IMPROVEMENT OF THE SOIL CARBON SINK USING COVER CROPS IN RAINFED OLIVE ORCHARDS IN SEMIARID CLIMATES

Márquez, F.[1 & 2]; Ordóñez, R.[3 & 2]; González-Sánchez, E.[1 & 2]; Gil-Ribes, J.A.[1 & 2]

Rural Engineering Department, University of Cordoba. Build. Leonardo Da Vinci. Campus de Rabanales, Ctra. N IV, km. 396, 14014 Córdoba, Spain. fmarquez@agriculturadeconservacion.org. 0034957212689
Spanish Association for Conservation Agriculture / Living Soils (AEAC/SV). IFAPA Alameda del Obispo. Build.. 3. Olivicultura. Av. Menéndez Pidal s/n. 14004. Córdoba. Spain.
Ecological Production and Natural Resources Area. Centre "Alameda del Obispo" IFAPA, Avda. Menéndez Pidal s/n, Apdo. 3092, 14080 Córdoba, Spain.

Andalusia, located in the south of Spain, is the main olive producer in this country, with the 60.2% of the total area cultivated with this tree. This region produces the 39% of the world olive oil and 24% of the table olive. However, this kind of production based on the tillage of the soil produces many environmental problems. Especially related to the soil and carbon dioxide losses associated not only to the sediment dragged, but also to the combustion of gasoil and oxidation of the organic matter (OM) of the ground. Conservation agriculture systems in woody crop, cover crops (CC), significantly reduce soil losses. Also decrease the emission of CO_2 to the atmosphere by two ways: less fuel consumption, due to the suppression of the tillage, and increase of the soil carbon sink, by enhancing its structure and providing large amount of plant debris.
The objective of this work is to quantify the efficiency of the CC as a method to improve the soil carbon sink capacity in rainfed olive groves in semiarid climates. The study was carried out during 4 seasons in 5 experimental fields distributed in different olive-growing regions. In two different soils management systems, conventional tillage (CT) and CC, were measured diverse parameters as: OM associated to sediments and temporal evolution of the amount of OM in the ground.
After 4 year of experimentation, we observed that the CC promoted an average reduction of the losses of the OM associated to sediments of 67.7%. Respect to the improvement of carbon sink in the soil, both management systems provide positive results, by increasing the carbon stock. However, these values were significantly higher in CC, 15.88 Mg $ha^{-1}y^{-1}$, respect to the 3.57 Mg $ha^{-1}y^{-1}$ of the CT.

Keywords: *olive, cover crops, climate change, organic matter*

Introduction

Olive tree is one of the most important crops in Mediterranean basin, but it is in Spain where has reached a bigger development. Andalusia located in the South of Spain is the main producer of the country, with the 60.2 % of Spain's total growing area (MARM, 2010), producing 39% of the world's olive oil and 24% of world's table olives (Consejería de Agricultura y Pesca, 2011 and International Olive Oil Council, 2011).
Most of plantations are grown in relatively poor soils, with high slopes. Only 18% of the groves are found on slopes of less than 5% and approximately the 75% of the total cultivated area is under rainfed conditions (Consejería de Agricultura y Pesca, 2003). These facts, together with a Mediterranean climate and the soil tillage as the most common soil management system, produce high erosion rates (Pastor, 2004; Gómez et al., 2005).
Although, the soil loss is one of the most important problems related to the olive farming, the increase of atmospheric carbon dioxide (CO_2) during last years (Mckibben, 2007) has made that the loss of soil organic carbon (SOC) associated with plowing is considered a serious threat. The global amount of carbon (C) accumulated in the soil is estimated to be around 2500 Gt, with 62% found in the organic form (SOC) and the rest as inorganic carbon (SIC). This reserve is 2 times that found in the atmosphere (760 Gt) and 2.8 times that of the biotic mass (560 Gt). It is estimated that between

55 and 78 Gt of C have been lost from the soil due to bad management practices. This figure corresponds with its potential capacity as sink for this element. However, the real capacity to store C from the soil is found to be between 50 and 66% of its potential capacity (Lal, 2004). Carbon sequestration requires transferring atmospheric C to a storage that does not be reemitted immediately. The degradation velocity of OM in non alterated or degradated soils is in order of centuries (Paul et al., 1997; Torn et al., 1997), so increasing SOC using appropriate soil management practices is an interesting option. CC reduce soil erosion (Francia et al., 2006; Ordóñez et al., 2007a), decreasing the transport of C associated to the sediment, also increase OM content by enhancing soil structure (Franzluebbers, 2002) and contribute many organic residues (Moreno et al. 2009). So, presumably these systems should increase the C concentration in the soil.

