.39 and 37.15° N, 4.50 and 4.15° W (Fig. 1) and comprises 10 600 ha that dominant land use is OG. Temperatures are low in winter (–2 °C is the lowest temperature), and

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high in summer (40 °C is the maximum temperature). The study area is characterized by cold winters and warm, and the average annual rainfall is 600 mm. The climate is temperate semi-arid Mediterranean with continental influence. The moisture regime is dry Mediterranean; high temperatures and long drought cause water deficits up to 400 mm. The relief is smooth with slopes ranging from 3 % to 8 %, and the parent material is granite. According to IUSS Working Group WRB (2006), the most abundant soils are Cambisols (CM), Luvisols (LV), Regosols (RG) and Leptosols (LP). Fluvisols and Acrisols are also available.

Two soil management practices were selected: OF and CT in four soil types (CM, LV, RG and LP) (IUSS-ISRIC-FAO, 2006). The OF were under this practice for 20 yr (2009–1989); with no synthetic mineral fertilization or pesticides and untilled soils, in which the vegetative cover is kept under control by mowing from early to late spring and animal manure is incorporated about every 10 yr. CT is characterized by three ploughing per year to a depth of 15–20 cm from early spring (disk harrow and cultivator) to early autumn (tine harrow), weed control with residual herbicides, and annual application of ammonium sulfate (250 kg ha^{-1}). Moreover, two applications of foliar fertilization per year were performed in CT, in spring (0.3 kg amino acids ha^{-1}, 0.7 kg N ha^{-1}, 0.4 kg P ha^{-1} and 0.3 kg K ha^{-1}) and in autumn (0.09 kg amino acids ha^{-1} and 1 kg K ha^{-1}).

In all cases (soil types and management practices), the average density of *Olea europaea* spp. *europaea* in OG is 100–110 trees ha^{-1} (data offered by Department of Organic Production of Andalusia for the study area).

2.2 Soil sampling and analyses

Soil samples (soil entire profiles: 50 in CM, 20 in LV, 28 in LP and 16 in RG) were collected in a random sample design (representative of the whole study zone): 70 samples in CT and 44 samples in OF in the Los Pedroches Valley in 2009 in OG. We have selected fewer soil profiles in OF because the study area was lower than the study area in CT. The profiles recognition in CT and OF was carried out with georeferenced information from the Department of Organic Production of Andalusia. Soil entire profiles were

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collected in the open areas and flat (slope $< 3\%$). Forty years old olive trees, spaced 10 m × 10 m were selected for the study.

Some soil properties measured were not incorporated in this analysis: trees characteristics were not included because there are not soil properties that responded to the soil management system and soil structure was not incorporated because it was better correlated with soil type and not significantly with soil management.

Soil sample were air-dried at a constant room temperature (25 °C) and sieved (2 mm) to remove coarse soil particles. Four replications in each one were performed in laboratory (114 profiles × 3 or 2 horizons × 4 replications). Analytical methods and others parameters calculated are described in Table 1.

2.3 Statistical analysis

Soil properties (physicals and chemicals) by horizons for each management system were subjected to statistical analysis. Pearson's correlation coefficients were carried out to understand the relationships between different parameters (physicals and chemicals). An analysis of variance (ANOVA) was done to determine the importance of three sources of variability (mains factors): soil type (CM, LV, LP and RG), soil management (CT and OF), and horizons (Ap-h, Bw-t and C), and their interactions for each parameter. Significant differences between levels by means of Turkey's test $p < 0.05$ were deemed statistically. A principal component analysis (PCA) was performed to minimize and explain the variability of the system and to represent samples in the PCs scatterplot; only the eigenvalues > 0.3 were considered for PCA interpretation. The Anderson-Darling normality test was used to check the normal distribution of SR index. All calculations, including statistical analysis were computed using the Minitab software package (Minitab, 2000).

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3 Results

3.1 Soil properties and principal components analyses

Data for the soil profiles are compiled in Table 2. The studied soils in the Los Pedroches Valley were CM, LP, RG and LV (IUSS-ISRIC-FAO, 2006). Morphologically, we are dealing with soils showing different evolutionary features, according to topography, physiographic location parent material and climate. The studied soils exhibited differences in some physical and chemical properties with respect to management type and soil depth.

LV were deeper soils (88 cm in CT vs. 140 cm in OF), less gravelly (< 2.2 %) and more clayey in Bt horizon (39.6 % in CT vs. 30.2 % in OF). Generally, all studied soils were sandy soils, in some cases with more than 80 % of sands. From an analytical point of view (Table 2 and Table 3) LV were characterized by high cation exchange capacity (CEC) (> 25 $cmol\,kg^{-1}$). Normally all soil types having an acid pH (5.3–6.7) to the exception of RG-CT (7.3–7.4) and moderated or saturated base saturation (BS) (100–77.3 %), mainly calcium, to the exception of LV (77.3–35.7 %); normal values of total nitrogen (TN) in LP and RG (0.17 % A-horizon in RG-OF; 0.04 % C-horizon in LP-CT) and lower in CM and LV (0.13 % A-horizon in CM-OF; 0.02 % B-horizon in LV-CT). The principal characteristic of these soils was a decreasing in nutrients content in depth. The sand content was higher in OF with respect to CT in LV, RG and LP, however, an opposite trend (more in CT than OF) was observed for clay content, pH, BS and hydraulic conductivity (HC). Other notable feature was a low SOC content, in all studied soils decreased in depth, but this decreased was greater in CT. In addition, the carbon/nitrogen (C : N) ratio suggested generally suitable conditions for active microbial development and humus recycling (Tables 2 and 3).

PCA was first applied using the Pearson's correlation matrix (Table 4). Numerous significant linear correlations were existed among soil properties. Some variables relationship between us were: SOC and TN, sand and clay content, sand and silt content, exchangeable Mg^{2+} and CEC, exchangeable Ca^{2+} and CEC and SOC and C : N ratio with a extremely strong correlation ($p < 0.001$; $r = 0.997$, $r = -0.810$, $r = -0.753$, $r = 0.662$, $r = 0.629$ and $r = 0.624$ respectively). Other significant relationship were: TN and C : N ratio, exchangeable Ca^{2+} and exchangeable Mg^{2+}, pH and exchangeable Ca^{2+}, exchangeable K^+ and bulk density (BD), TN and BD, SOC and BD, pH and CO_3Ca and exchangeable Ca^{2+} and BS with a relatively very strong correlation ($p < 0.001$; $r = 0.581$, $r = 0.578$, $r = 0.546$, $r = -0.459$, $r = -0.458$, $r = -0.455$, $r = 0.453$, $r = 0.451$ respectively). In addition, pH and BS ($r = 0.389$), pH and exchangeable K^+ ($r = 0.378$), exchangeable Ca^{2+} and exchangeable K^+ ($r = 0.378$), TN and clay content ($r = -0.358$), SOC and clay content ($r = -0.343$), TN and sand content ($r = 0.324$), exchangeable K^+ and BS ($r = 0.308$) and SOC and sand content ($r = 0.305$), among others, had a moderate correlation ($p < 0.001$).

Since very strong and strong correlations were found in matrix correlation (Table 4). It was needed identify critical factors that determining land development in the Los Pedroches Valley using PCA. The PCA was performed for fifteen soils properties (physicals and chemicals). The PCA identified four factors (PC1, PC2, PC3 and PC4) with eigenvalues > 0.3 (Table 5). Considering average data for each soil properties, we have found thirteen factors that account for 65 % of the variance. PCA explained 22.5 %, 19.9 %, 13.3 % and 9.3 % of the variance from PC1, PC2, PC3 and PC4 respectively. Factor PC1 is positively correlated with exchangeables K^+ and Ca^{2+}, BD and SOC; this factor groups thus mostly parameters related to the soil chemical conditions. PC2 received the greatest loading from sand content, clay content and thickness, all negative except sand content, grouping parameters related to the soil physical condition. PC3 grouped parameters related to the soil chemical condition (exchangeable Ca^{2+}, exchangeable Mg^{2+} and CEC) all with positive performance. Finally, PC4 grouped C : N ratio, exchangeable Na^+, BS and HC all positive except C : N ratio (Table 5).

