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Sustainable agricultural practices for Mediterranean olive groves. The effect of soil management on soil properties

Uso sostenible de suelos de olivar. Efecto del manejo del suelo en sus propiedades
Uso sustentável de solos de olival. Influência das técnicas de maneio nas suas propriedades

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ABSTRACT

The olive is one of the most important crops grown in the Mediterranean region, both in terms of total surface area and its socioeconomic and environmental impact. In the present work, the main soil parameters of olive groves under different management systems are compared to an uncultivated area. Soil samples were collected and analysed from native vegetation (NV) and olive groves under three different soil management systems: conventional tillage (T), no-tillage bare soil (NT) and cover crop (CC). The groves (T, NT, and CC) increased the calcium carbonate content in the uppermost part of the soil profile with respect to NV. The lowest calcium carbonate concentrations were recorded in the top few centimetres of NV soil, with concentrations increasing with depth, while in the cultivated soils, no depth-related variations were found. The results showed an accumulation of soil organic carbon (SOC) in the shallowest soil layer resulting in a high stratification value in the NV; however, this diminished in the cultivated soil and particularly in the tilled plots. The plots under these types of soil management also presented the lowest SOC, nitrogen, potassium and C/N values. CC was the soil management system that showed the best soil properties. Our results indicate that using cover crops and eliminating tillage practices significantly improve soil quality in Mediterranean olive groves.

RESUMEN

El olivo es uno de los cultivos más importantes en la región mediterránea, tanto por la extensión que ocupa como por su impacto económico, social y medioambiental. En este trabajo se comparan los principales parámetros del suelo en un olivar bajo distintos manejos del suelo con un área natural donde no se ha implantado el cultivo. En concreto, se recogieron y analizaron muestras de suelo bajo vegetación nativa (NV), suelo de olivar labrado (T), parcelas en no laboreo con suelo desnudo (NT) y parcelas con cubierta vegetal espontánea (CC). El cultivo (T, NT y CC) incrementó el contenido de carbonato cálcico en los primeros centímetros. Las concentraciones más bajas se registraron en los primeros centímetros de la NV, donde además se observaron incrementos con la profundidad, mientras que en los suelos cultivados no se apreciaron diferencias con la profundidad. Los resultados mostraron una acumulación del carbono orgánico del suelo (SOC) en las capas más superficiales, que dio lugar a un valor de estratificación muy alto en NV y que disminuyó en los suelos cultivados, especialmente en los que recibieron un pase de labor. La parcela T presentó además los valores más bajos de SOC, nitrógeno (N), potasio (K) y relación C/N. Nuestros resultados indican cómo la implantación de cubierta vegetal, así como la eliminación de las labores, mejoran significativamente la calidad del suelo en cultivos mediterráneos.

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RESUMO

O olival é uma das culturas mais importantes da região da bacia Mediterrânica, tanto pela superfície que ocupa como pelo seu impacto sócio-económico e ambiental. Neste trabalho comparam-se os principais parâmetros de um solo de olival sujeito a diferentes tipos de maneio com uma área natural não cultivada. Especificamente, recolheram-se e analisaram-se amostras de solo com vegetação nativa (NV) e de solo de olival sujeito a três diferentes tipos de maneio: lavoura convencional (T), não-lavoura com solo a descoberto (NT) e coberto vegetal espontâneo (CC). A presença de cultura (T, NT e CC) aumentou o teor de carbonato de cálcio nos primeiros centímetros de solo. As concentrações mais baixas foram registadas na camada superficial do solo NV, aumentando com a profundidade, enquanto que nos solos cultivados não foram encontradas quaisquer diferenças com o aumento da profundidade. Os resultados mostram uma acumulação de carbono orgânico do solo (SOC) nas camadas mais superficiais, resultando num elevado valor de estratificação em NV, que diminuiu nos solos cultivados, principalmente nas parcelas sujeitas a lavoura. A parcela T apresentou os menores valores de SOC, azoto, potássio e razão C/N. O CC foi a técnica de maneio do solo que contribuiu para as melhores propriedades do solo. Os resultados obtidos indicam que o uso de coberto vegetal, bem como a eliminação de práticas de lavoura melhoraram significativamente a qualidade do solo em olivais instalados na região da bacia Mediterrânica.