To reduced and explained, the system variability was made a PCs scatterplot. The relations between components for PCA (PC1, PC2, PC3 and PC4) were: PC2/PC3 and PC3/PC4, the first coefficient related A-horizons individually and the second coefficient related management practices and soils types (Figs. 2 and 3).

The ANOVA (Table 6) for PCA (horizons, soil type and management) indicated that there were significant differences ($p < 0.001$) between soil types for PC2, related to physical and chemical properties. However, when management system was analyzed, significance differences were found in PC1 ($p < 0.001$) and PC2 and PC3 ($p < 0.05$) influencing by physical properties principally (Table 6, Fig. 2). In the case of horizon type, significant differences were found in PC1 ($p < 0.001$) and PC2 ($p < 0.05$) caused by thickness, SOC, TN, BD, clay and K^+ (Table 6, Fig. 2).

The dispersion trends (PC2, PC3 and PC4) were affected by management type (Fig. 3); with respect to PC2 presents a behavior-trend for the right side (positive) of the OF axis, caused by thickness and texture, this is particular relevant in CM, RG (located on the right side – positive) and LV (located on the left side – negative). In PC4, the OF is located on the left side (negative), influenced by HC and C : N ratio (Fig. 3).

3.2 Soil organic carbon (SOC), total nitrogen (TN) and C : N ratio

The SOC and TN concentrations decreased in depth (Table 3). In OF the SOC and TN content were greater in top soil (A-horizon) for all soil types with respect to CT, with the exception of Ah-horizon in LP for SOC (20.55 $g\,kg^{-1}$-CT; 18.03 $g\,kg^{-1}$-OF). In the surface horizons, the SOC values were highly heterogeneous ranged from 20.55 $g\,kg^{-1}$ to 7.63 $g\,kg^{-1}$ for LP-CT and CM-CT respectively; the TN had similar trend ranging from 1.70 $g\,kg^{-1}$ to 0.76 $g\,kg^{-1}$ (RG-OF; CM-CT). Normally, high SOC values involved high TN values. The SOC in CT was $< 10\,g\,kg^{-1}$ with the exception of LP in Ap-horizons (20.55 $g\,kg^{-1}$), by contrast, in OF the SOC was higher ($> 10\,g\,kg^{-1}$) in all studied soils.

With respect to the management system, the SOC and TN showed significant differences ($p < 0.05$) in all horizons for CM, LP and RG (Table 3). In the case of total SOC (T-SOC) content significant differences ($p < 0.05$) only were found in CM. However, when total TN (T-TN) was analyzed in all soil studied were found significant differences ($p < 0.05$) by management type. The C : N ratio at the surface to depth was generally higher in OF compared to CT. For OF in CM, LP and RG, the C : N ratio tended to

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decrease in depth, by contrast in CT in CM and LV was observed an opposite trend (increase of C : N ratio in depth).

To correlating SOC content with the soil variables (Table 4), the SOC had strong positive correlations ($p < 0.001$) with TN ($r = 0.997$) and C : N ratio ($r = 0.624$), similar trend was observed with respect to BD, but in this case the correlation was negative ($r = -0.455$), when SOC increased the BD decreased. However, when thickness horizon increased, the SOC is scattered and undergoes a redistribution process. Others small correlations ($p < 0.001$) were observed for sand content ($r = 0.305$) and clay content ($r = -0.343$). Equally were found correlations between SOC and other soil parameters in the surface horizon (Fig. 2); SOC was correlated strongly with TN, clay content and exchangeable Na^+ ($r = 0.999$, $p = 0.000$; $r = -0.350$, $p = 0.008$; $r = -0.342$, $p = 0.009$). In addition, SOC was correlated moderately with sand content and exchangeable K^+ and Ca^{2+} ($r = 0.263$, $p = 0.048$; $r = -0.334$, $p = 0.011$; $r = -0.279$, $p = 0.036$).

3.3 Management effect on soil organic carbon (SOC) and total nitrogen (TN) stocks

A critical issue has been to analyze the management influence on SOC stock (SOC-S). The highest total SOC-S (T-SOC-S) was found in LV-OF (95.4 $Mg\,ha^{-1}$) and the lowest in LP-OF (42.77 $Mg\,ha^{-1}$) (Table 3). In all studied soils were found significant differences ($p < 0.05$) by management type with respect to T-SOC-S, therefore, the management system affected to the T-SOC-S for 20 yr. In CM, LV was found more T-SOC-S in OF than in CT; however, an opposite trend was found in RG and LP (more T-SOC-S in CT than in OF). The SOC-S varies within the soil profile, with higher values in the topsoil in OF than CT for CM, LV and RG; similar values were found in LP for OF vs. CT (31.65 $Mg\,ha^{-1}$ CT; 30.0 $Mg\,ha^{-1}$ OF). SOC-S on the surface horizon varied between 34.95 $Mg\,ha^{-1}$ for RG-OF and 23.22 $Mg\,ha^{-1}$ for LV-CT. Nevertheless, high values of SOC were found in soils less sandy (RG and LV) (Table 2 and Table 3). By contrast, SOC-S was higher in subsoil (Bt and C horizons) in LV-OF and RG-CT than surface horizon.

Significant differences by horizons and soil types ($p < 0.05$) were found when management system was analyzed to the exception of LP (Ah horizon), nevertheless, in all studied soil were found significant differences ($p < 0.05$) for T-SOC-S. With respect to TN stock (TN-S), the behavior was similar to SOC-S. The total TN-S (T-TN-S) showed significant differences ($p < 0.05$) in all soils with respect to management practices. When TN was analyzed, the results indicated a parallelism between TN and SOC concentrations (with similar behavior) shows a positive C : N relation (Table 4).

3.4 Stratification of SOC, TN and C : N ratio

In all studies soils, the SR of SOC increased in deep (Table 7). The SR of SOC for the surface to depth [SR1] was greater in CT compared to OF with the exception of RG (SR1-RG-CT 2.13; SR1-RG-OF 3.33), in which the relation was opposite caused by the low SOC concentration in Ah/C in CT. The [SR2] had similar behavior in CM and LV. In LP and RG, this relation cannot be performed due to lack of deep horizons. Significant differences ($p < 0.05$) between management system (by horizons) were found in CM, LV and RG for SR of SOC.

In the study soils, good quality (SR > 2) was shown when SR index was applied for SOC in both management systems to the exception of SR1-LV-OF (1.38). A critical issue was the reduction rates of SR in OF compared to CT in all soils except for SR2-LV and SR1-RG that increased. This scenario implied a reduction of soil quality when OF is applied for long-term (20 yr) in CM and LP. The SR of TN showed a similar trend that SR of SOC. The SR of C : N ratio increased in depth to the exception of LV-CT that decreased in depth. Significant differences ($p < 0.05$) between management system (by horizons) were found in LV and RG for SR of TN.

In top soil for CM and RG, the SR was higher in OF with respect to CT. The SR of C : N ratio, normally increased in depth in OF with respect to CT. Significant differences

($p < 0.05$) between management system (by horizons) were found in CM, LV and RG for SR of C : N ratio.

In summary, the SR indexes in the study soils show three different results by soil type and management practices. In LP, the management practices have little effect on carbon and nitrogen accumulation on soil. In LV and RG, the management practices affecting on carbon accumulation in OF: in LV the SR of SOC decreased in top soil but increased in deep, for RG land management changes increased the SR of SOC. In CM was observed a negatively trend, decreasing the SR. Therefore, the management practices affect to SOC accumulation. The mean values of SR of SOC and TN generally were > 2 in all cases to the exception of LV-OT (SR1-SOC 1.38; SR1-TN 1.28) (Table 7).

4 Discussion

4.1 Soil properties and principal components analyses

The soils properties in the Los Pedroches Valley are conditioned by lithology (granite and granodiorite) and their low development is the cause by their formation age (Porta et al., 2003), also, the formation processes of these soils take place with low slope (< 2 %) (Nerger et al., 2007), thus are shallow soils (Marañón, 1988).