KEY WORDS
Native vegetation, tillage, no-tillage, cover crop, soil organic carbon

PALABRAS CLAVE
Vegetación nativa, laboreo, no laboreo, cubierta vegetal, carbono orgánico del suelo

PALAVRAS-CHAVE
Vegetação nativa, lavoura, não lavoura, coberto vegetal, carbono orgânico do solo

1. Introduction

The olive grove is one of the most important crops in the Mediterranean region, both for the large surface area covered and for its great socioeconomic and environmental impact. The traditional cultivation practices are based on a low density of trees, with two or three trunks each, weed control by tillage and chemical treatment (Saavedra and Pastor 2002), and biennial pruning with the debris being burned in situ (García-Ortiz et al. 2004). Although in recent years the planting density has increased and irrigation has been introduced in many areas, tillage still is one of the most generalized practices in the olive grove.

Inappropriate soil management practices for a specific area have generated diverse problems, including erosion and desertification (Ordóñez-Fernández et al. 2007; Martínez-Mena et al. 2008; Gómez et al. 2009). Authors such as Francia et al. (2006) have recorded high erosion rates in tilled olive groves situated on slopes of 30%, with soil losses ranging from 1.0 to 10.4 Mg ha^{-1} $year^{-1}$. This loss of sediments is related to declining soil organic carbon. In fact, the losses associated with erosive events can reach 5.12 g C ha^{-1} in 15 months (Martínez-Mena et al. 2008). Additionally, tillage increases the mineralization of SOC and favours the respiration of the soil (Balesdent et al. 2000).

In the 1960s, no-tillage practices began to be studied, revealing a number of benefits with respect to tillage, including increased yield (Saavedra and Pastor 2002). At present, live or inert cover crops constitute one of the leading agro-environmental trends in Mediterranean olive-grove cultivation. The prime objective is to protect the soil from degradation and erosion caused by rain and wind. In addition, weeds are controlled so the covers acting as an alternative to tilling. It bears emphasising the function of the cover as amendment because it increases the organic carbon content and improves the structure and fertility of the soil, especially in the upper layers (Ordóñez et al. 2001; Castro et al. 2008; Gómez et al. 2009; Ramos et al. 2010). Furthermore, the joint effect of the plant covers, together with the non-tillage techniques in Mediterranean olive groves, contribute to the atmospheric carbon sequestration (Nieto et al. 2010). The aim of this work was to determine the soil quality in Mediterranean olive grove under different soil management systems. In the present work, comparisons are made between native vegetation, a tilled olive grove, no-tillage with bare soil, and cover crop controlled by herbicides.

2. Materials and Methods

The study area is located in the province of Granada, S Spain (37°12'N, 3°88'W, 720 m). The climate is continental Mediterranean, with an average precipitation of 452 mm and a mean annual temperature of 15.2 °C. The relief is characterized by gentle slopes, with parent material of marl and marly limestone. The potential vegetation belongs to the dry-subhumid basophilous Betic Mesomediterranean oak (*Quercus rotundifolia*) series *Paeonio coriaceae-Querceto rotundifoliae S.* (Valle 2003). Cultivation has displaced the potential vegetation of the area, leaving only small, isolated intact patches of holm-oak trees and scrub.

The grove is composed of adult olive trees (cv. *Picual*) with a planting density of 204 trees ha^{-1}. The slope is between 3 and 8%. Following the WRBSR (FAO 2006), the soils are Vertic Calcisols. The soil-management system included conventional tillage (T) until 1993, when a experiment was made, establishing plots for no-tillage (NT) and plots with a cover crop (CC). The T consisted of two or three passes (0.20 m deep) with a disc harrow and cultivator twice a year to control weeds. This operation was applied only to the open gaps between trees. Weeds beneath the trees were eliminated with pre- and post- emergence herbicides. The NT consisted of maintaining the soil bare of vegetation, avoiding the germination of weeds by using herbicides in autumn and spring. The CC was made up of spontaneous Gramineae which were annually controlled with post-emergence herbicides in spring. Sampling was made in the native vegetation patches (NV) and in the olive tree plots for the three different management systems: T, NT, and CC.

Soil samples were randomly taken between trees after removing the fresh plant debris from the soil surface. Three replicate plots per soil use and management were sampled. The soil samples were collected in five intervals at the depths of 0-2, 2-5, 5-10, 10-15, and 15-30 cm. The bulk density was determined by following the method of Blake and Hartge (1986). All soil samples were air-dried, ground and sieved through a 2 mm sieve. We measured the particle size distribution, pH, equivalent $CaCO_3$, soil organic carbon (SOC), total nitrogen (N) and potassium (K). The samples were analysed in the laboratory of the Department of Pedology and Agricultural Chemistry of the University of Granada (Spain), following the official analysis methods (MAPA 1994). According to Franzluebbers (2002), the SOC stratification is an index that is used to evaluate the quality or the functioning of the soil ecosystem, since the superficial organic matter is essential to control erosion, to encourage water infiltration, and to conserve nutrients. This index was calculated from SOC at 0-5 cm divided by those at 15-30 cm.

Statistical analysed were performed by using SPSS v.15.0. The effects of the soil use and management for each variable were determined by a one-way ANOVA. The combined effect of depth and soil management on its properties was tested by two-way ANOVA. Tukey-HSD tests were performed for *post hoc* comparisons between levels within each factor considered. Bartlett and Shapiro-Wilk tests were applied to check homocedasticity and normality, respectively, to ensure that the assumptions of the model were met.

3. Results and Discussion

Most of the properties studied varied significantly with the management type, soil use, and soil depth, especially when the statistical analysis included data from the NV. The equivalent $CaCO_3$ content ranged from 8 to 71% (mean 49 ± 14%) according to the depth sampled, with 75% of the samples having contents exceeding 44% (**Table 1**). The conventional soil management of the olive grove affected the redistribution of the carbonate in the profile, with the lowest values in the uppermost cm of the NV. This finding indicates a process of washing that disappeared in the cultivated soils due to the continuous tillage. Despite the fact that in NT and CC tillage was discontinued, the time elapse was not long enough to homogenize the soil and mask this effect. The pH (**Table 1**) varied with the soil management, especially in the uppermost layers, where it diminished with higher organic matter contents as indicated by some authors (Rhoton et al. 1993; Jarecki and Lal 2005). In depth, the pH depended on the carbonate concentration, with maxima of 8.9 in the lowest layer sampled from T and minima of nearly 7.0 in the uppermost cm of the NV.

The differences between NV and the grove for the bulk profile are shown in **Table 2**. The soil texture was clay, locally silty-clay loam at certain depths of the tilled soil. In the uppermost 30 cm of the profile, the clay content varied significantly between T and NV, with percentages also high, although without significant differences in NT and CC. These differences were mainly due to the presence of a silt-enriched layer between 5 and 10 cm in depth in plot T.

The soil use and management also altered the contents in clay, SOC, N, C/N ratio and K throughout the profile (**Table 2**). The highest values of SOC and N were recorded in NV, with significant differences in comparison with cultivated soils. The C/N ratio was close to or greater than 10 in all cases except in T, where it was significantly lower. The distribution of SOC throughout the profile gave rise to a very high stratification value in NV which diminished in cultivated soils. With tillage, the quantity of SOC was significantly lower, as noted by other authors (Guo and Gifford 2002; Dawson and Smith 2007). The change in management boosted the SOC content, being significantly higher in CC; meanwhile, the NT presented intermediate values. Similar results were reported by Gómez et al. (2009).

According to Franzluebbers (2002), stratification ratios greater than 2 are uncommon under degraded conditions. In the present work, only T soils registered a ratio lower than 2, with values slightly higher in NT. In the case of CC, the data recorded confirms an improvement in soil quality, slowing erosive and degrading processes.

Figure 1 presents the contents in SOC, N, and K in the soils with different management systems. In the surface layers, the SOC and N contents of CC soils increased up to 4- and 2-fold, respectively, in relation to T soils. These values tended to become equal in depth from 10 cm on. The decline in these elements in depth coincides

Table 1: Mean values (± standard deviation) of pH and $CaCO_3$ (%) for the different soil uses, management practices, and depths studied, and results of two-way (management and depth) analyses of variance (ANOVA)