LV cases are fertile soils and suitable for a wide range of Mediterranean uses such as cereals, fruit trees, olives and vineyards (Zdruli et al., 2011). The principal characteristic of these soils is a high clay content in the subsoil (CT-LV-Bt: 39.6 %; OF-LV-Bt: 30.2 %) compared to topsoil (CT-LV-Ap: 16.8 %; OF-LV-Ap: 11.7 %) as the result of pedogenetic processes (clay migration) leading to an argillic subsoil horizon (Bt). An important feature of these soils is the low OM content (González and Candás, 2004), justifying this behavior by climate (semiarid Mediterranean conditions, accentuated in Europe's southern) and soil texture (sandy soils) that contribute to a low OM content (Parras-Alcántara et al., 2013b; Parras-Alcántara et al., 2014). With respect to CM, RG and LP, these soils are characterized by low fertility, poor physical conditions and a marginal capacity for agricultural uses. CM are more developed soils than RG and LP. In the study zone, LP are the less developed soils, influenced by topography and physiographic location (Recio et al., 1986).

The CEC was high, ranges from 12.45 $cmol\,kg^{-1}$ and 30.66 $cmol\,kg^{-1}$ (limit proposed by Hazelton and Murphy (2007) based on Metson, 1961). Ruiz et al. (2012) in Mediterranean rangeland obtain similar results; by contrast, Pulido-Fernández et al. (2013) in Iberian open woodland rangelands obtained low CEC values caused by nutrient scarcity. The higher SOC content in topsoil in OF can be justified by management type, that increase the soil vegetal cover and maximize the organic residues transfer, also, reduced the soil erosion risk. Similar results were obtained by Corral-Fernández et al. (2013) for evergreen oak woodland with OF in the Los Pedroches Valley. In this line, OF can be considered a key factor for long-term, considering as friendly environmental management practices (Hathaway-Jenkins et al., 2011).

The factors that affected to soil development in the study area using PCA were predominantly parameters related to the soil chemical properties (PC1, PC3 and PC4) and parameters related to the soil physical conditions (PC2). With respect to the soil chemical properties, the study soils are defined by the dominance of basic cations, conditioned by lithology (Recio et al., 1986) and carbonates presence (Nerger et al., 2007), especially in RG and LP. According to this, Nerger et al. (2007), in the Los Pedroches Valley justify the high influence of chemical properties caused by carbonates presence (high Ca^{2+}, basic pH and low OM in the top soil) that could affect to soil development. In addition, the Ca^{2+} enrichment could be related with the continental influence (ions enrichment in the soil solution) due to climatic conditions (high rainfall in some seasons). However, a high trees density could be affect to OM content increasing the SOC content (González et al., 2012). This coincides with our data (high nutrient contents and high CEC) compared with others Mediterranean rangeland. The PCA indicated that the sand content (PC2) is a key factor that can affect the soil development in the Los Pedroches Valley, in this line, Hontoria et al. (2004) suggested that the variables that affect the soil development in the driest areas of Spain are the variables related to the texture more than variables related to management or the climate. In addition, Castro et al. (2008) reported that soil texture is the first property that influence on SOC in agricultural soils.

When variance analysis (ANOVA) was applied, we found differences between soil and management types. However, when T-SOC was analyzed were not found bigger differences for managing system in LV, LP and RG. In this line, Parras-Alcántara et al. (2014) indicates that organic farming has little effect on carbon stock in Mediterranean dehesa. Also, Bradford and Peterson (2000), for various land uses, indicate that sometimes, there is no difference between conventional, minimum, or reduced tillage.

4.2 Soil organic carbon. Management influence

SOC concentrations in the Los Pedroches Valley decreased in depth in all soil types and management practices, but this reduction was greater in CT with respect to OF. Castro et al. (2008) in OG observed a similar trend at different depths. In this line, Bronick and Lal (2005), explain that CT (low input OM, ploughing and low vegetal soil cover) in OG minimize the organic residues incorporation and enhanced the erosion risk. In addition, the formation process between OM and mineral aggregates diminishes in the surface horizons in sandy soils (González and Candás, 2004); this justifies high levels of transformed OM and explains low OM concentrations at greater depths in the studied soil. In this sense, López-Garrido et al. (2011) have observed similar results for different crops and management systems. Besides, Franzluebbers (2005) conclude that the topsoil is more susceptible to changes by management practices, and the carbon sequestration occurs principally in upper horizons. However, the superficial horizon is not the layer with more potential for SOC sequestered because the SOC in depth occurs in stable forms and it is highly recalcitrant to biodegradation processes (Lorenz and Lal, 2005). Nevertheless, CT promotes a rapid mineralization of SOM in Mediterranean agricultural soils (Melero et al., 2009).

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The SOC in the study area was affected for the physical parameters, this coincides with exposed by Hontoria et al. (2004) which suggests that the variables that affect to the soils development in the driest areas of Spain are the physical variables, more than management types or the climatic one. The SOC and TN contents were greater in the surface horizons for CM and LV in OF with respect to CT caused by the high OM concentration in the Ap horizons. The SOC in CT in surface horizons was $< 10\,\mathrm{g\,kg^{-1}}$ in CM and LV, these low SOC concentrations are due to the high mineralization of the OM and the absence of harvest residues after periods of drought (Hernanz et al., 2009). In agricultural soils, low SOC levels have a negative impact on soil physical properties and nutrient cycling, mainly associated with soils degradation (Romanya and Rovira, 2011). However, the SOC in OF in surface horizons was $> 10\,\mathrm{g\,kg^{-1}}$ in CM, LP and RG in the Los Pedroches Valley for 20 yr. Similar results were reported by Álvarez et al. (2007) in OG in OF. According to Aranda et al. (2011), OF could affect to carbon retention under stable forms and could help to increase the SOC stock, contributing to agro-environmental benefits, such as increased of soil fertility, erosion prevention. . . , etc.

The C : N ratio from the surface to depth was higher in OF compared to CT in CM and LV. This accords with Blanco-Canqui and Lal (2008) and could be explained by the higher contribution of residue input on the surface under OF compared to CT. Also, this may reflect less OM decomposed in surface soil in OF. Additionally, the residue retention can increase the SOC (Xu et al., 2011) with lower decomposition degree and higher C : N ratio (Yamashita et al., 2006). In OF the C : N ratio tended to decrease in depth in CM, LP and RG associated to clay content (that increased in depth); high clays levels are associated with high decomposed OM and lower C : N ratio (Diekow et al., 2005; Yamashita et al., 2006). By contrast in CT, in some soils, was observed an opposite trend (increase of C : N ratio in depth) that may be attributed to high C : N soluble organic compounds leaching into deeper layers (Diekow et al., 2005).

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4.3 Soil organic carbon and total nitrogen stocks

The T-SOC-S for soil groups in Peninsular Spain (Rodríguez-Murillo, 2001) are 71.4 Mg ha^{-1}, 98.8 Mg ha^{-1}, 48.7 Mg ha^{-1} and 66 Mg ha^{-1} for CM, LP, RG and LV respectively and for soil used (OG) is 39.9 Mg ha^{-1}. The highest T-SOC-S in the Los Pedroches Valley was found in LV-OF (95.4 Mg ha^{-1}) and the lowest for LP-CT (42.7 Mg ha^{-1}). These differences between T-SOC-S for soil groups in Peninsular Spain and the study soils are caused by soil thickness (we used soil complete profile and Rodriguez-Murillo (2001) used descriptions of soil profiles deeper than 1 m.

We can observe that management systems affect to the T-SOC-S for 20 yr in all soils types. In CM and LV was found more T-SOC-S in OF than in CT. However, in LP and RG the trend was opposite (more T-SOC-S in CT than OF). Similar results were obtained by Novara et al. (2012), justifying this behavior for the mixing of the upper soil layers during soil tillage. The SOC stored varies within the soil profile, with higher values in topsoil in OF compared to CT. The SOC-S in surface horizons varied between 34.95 Mg ha^{-1} for RG-OF and 23.22 Mg ha^{-1} for LV-CT. Two behaviors were observed in the study soils. In the first case, soils with low SOC, this can be explain by texture (sandy soils) associated to vegetation losses and unsustainable soil management practices; this situation favors a continuous impoverishment of the SOM content causing low soils productivity and derived in unsuitable chemical properties. In the second case, soils with high SOC values; this was especially important in clayey soils (RG and LV) related to the clay stabilization process in the soil, increasing the clay content with respect to CM and LP, similar results were obtained by Leifeld et al. (2005). This is especially important in Bt and C horizons in LV-OF and RG-CT that increased the SOC-S with respect to the surface horizon; in this line, Shrestha et al. (2004) explained that this increased could be due to the translocation of carbon in the form of dissolved organic carbon, soil fauna activity, and/or the effects of deep-rooting crops.

In the Los Pedroches Valley, there was a positive correlation between TN and SOC, shows a C : N positive relation. According to this, the clay content slows the SOC oxida-

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tion and could have a positive relationship between clay and nitrogen; similar result was obtained by Sakin et al. (2010). Others studies state that N mineralization decreases when clay content increases (Côté et al., 2000), this effect was particularly important in CT in the Los Pedroches Valley (TN decreased when clays increased), in this line, McLauchlan (2006) explained that the aggregate formation increase and the potential N mineralization decrease when clays content increases in soil.

Melero et al. (2009) suggest that OF can increase SOC under longer experimental duration; we confirmed this because SOC and TN stock increased in OF for long-term (20 yr).

4.4 Stratification ratio of SOC

Many authors have shown SRs ranges from 1.1 to 1.9 for CT and 2.1 to 4.1 for OF (Franzluebbers, 2002; Hernanz et al., 2009) for non-degraded soils. In the studied soils, the SR of SOC shown good soils quality, to the exception of LV-OF. The SR of C : N ratio, normally increased in depth in OF with respect to CT, but was not found significant differences ($p < 0.05$) between management system (by horizons) in LP. This may be explained by a higher contribution of residue relative to root inputs leading a higher soil C : N ratio (Puget and Lal, 2005). Under OF, 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 would involve little effect in the management system on the carbon accumulation in the soil. In this line, Balesdent and Balabane (1996) do not find any significant differences in SR, in a Geauga farm (Ohio).

Our results provide evidence for the preferential accumulation of SOC in surface horizons. According to Franzluebbers (2005), the SR of SOC in depth under Mediterranean climatic conditions affect potentially to carbon incorporation in the soil as the residue accumulation in subsurface horizon affecting to carbon incorporation and the decomposition rates in deeper horizons being more lower than in the upper soil hori-

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zons (Lorenz and Lal, 2005). In addition, the SR of SOC provided information about the SOC effects in the top soil layer, furthermore could be affect to SOC accumulation in the soil profile, this is important in the study soils (with high values of SR of SOC and TN). According to Jobbágy and Jackson (2000), in reviewing over 2700 soil profiles worldwide concluded that vegetation and climate were associated with the vertical distribution of SOC, but climate and clay content were more decisive in the SOC stored.

5 Conclusions

The study concludes that the management system (CT and OF) in CM, LV, RG and LP between 1985 and 2009 (long-term) in OG in the Los Pedroches Valley (Mediterranean rangelands) affects to soil physical-chemical properties, especially to SOC content, exchangeable macroelements (Ca^{2+} and K^{+}), texture (sand and clay) and TN, and in lesser degree affected to BS, silt content and HC. With respect to the top soil there are significant differences between soil types and management systems ($p < 0.001$), affecting some soils properties principally to SOC content, exchangeable K^{+}, BD, thickness, clay content and pH, this indicate that there are significant variations between CT and OF in OG in the study area.

The main feature of the studied soils is the low OM concentrations in depth, conditioned by high sand content (texture) and climate (semiarid Mediterranean conditions). OF has a positive impact in CM and LV (increasing the T-SOC-S and T-TN-S) with respect to CT, by contrast, there is a negative impact in RG and LP caused by mixing of the upper soil layers during soil tillage. Also, this reduction of SOC with respect to the management system can be explain by degraded soil process and for the reduced input of OM, as well as to the reduced physical protection of soil from erosion and the increased decomposition rate as a consequence of tillage. Which respect to TN concentrations is high in areas where the SOC is high shows a positive relation C : N ratio.

The soil quality index (SR) in the study soils indicates good soils quality. In all cases, the SR of SOC and TN increased in deep. The SR of SOC for surface to depth was greater in CT than OT, this indicates a loss soil quality when OF is applied. Our results indicate preferential accumulation of SOC in the surface horizons, influenced by Mediterranean climate. In subsurface horizons, the carbon decomposition rates are lower than in the upper soil layers. The SR of C : N ratio increased in some cases in depth. Significant differences ($p < 0.001$) with respect to the management practices have been found, this can be explaining by higher contribution of residue that implied a higher C : N ratio. Under OF the SOC is concentrated on soil surface, also, the soil C : N ratio is stratified, this slight change in C : N ratio suggests a decomposition degree of SOC, decreasing toward the surface. This indicated little effect in management system on the carbon accumulation in top soil.

This research corroborates the necessity to analyze soil entire profiles under different management systems because in temperate climates, large amounts of SOC may be stored in subsoil horizons (SOC can be transported to deeper soil horizon, contributing to the subsoil C storage). The study shows that OF in OG in the Los Pedroches Valley (Mediterranean rangelands) for long-term (1985 and 2009) contributes to a better soil and contributes to a more sustainable agriculture.

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Table 1. Methods used in field measurements, laboratory analysis and calculated from field data.

Parameters	Method
Field measurements	
Bulk density ($Mg\,m^{-3}$)	Cylindrical core sampler[a] (Blake and Hartge, 1986)
Laboratory analysis	
Particle size distribution	Robinson pipette method (USDA, 2004)[b]
pH – H_2O	1 : 2.5 suspension in water (Guitián and Carballas, 1976)
Total N (%)	Kjeldahl method (Bremner, 1996)
CO_3Ca equivalent	Volumetric with Bernard calcimeter (Duchaufour, 1975)
Organic C (%)	Walkley and Black method (Nelson and Sommers, 1982)
Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, C.E.C ($cmol\,kg^{-1}$)	(Bower et al., 1952)
Base saturation (%)	(Duchaufour, 1975)
Hydraulic conductivity ($mm\,h^{-1}$)	Mono-disc multiple potential process (Reynolds and Elrick, 1991)
Parameters calculated from field data	
C : N ratio	Ratio organic C organic N
SOC stock ($Mg\,ha^{-1}$)	(SOC concentration × BD × d × (1-$\delta_{2\,mm}$%) × 0.1)[c] (Wang and Dalal, 2006)
Total SOC stock ($Mg\,ha^{-1}$)	$\Sigma_{horizons}$ SOC $Stock_{horizon}$ (IPCC, 2003)
SR	(SOC-Ap onto SOC-Bw/C)[d] (Franzluebbers, 2002)

[a] 3 cm in diameter, 10 cm in length and 70.65 cm^3 in volume.

[b] Prior to determining the particle size distribution, samples were treated with H_2O_2 (6 %) to remove organic matter (OM). Particles larger than 2 mm were determined by wet sieving and smaller particles were classified according to USDA standards (2004).

[c] Where SOC is the organic carbon content ($g\,kg^{-1}$), d the thickness of the soil layer (cm), $\delta_{2\,mm}$ is the fractional percentage (%) of soil mineral particles > 2 mm in size in the soil, and BD the soil bulk density ($Mg\,m^{-3}$).

[d] 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 two SRs for the CM and LV [SR1 (Ap/Bw-Bt) and SR2 (Ap/C)] and one SR for LP and RG [SR1 (Ah/C)].

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Table 2. Soil properties evaluated (average ±SD[b]) in the Los Pedroches Valley (Mediterranean rangeland) in olive groves.