	Depth (cm)	NV	Soil use and management			Factor (*p-value*)		
			T	CC	NT	Management	Depth	Management x Depth
pH	0-2	7.3 ± 0.3	8.5 ± 0.1	8.0 ± 0.1	8.0 ± 0.2	<0.001	<0.001	0.444
	2-5	7.3 ± 0.2	8.7 ± 0.1	8.3 ± 0.1	8.3 ± 0.1			
	5-10	8.0 ± 0.7	8.7 ± 0.1	8.5 ± 0.1	8.3 ± 0.1			
	10-15	7.9 ± 0.3	8.8 ± 0.1	8.4 ± 0.0	8.2 ± 0.2			
	15-30	8.0 ± 0.1	8.9 ± 0.1	8.5 ± 0.1	8.3 ± 0.2			
$CaCO_3$ (%)	0-2	12 ± 7	56 ± 1	51 ± 6	55 ± 1	0.088	0.027	0.882
	2-5	17 ± 13	55 ± 0	54 ± 7	52 ± 7			
	5-10	33 ± 6	57 ± 2	56 ± 6	55 ± 1			
	10-15	40 ± 2	59 ± 4	57 ± 5	53 ± 4			
	15-30	43 ± 1	66 ± 5	59 ± 7	58 ± 7			

NV: native vegetation; T: tillage; CC: cover crop; NT: no-tillage.

Table 2: Mean values (± standard deviation) of clay, pool and stratification of soil organic carbon (SOC), nitrogen pool (N), and C/N ratio for the studied profiles (0-30 cm)

	NV		T		CC		NT		Sig. (*p*)
Clay (%)	47.1 ± 3.2	a	32.0 ± 9.2	b	45.8 ± 4.2	ab	46.0 ±1.0	ab	0.026
SOC (Mg C ha^{-1})	148.0 ± 40.0	a	14.7 ± 1.6	b	59.9 ± 5.8	b	45.9 ± 9.9	b	<0.001
N (Mg N ha^{-1})	13.5 ± 2.3	a	2.2 ± 0.1	b	4.8 ± 0.4	b	4.6 ± 0.8	b	<0.001
C/N	9.6 ± 1.0	a	6.9 ± 0.6	b	11.8 ± 1.0	c	9.9 ± 0.6	ac	0.001
SOC stratification	10.0 ± 1.4	a	1.4 ± 0.5	c	4.3 ± 1.0	b	2.4 ± 1.0	bc	<0.001

NV: native vegetation; T: tillage; CC: cover crop; NT: no-tillage. Sig.: Significance (*p* value)
Rows with different letters indicate differences in management according to Tukey test ($p < 0.05$).

with the findings of other authors in crops of the Mediterranean area (Hernanz et al. 2002, Castro et al. 2008). Also, K increased significantly after tillage was discontinued, with values higher than or equal to 1.0 $cmol_{(+)}$ kg^{-1} in the uppermost 5 cm. This increase has been related in literature to the input of organic remains (Gómez et al. 2009) and to the reduction of losses by erosion (Francia et al. 2006; Rodríguez-Lizana et al. 2008). The results of the two-way ANOVA for the soil-management systems of the olive grove and depth showed significant differences of SOC and N between T, CC and NT. However the K content and its distribution in the soil profile was similar for CC and NT, with significant differences only for T. This result was related to greater plant debris, high clay content and its mineralogy, which improved K adsorption (Caravaca et al. 1999). Higher erosion taxes in T could be the cause of low K content (Rodríguez-Lizana et al. 2008).