Soil	Til.	Hor.	Depth	Thickness	Gravel	Sand	Silt	Clay	B.D.	pH	CO_3Ca	Na^+	K^+	Ca^{2+}	Mg^{2+}	CEC	BS	HC
			cm		%				$Mg\,m^{-3}$	H_2O	%			$cmol\,kg^{-1}$			%	$mm\,h^{-1}$
CM	CT n = 32	Ap	0–21	21 ± 1.3	2.9 ± 0.5 a	75.9± 6.4 a[a]	17.9± 3.6 a[a]	6.2 ± 0.6 a	1.55± 0.21 a[a]	6.3 ± 0.2 a[a]	0 a[a]	0.75± 0.04 a[a]	0.37± 0.02 a[a]	9.29± 0.12 a[a]	3.72± 0.08 a[a]	18.67± 1.08 a[a]	85.6± 9.85 a[a]	6.66± 2.05 a
		Bw	21–47	26 ± 2.5	3.2 ± 0.6 a	72.7± 5.9 a	20.6± 3.5 b	6.7 ± 0.7 a	1.61± 0.23 b	6.1 ± 0.1 a	0 a	0.49± 0.03 b[a]	0.24± 0.01 b[a]	10.10± 0.15 a[a]	5.19± 0.25 b[a]	17.69± 1.22 a[a]	94.7± 8.54 b[a]	5.06± 1.28 b
		C	47–79	32 ± 2.9	4.1 ± 1.0 b	81.1± 6.4 b	15.1± 2.9 a	3.8 ± 0.4 b[a]	1.62± 0.28 b	5.8 ± 0.4 b	0 a	0.35± 0.02 c[a]	0.18± 0.01 c[a]	10.43± 0.17 a[a]	5.23± 0.27 b[a]	22.19± 1.58 b[a]	84.2± 7.45 a[a]	8.44± 2.56 c[a]
	OF n = 18	Ap	0–17	17 ± 1.8	2.8 ± 0.5 a	69.4± 4.3 c	24.4± 3.1 c	6.2 ± 1.2 a	1.39± 0.31 c	5.8 ± 0.1 b	9.1 ± 25.74 b	0.57± 0.03 d	0.62± 0.03 d	2.59± 0.08 b	4.95± 0.18 b	14.81± 0.82 c	64.6± 5.23 c	6.21± 1.58 d
		Bw	17–49	32 ± 3.2	3.3 ± 0.6 a	75.7± 5.3 a	18.0± 2.5 a	6.3 ± 1.4 a	1.57± 0.21 a	5.4 ± 0.2 b	0 a	0.19± 0.01 e	0.64± 0.04 d	2.89± 0.09 b	2.61± 0.09 c	12.46± 0.56 d	80.1± 9.94 d	6.05± 1.98 d
		C	49–74	25 ± 2.5	4.3 ± 0.9 a	77.1± 4.8 a	15.5± 2.2 a	7.4 ± 2.1 a	1.58± 0.32 a	5.9 ± 0.1 a	0 a	0.25± 0.02 f	0.95± 0.10 e	4.07± 0.15 c	3.16± 0.15 a	18.57± 1.42 a	72.4± 7.85 e	5.65± 1.68 b
LV	CT n = 12	Ap	0–20	20 ± 2.0	1.5 ± 0.3 a	55.2± 3.6 a	28.0± 3.6 a	16.8± 2.6 a	1.50± 0.24 a	6.0 ± 0.2 a	0 a	0.46± 0.03 a[a]	0.44± 0.03 a[a]	6.12± 0.31 a[a]	2.02± 0.11 a[a]	14.47± 0.85 a[a]	77.3± 8.65 a[a]	1.82± 0.09 a
		Bt	20–55	35 ± 3.5	1.7 ± 0.4 b	33.4± 4.2 b[a]	27.0± 5.1 a	39.6± 4.5 b[a]	1.51± 0.35 a	5.7 ± 0.1 b[a]	0 a	0.45± 0.02 a[a]	0.24± 0.01 b[a]	5.33± 0.22 a[a]	4.23± 0.21 b[a]	27.59± 1.57 b	40.8± 5.36 b	0.32± 0.04 b[a]
		C	55–88	33 ± 3.1	2.2 ± 0.3 c	50.7± 5.7 a	27.6± 2.3 a[a]	21.7± 2.3 c[a]	1.54± 0.31 b	5.5 ± 0.1 b[a]	0 a[a]	0.32± 0.02 b[a]	0.19± 0.01 c[a]	5.10± 0.21 a[a]	3.84± 0.19 b[a]	21.17± 1.23 c[a]	46.0± 6.05 b[a]	0.71± 0.01 c
	OF n = 8	Ap	0–26	26 ± 1.7	1.4 ± 0.1 a	57.6± 4.9 a	30.7± 4.7 b	11.7± 1.8 d	1.52± 0.28 a	6.2 ± 0.3 a	0 a	0.25± 0.01 c	0.65± 0.03 d	2.40± 0.07 b	3.20± 0.14 c	25.78± 1.65 b	51.4± 6.52 c	2.15± 0.10 a
		Bt	26–67	41 ± 3.2	1.7 ± 0.3 b	42.0± 4.6 c	27.8± 3.5 a	30.2± 4.2 e	1.52± 0.24 a	5.3 ± 0.1 c	0 a	0.17± 0.01 d	0.61± 0.03 d	3.98± 0.14 b	8.51± 0.45 d	30.66± 2.69 d	38.1± 3.65 b	1.52± 0.09 a
		C	67–140	73 ± 5.4	2.1 ± 0.2 a	48.7± 5.0 c	35.4± 4.1 c	15.9± 2.8 a	1.54± 0.32 b	5.0 ± 0.1 c	24.66± 42.72 b	0.18± 0.01 d	0.54± 0.02 e	1.80± 0.05 c	8.00± 0.38 d	25.66± 1.65 b	35.7± 2.36 d	0.81± 0.01 c

Table 2. Continued.

Soil	Til.	Hor.	Depth	Thickness	Gravel	Sand	Silt	Clay	B.D.	pH	CO_3Ca	Na^+	K^+	Ca^{2+}	Mg^{2+}	CEC	BS	HC
			cm		%				$Mg\,m^{-3}$	H_2O	%			$cmol\,kg^{-1}$			%	$mm\,h^{-1}$
LP	CT n = 18	Ah	0–11	11 ± 1.1	2.4 ± 0.3 a	50.8± 3.2 a[a]	34.4± 4.2 a[a]	14.8± 3.1 a[a]	1.40± 0.19 a[a]	6.7 ± 0.4 a	9.77± 7.24 a[a]	1.01± 0.09 a[a]	0.85± 0.04 a[a]	12.75± 0.53 a	5.75± 0.26 a[a]	24.45± 1.42 a[a]	86.7± 8.57 a[a]	27.37± 3.25 a[a]
		C	11–35	24 ± 2.1	3.2 ± 0.4[a] b	46.0± 4.5 a[a]	35.6± 4.4 a[a]	18.4± 3.5 b[a]	1.56± 0.36 b	6.4 ± 0.2 a[a]	10.20± 7.35 a[a]	0.97± 0.09 a[a]	0.53± 0.03 b	11.43± 0.54 a[a]	8.68± 0.47 b[a]	24.92± 1.51 a[a]	88.6± 9.2 a[a]	6.60± 0.98 b[a]
	OF n = 10	Ah	0–16	16 ± 1.3	2.5 ± 0.2 a	74.3± 6.2 b	18.3± 3.5 b	7.4 ± 1.5 c	1.04± 0.09 c	6.6 ± 0.2 a	35.12± 66.81 b	0.62± 0.04 b	0.76± 0.04 c	13.10± 0.67 b	8.14± 0.43 b	14.40± 0.84 b	79.7± 7.89 b	5.79± 0.52 b
		C	16–33	17 ± 2.0	4.1 ± 0.3 c	72.2± 5.4 b	17.3± 2.9 b	10.5± 1.9 d	1.54± 0.32 b	5.6 ± 0.1 b	6.40± 14.31 b	0.19± 0.01 c	0.55± 0.03 b	18.55± 0.71 c	11.25± 0.52 c	12.71± 0.62 b	73.7± 6.58 b	4.09± 0.41 c
RG	CT n = 8	Ah	0–15	15 ± 1.8	3.2 ± 0.3 a	63.5± 5.1 a[a]	17.7± 2.4 a	18.8± 2.1 a[a]	1.14± 0.20 a	7.3 ± 0.4 a[a]	8.20± 5.23 a[a]	0.63± 0.04 a[a]	1.41± 0.14 a[a]	9.28± 0.14 a[a]	1.73± 0.05 a[a]	13.05± 0.78 a	100 ± 9.91 a[a]	10.23± 1.23 a[a]
		C	15–70	55 ± 4.5	4.3 ± 0.5 b	33.4± 3.5 b[a]	24.1± 3.6 b[a]	42.5± 4.8 b[a]	1.49± 0.19 b[a]	7.4 ± 0.3 a[a]	8.76± 11.65 a[a]	1.15± 0.10 b[a]	0.87± 0.05 b[a]	18.55± 0.62 b[a]	2.92± 0.08 b[a]	24.12± 1.45 b[a]	98.3± 9.23 a[a]	3.17± 0.58 b[a]
	OF n = 8	Ah	0–16	16 ± 1.9	2.8 ± 0.3 c	70.9± 4.8 c	22.5± 3.8 b	6.6 ± 0.5 c	1.17± 0.08 a	5.7 ± 0.1 b	0 b	0.79± 0.05 c	0.78± 0.04 c	4.83± 0.14 c	4.96± 0.17 c	15.50± 0.91 c	86.3± 8.24 b	4.55± 0.65 b
		C	16–37	21 ± 2.1	4.5 ± 0.5 b	80.3± 5.9 d	15.6± 3.5 a	4.1 ± 1.1 c	1.55± 0.32 c	5.8 ± 0.1 b	0 b	0.24± 0.02 d	0.74± 0.02 c	5.44± 0.17 c	4.58± 0.14 c	15.73± 0.94 c	82.1± 6.81 b	5.32± 0.71 c

CM: Cambisol; LP: Leptosol; RG: Regosol; LV: Luvisol. CT: Conventional tillage; OF: Organic farming. Til.: Tillage; Hor.: Horizon; BD: Bulk density; CEC: Cation exchange capacity; BS: Base saturation; HC: Hydraulic conductivity. n = Sample size.

[b] Standard deviation.

[a] Significant differences ($P < 0.05$) between CT and OF treatments (by horizons).

Numbers followed by different lower case letters within the same column have significant differences ($P < 0.05$) between depth, considering the same soil type.

Table 3. Soil Organic Carbon, Total Nitrogen and C : N ratio stock (average ±SD[a]) in the Los Pedroches Valley (Mediterranean rangeland) in olive groves.

Soil	Tillage	Horizon	SOC	T-SOC	TN	T-TN	SOC-S	T-SOC-S	TN-S	T-TN-S	C : N ratio
			$g\,kg^{-1}$	$g\,kg^{-1}$	$g\,kg^{-1}$	$g\,kg^{-1}$	$Mg\,ha^{-1}$	$Mg\,ha^{-1}$	$Mg\,ha^{-1}$	$Mg\,ha^{-1}$	
CM	CT $n = 32$	Ap	7.63 ± 3.09 a[a]	11.67 ± 1.99 a[a]	0.76 ± 0.25 a[a]	1.33 ± 0.17 a[a]	24.84 ± 5.46 a[a]	43.75 ± 5.11 a[a]	2.47 ± 0.37 a[a]	5.11 ± 0.81 a[a]	10.06 ± 1.02 a
		Bw	2.04 ± 1.21 b[a]		0.31 ± 0.08 b[a]		8.54 ± 4.86 b[a]		1.29 ± 0.28 b[a]		6.62 ± 0.54 b[a]
		C	2.00 ± 1.67 b[a]		0.26 ± 0.17 c[a]		10.37 ± 5.00 b[a]		1.35 ± 0.48 b		7.68 ± 0.57 c
	OF $n = 18$	Ap	14.23 ± 4.43 c	23.31 ± 3.23 b	1.33 ± 0.37 d	2.34 ± 0.27 b	33.63 ± 9.86 c	74.7 ± 6.67 b	3.14 ± 0.84 c	7.69 ± 0.71 b	10.71 ± 0.97 a
		Bw	4.88 ± 3.09 d		0.53 ± 0.26 e		24.52 ± 5.15 a		2.66 ± 0.39 a		9.21 ± 0.84 a
		C	4.19 ± 2.18 d		0.48 ± 0.19 e		16.55 ± 5.01 d		1.89 ± 0.9 d		8.76 ± 0.52 d
LV	CT $n = 12$	Ap	7.74 ± 1.61 a	14.31 ± 1.15 a	0.77 ± 0.12 a	1.38 ± 0.09 a[a]	23.22 ± 1.29 a[a]	57.28 ± 3.56 a[a]	2.31 ± 0.21 a[a]	5.46 ± 0.17 a[a]	10.05 ± 0.95 a
		Bt	3.36 ± 0.98 b[a]		0.23 ± 0.10 b[a]		17.75 ± 4.06 b[a]		1.22 ± 0.25 b[a]		14.55 ± 1.14 b[a]
		C	3.21 ± 0.87 b[a]		0.38 ± 0.07 c[a]		16.31 ± 5.32 b[a]		1.93 ± 0.05 c[a]		8.45 ± 0.69 c[a]
	OF $n = 8$	Ap	7.74 ± 1.93 a	16.01 ± 2.05 a	0.77 ± 0.16 a	1.64 ± 0.18 b	30.59 ± 9.71 c	95.4 ± 8.16 b	3.04 ± 0.16 d	9.82 ± 0.43 b	10.06 ± 0.89 a
		Bt	5.62 ± 2.96 b		0.60 ± 0.26 d		35.02 ± 7.40 d		3.74 ± 0.94 e		9.36 ± 0.79 a
		C	2.65 ± 1.26 c		0.27 ± 0.12 e		29.79 ± 7.38 c		3.04 ± 0.20 d		9.80 ± 0.74 a
LP	CT $n = 18$	Ah	20.55 ± 8.50 a	25.89 ± 5.06 a	1.40 ± 0.71 a	1.81 ± 0.42 a[a]	31.65 ± 11.85 a	51.64 ± 9.64 a[a]	2.16 ± 0.19 a[a]	3.69 ± 0.58 a[a]	14.65 ± 1.12 a[a]
		C	5.34 ± 1.62 b		0.41 ± 0.13 b		19.99 ± 7.43 b[a]		1.53 ± 0.97 b[a]		13.06 ± 1.11 b[a]
	OF $n = 10$	Ah	18.03 ± 4.02 a	22.91 ± 3.69 b	1.63 ± 1.15 a	2.12 ± 0.73 a	30.00 ± 10.69 a	42.77 ± 7.15 b	2.71 ± 0.16 c	3.99 ± 0.47 b	11.07 ± 1.09 c
		C	4.88 ± 3.36 b		0.49 ± 0.31 b		12.77 ± 3.60 c		1.28 ± 0.77 b		9.98 ± 0.78 c
RG	CT $n = 8$	Ah	15.36 ± 3.60 a[a]	22.57 ± 2.98 a	1.19 ± 0.17 a[a]	1.77 ± 0.17 a[a]	26.27 ± 3.03 a[a]	85.35 ± 6.27 a[a]	2.03 ± 0.88 a[a]	6.78 ± 0.90 a[a]	12.94 ± 1.05 a[a]
		C	7.21 ± 2.36 b[a]		0.58 ± 0.17 b		59.08 ± 9.52 b[a]		4.75 ± 0.92 b[a]		12.44 ± 1.17 a[a]
	OF $n = 8$	Ah	18.67 ± 3.44 a	24.27 ± 3.23 a	1.70 ± 0.29 c	2.31 ± 0.27 b	34.95 ± 6.65 c	53.18 ± 5.94 b	3.18 ± 0.59 c	5.13 ± 0.70 b	10.99 ± 1.01 b
		C	5.60 ± 3.01 b		0.60 ± 0.25 b		18.23 ± 5.23 d		1.95 ± 0.81 a		9.35 ± 0.89 b

SOC: Soil organic carbon; T-SOC: Total SOC; SOC-S: SOC stock; T-SOC-S: Total SOC stock; TN: Total nitrogen; T-TN: Total TN; TN-S: TN stock; T-TN-S: Total TN stock. CM: Cambisol; LP: Leptosol; RG: Regosol; LV: Luvisol. CT: Conventional tillage; OF: Organic farming.
n = Sample size.
[a] Standard deviation.
[b] Significant differences ($P < 0.05$) between CT and OF treatments (by horizons).
Numbers followed by different lower case letters within the same column have significant differences ($P < 0.05$) between depth, considering the same soil type.