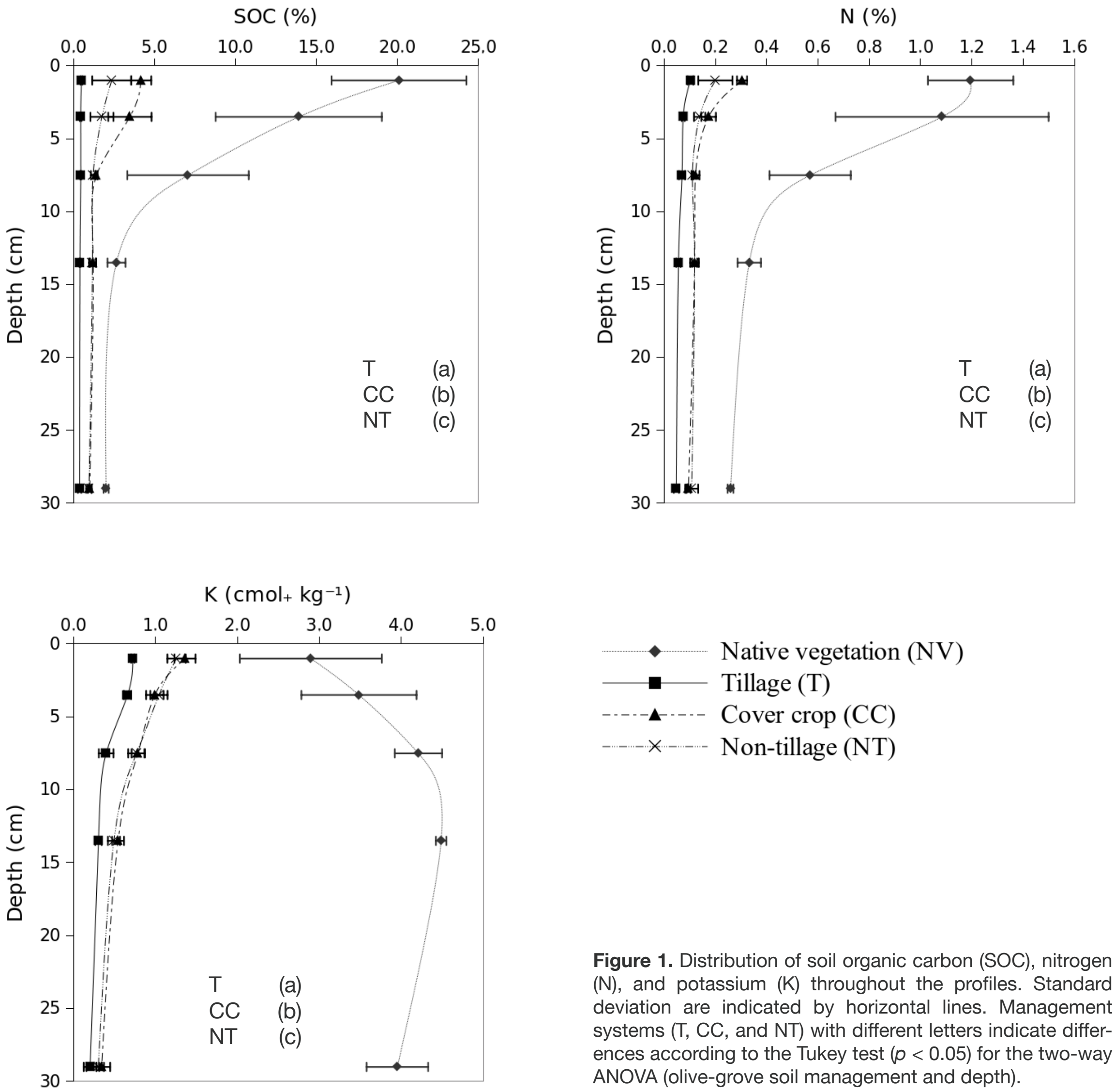

Figure 1. Distribution of soil organic carbon (SOC), nitrogen (N), and potassium (K) throughout the profiles. Standard deviation are indicated by horizontal lines. Management systems (T, CC, and NT) with different letters indicate differences according to the Tukey test ($p < 0.05$) for the two-way ANOVA (olive-grove soil management and depth).

As shown in **Table 3**, SOC is positively correlated with the clay content in the soils lacking organic remains (T and NT). This finding is consistent with the results reported by Hassink (1997), who indicated high correlations between the fine particles of the soil and the smallest SOC fraction, and disappeared in soils with a greater biomass input. The SOC also correlated positively with the N content in all the management systems, especially in those with the greatest content in plant remains (NV and CC). Finally, K presented the highest correlation coefficients in CC. In NV, the negative relation between K and SOC indicated high extraction of this element by the plants. According to Marschner (1995), potassium is slowly released from fresh plant debris by mineralization and, once in the soil solution, is quickly lost.

Table 3: Spearman correlation coefficients and different soil parameters in the soil management systems studied

Soil use and management	SOC (Mg ha^{-1}) Clay		SOC (%) N		C/N		K	
Native vegetation	0.22		0.96	**	0.89	**	-0.60	*
Tillage	0.79	**	0.69	**	-0.29		0.59	*
Cover crop	0.24		0.93	**	0.86	**	0.92	**
No-tillage	0.69	**	0.76	**	0.73	**	0.85	**

Correlation is bilaterally significant at the level ** $p < 0.01$ and * $p < 0.05$.

4. Conclusions

In Mediterranean olive groves, soil-management practices that eliminate tillage significantly improve soil quality by increasing the carbon content and SOC (soil organic carbon) stratification. The SOC reported for the upper ... cm the soil profile for CC and cover crop (which was similar to NV, native vegetation) showed the high potential of this soil management system for carbon sequestration. The concentrations of elements such as N and K also increased, especially where the management system included a cover crop.

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