Table 4. Pearson's correlation coefficients among soil properties in the Los Pedroches Valley. pH: pH (H_2O); SOC: soil organic carbon ($g\,kg^{-1}$); TN: total nitrogen ($g\,kg^{-1}$); C : N: C : N: ratio; CO_3Ca (%); Exchangeable Ca^{2+}, Mg^{2+}, Na^+, K^+ ($cmol\,kg^{-1}$); CEC: cation exchange capacity ($cmol\,kg^{-1}$); BS: base saturation (%); BD: bulk density ($Mg\,m^{-3}$); HC: hydraulic conductivity ($mm\,h^{-1}$); Sand, Silt, Clay (%).

	pH	SOC	TN	C : N	CO_3Ca	Ca^{2+}	Mg^{2+}	Na^+	K^+	CEC	BS	BD	HC	Sand	Silt	Clay
pH	1															
SOC	−0.045	1														
TN	−0.061	0.997[b]	1													
C : N	0.038	0.624[b]	0.581[b]	1												
CO_3Ca	0.453[b]	0.064	0.067	0.025	1											
Ca^{2+}	0.546[b]	−0.128	−0.127	−0.189[a]	0.233[a]	1										
Mg^{2+}	0.141	−0.075	−0.093	0.048	−0.074	0.578[b]	1									
Na[a]	0.194[a]	0.002	−0.013	0.056	−0.009	0.120	0.010	1								
K^+	0.378[b]	0.042	0.041	−0.013	−0.017	0.387[b]	0.113	0.297[b]	1							
CEC	0.272[a]	−0.147	−0.149	−0.159	−0.024	0.629[b]	0.662[b]	0.024	0.161	1						
BS	0.389[b]	0.033	0.022	0.098	0.226[a]	0.451[b]	0.231[a]	0.222[a]	0.308[b]	−0.231[a]	1					
BD	−0.087	−0.455[b]	−0.458[b]	−0.198[a]	0.102	−0.144	−0.044	−0.082	−0.459[b]	−0.043	−0.138	1				
HC	0.186[a]	−0.096	−0.092	−0.102	−0.034	0.183[a]	0.131	0.039	0.231[a]	0.090	0.129	−0.226[a]	1			
Sand	−0.034	0.305[b]	0.324[b]	0.178	0.012	−0.177	−0.083	−0.214[a]	−0.291[b]	−0.241[a]	0.063	0.036	0.035	1		
Silt	0.129	−0.122	−0.138	0.023	0.072	0.090	0.016	0.077	0.229[a]	0.108	−0.031	−0.001	−0.046	−0.753[b]	1	
Clay	−0.065	−0.343[b]	−0.358[b]	−0.285[a]	−0.081	0.181[a]	0.108	0.248[a]	0.226[a]	0.260[a]	−0.066	−0.053	−0.011	−0.810[b]	0.224[a]	1

[a] Correlation is significant at $p < 0.05$.
[b] Correlation is significant at $p < 0.001$.

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Table 5. Ordinary components for principal components analysis (PCA) of selected soil properties measured for all the soil types grouped[a].

Variable or factor	PC1	PC2	PC3	PC4
Thickness (cm)	−0.155	**−0.303**	0.023	−0.062
BD ($g\,cm^{-3}$)	**0.385**	0.167	0.222	0.108
SOC ($g\,kg^{-1}$)	**0.380**	0.255	−0.214	0.025
C : N	0.058	0.287	−0.054	**−0.428**
pH (H_2O)	0.277	0.026	0.215	0.061
Ca^{2+} ($cmol\,kg^{-1}$)	**0.302**	−0.083	**0.485**	0.070
Na^{+} ($cmol\,kg^{-1}$)	0.211	−0.031	−0.108	**0.365**
Mg^{2+} ($cmol\,kg^{-1}$)	0.153	−0.073	**0.489**	−0.234
K^{+} ($cmol\,kg^{-1}$)	**0.419**	0.103	−0.083	0.168
CEC ($cmol\,kg^{-1}$)	0.237	−0.276	**0.364**	−0.260
BS (%)	0.023	0.286	0.252	**0.350**
HC ($mm\,h^{-1}$)	0.170	0.181	0.083	**0.380**
Sand (%)	−0.260	**0.414**	0.241	0.034
Silt (%)	0.271	−0.271	−0.170	−0.287
Clay (%)	0.158	**−0.407**	−0.225	0.222
Eigenvalues	3.608	3.178	2.135	1.494
% variance	22.5	19.9	13.3	9.3
Cumulative explanation	22.5	42.4	55.8	65.1

SOC: soil organic carbon; Exchangeable Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}; CEC: cation exchange capacity; BS: base saturation (%); BD: bulk density; HC: hydraulic conductivity.

[a] Variables underlined with eigenvectors (coefficients) > 0.3 are considered significant.

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Table 6. General lineal model (GLM). ANOVA (soil type and management) for soil. Statistical analyses of soil were carried out for A horizon samples (*r* coefficient).

One-way ANOVA						
	Soil type-management			Management-horizon		
Parameter	*S*	*M*	*S* × *M*	*M*	*H*	*M* × *H*
Th	0.227	0.713	0.012[a]	0.713	0.000[c]	0.888
pH	0.028[a]	0.397	0.010[b]	0.397	0.002[b]	0.151
SOC	0.727	0.000[c]	0.003[b]	0.000[c]	0.000[c]	0.007[b]
TN	0.452	0.000[c]	0.001[c]	0.000[c]	0.000[c]	0.008[b]
C : N	0.001[c]	0.370	0.002[b]	0.370	0.070	0.043[a]
Ca^{2+}	0.239	0.083	0.149	0.083	0.214	0.881
Mg^{2+}	0.832	0.132	0.177	0.132	0.342	0.903
Na^{+}	0.216	0.151	0.970	0.151	0.652	0.656
K^{+}	0.014[a]	0.000[c]	0.089	0.000[c]	0.000[c]	0.837
CEC	0.507	0.718	0.084	0.718	0.581	0.811
BS	0.008[b]	0.005[b]	0.946	0.005[b]	0.359	0.503
BD	0.037[a]	0.811	0.105	0.811	0.000[c]	0.393
HC	0.026[a]	0.017[a]	0.199	0.017[a]	0.076	0.132
Sand	0.360	0.000[c]	0.030[a]	0.000[c]	0.119	0.073
Silt	0.012[a]	0.007[b]	0.001[c]	0.007[b]	0.964	0.441
Clay	0.002[b]	0.000[c]	0.077	0.000[c]	0.017[a]	0.091
PC1	0.458	0.000[c]	0.016[a]	0.000[c]	0.861	0.719
PC2	0.000[c]	0.020[a]	0.156	0.020[a]	0.000[c]	0.465
PC3	0.416	0.020[a]	0.281	0.020[a]	0.017[a]	0.272
PC4	0.521	0.154	0.322	0.154	0.095	0.124

Th: Thickness (cm); pH: pH (H_2O); SOC: soil organic carbon ($g\,kg^{-1}$); TN: total nitrogen ($g\,kg^{-1}$); C : N: C : N: ratio; Exchangeable Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} ($cmol\,kg^{-1}$); CEC: cation exchange capacity ($cmol\,kg^{-1}$); BS: base saturation (%); BD: bulk density ($Mg\,m^{-3}$); HC: hydraulic conductivity ($mm\,h^{-1}$); Sand, Silt, Clay (%); PC1, PC2, PC3, PC4: factors PCA. *r* significance: [a] < 0.05, [b] < 0.01, [c] < 0.001.

Table 7. Stratification ratios of soil organic carbon concentration, total nitrogen concentration and C : N ratios in the Los Pedroches Valley (Mediterranean rangeland) in olive groves with conventional and organic farming. Data are means ±SD[b].

Soil	Tillage	Relations	SOC-SR	TN-SR	C : N-SR
CM	CT (n = 32)	SR1 (Ap/Bw)	3.74 ± 0.55 a[a]	2.45 ± 0.37 a	1.52 ± 0.11 a[a]
		SR2 (Ap/C)	3.82 ± 0.15 a[a]	2.92 ± 0.52 b	1.31 ± 0.21 b[a]
	OF (n = 18)	SR1 (Ap/Bw)	2.92 ± 0.57 b	2.51 ± 0.57 a	1.16 ± 0.08 c
		SR2 (Ap/C)	3.40 ± 0.03 c	2.77 ± 0.61 b	1.22 ± 0.13 d
LV	CT (n = 12)	SR1 (Ap/Bt)	2.30 ± 0.35 a[a]	3.35 ± 0.50 a[a]	0.69 ± 0.05 a[a]
		SR2 (Ap/C)	2.41 ± 0.15 a[a]	2.03 ± 0.28 b[a]	1.19 ± 0.11 b[a]
	OF (n = 8)	SR1 (Ap/Bt)	1.38 ± 0.65 b	1.28 ± 0.64 c	1.07 ± 0.10 c
		SR 2 (Ap/C)	2.92 ± 0.46 c	2.85 ± 0.48 d	1.03 ± 0.21 c
LP	CT (n = 18)	SR1 (Ah/C)	3.84 ± 0.75 a	3.41 ± 0.53 a	1.12 ± 0.22 a
	OF (n = 10)	SR1 (Ah/C)	3.69 ± 0.80 a	3.33 ± 0.29 a	1.11 ± 0.17 a
RG	CT (n = 8)	SR1 (Ah/C)	2.13 ± 0.47 a[a]	2.05 ± 0.26 a[a]	1.04 ± 0.12 a[a]
	OF (n = 8)	SR1 (Ah/C)	3.33 ± 0.85 b	2.83 ± 0.38 b	1.16 ± 0.18 b

SOC-SR: Stratification ratio of soil organic carbon; TN-SR: Stratification ratio of total nitrogen; C : N-SR: Stratification ratio of C : N ratio. CM: Cambisol; LP: Leptosol; RG: Regosol; LV: Luvisol. CT: Conventional tillage; OF: Organic farming.
n = Sample size.
[a]Significant differences ($P < 0.05$) between CT and OF treatments (by horizons).
[b]Standard deviation.
Numbers followed by different lower case letters within the same column are significant differences ($P < 0.05$) between depth, considering the same soil type.

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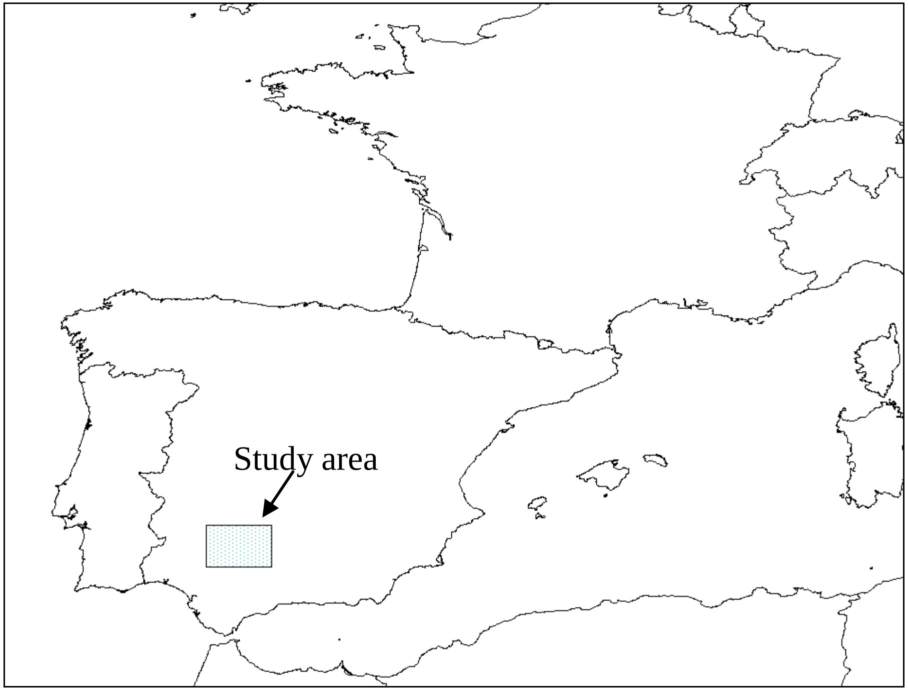

Fig. 1. Study area.

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Conventional tillage vs. organic farming

L. Parras-Alcántara and B. Lozano-García

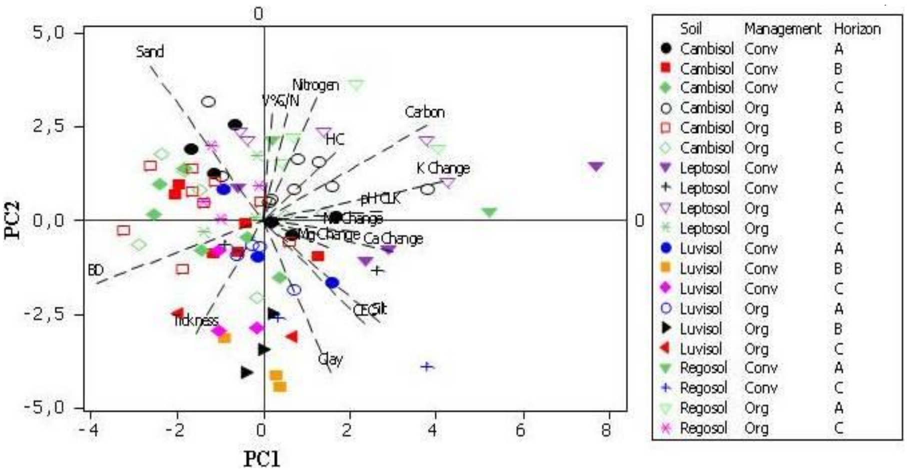

Fig. 2. Principal components analysis (PCA) for soils types and horizons in the Los Pedroches Valley (Mediterranean rangeland) in olive groves with conventional tillage and organic farming.

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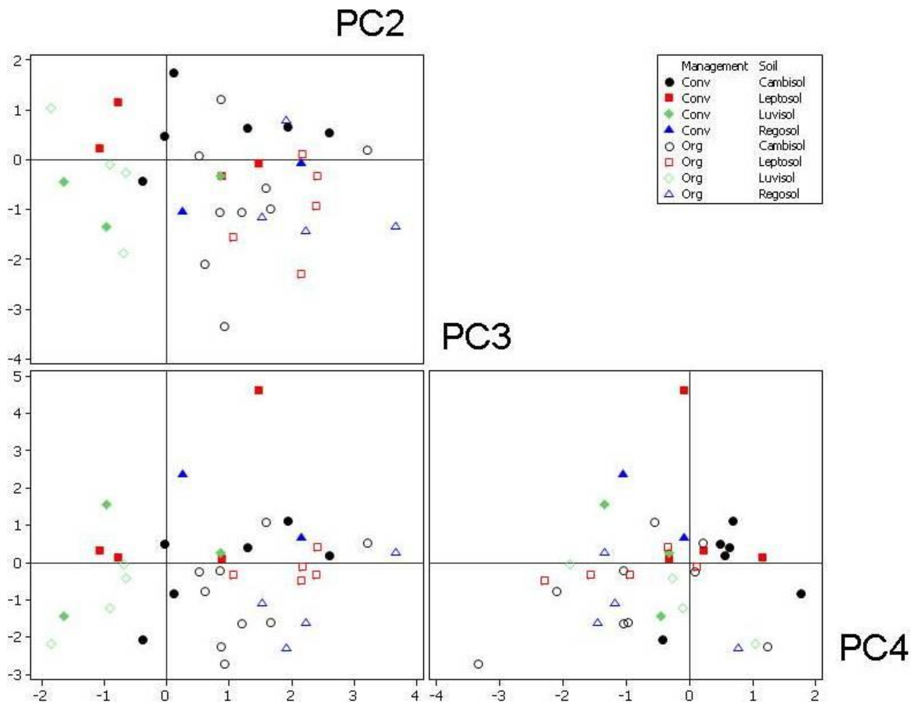

Fig. 3. Variables dispersion for the PCA (PC2/PC3 and PC3/PC4) the first coefficient related individually the A horizons and the second coefficient related management practices (conventional tillage and organic farming) and soils types (Cambisol, Luvisol, Leptosol and Regosol).

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