In spite of the above-mentioned advantages, there are still many questions regarding the role that soil management systems may play in atmospheric C sequestration (Smith et al., 2005; Pyke and Andelman, 2007; Ovando and Caparrós, 2009). Therefore, the aim of this study is to quantify the efficiency of CC as a method for improving the soil's capacity as a carbon sink in rainfed olive groves under semiarid conditions in Southern Spain.

Material and methods

The study was conducted over 4 seasons in 5 experimental fields distributed in different rainfed olive regions in Andalusia: two in the province of Cordoba (C3 and C5), 1 in the province of Jaen (J2), 1 in the province of Seville (S2) and 1 in the province of Huelva (H2). The most relevant characteristics of the fields appear in table 1, and their physical-chemical characterizations are shown in Rodriguez-Lizana et al. (2005).

To calculate the temporal evolution of the OM content of the soil, 3 pairs of 6 m^2 (3x2 m) subplots were installed per soil management system, CT and CC, and experimental field, see Img. 1. The distribution was a random block design. In each field, the 3 plots under conservation agriculture were established in the cover of the grove and the tillage plots were established in areas designed for this purpose.

Table 1 Main characteristics of the experimental fields.

Field	Frame (m^2)	Age (years)	Cover crop	Cover control	Slope (%)	Ground Type	Coordinates	
C3	8x8	12	Spontaneous	Mowing+ tillage	15.6	Calcic Haploxerecpt	37º 38' 18''	4º 29' 60''
C5	Undefined	>60	Spontaneous	Tillage	21.6	Ruptic-Lithict Xerorthent	38º 08' 26''	4º 46' 01''
J2	12x12	>70	Sown	Herbicide	18.6	Calcic Haploxerecpt	37º 49' 42''	3º 57' 36''
S2	8x6	10	Spontaneous	Weed trimmer	6.2	Typic Calcexerept	37º 34' 38''	5º 21' 37''
H2	6x8	9	Spontaneous	Weed trimmer	8.7	Typic Haploxerecpt	37º 21' 14''	6º 23' 42''

Image 1 Tillage subplot to measure OM content evolution.

Image 2 Pair of microplot for the collection of runoff and sediment.

Six microplots of 1 m^2 for the collection of runoff and sediment were used to measure the erosion, and the OM associated to the sediment, see Img. 2. The distribution was a random block design, with 3 pairs of microplots per experimental field, using the two previously described treatments, CC and CT. After each rainfall event, runoff and erosion was measured in each microplot.

In the experimental fields, each farmer managed the CC according to his/her needs. As a result, the timing and type of cover control were different for each field, corresponding to the actual practices of the area where they were located. Tillage inside the microplots managed under CT was performed according to the vegetative state of the grass and the usual practices of the area. For this purpose a rotary tiller was used. Working the soil until a depth of 20-25 cm.

At the beginning of the experiment and after 4 years of study, a sampling campaign to determine the soil OM content was carried out for both management systems. The samples were taken from the first 25 cm, since the surface layers show the most significant changes after the first years of CC implantation (Jarecki and Lal, 2005). The distribution of the depths sampled was: 0-2 cm, 2-5 cm, 5-10 cm and 10-25 cm, with each sample composed of 3 subsamplings from each 6 m^2 subplot.

At the same time as the OM sampling, drilling was performed to determine the apparent density of the soil, using a hollow stainless steel cylinder, 60 mm long and 52 mm in diameter. This operation was performed at two points in each soil management system and experimental field, drilling the 0-6 cm and 19-25 cm profile.

The runoff water and washed sediment were deposited into porcelain capsules in a forced-air oven at 110 ºC. After weighting the dry sediment, its concentration was obtained by extrapolation to the total runoff volume, to determine the erosion in each microplot. After drying, the soil and sediment samples were passed through a 2 mm sieve. Subsequently, the organic carbon content was analyzed following the Walkley-Black method (Sparks, 1996) by oxidation with $K_2Cr_2O_7$ in an acidic medium.

By knowing the SOC of each soil, the amount of CO_2 equivalent stored in the soil can be calculated using the following formulas:

$$Corg\left(\frac{g}{kg}\right) * \rho_a\left(\frac{t}{m^3}\right) * prof(m) * \frac{10.000\,m^2}{ha} * \frac{1\,kg}{1.000\,g} = C\left(\frac{t}{ha}\right)$$

$$C\left(\frac{t}{ha}\right) * 3,67 = CO_2\left(\frac{t}{ha}\right)$$

Where:

ρ_a : apparent density C: organic carbon CO_2: carbon dioxide

The data measured were analysed with the program Statistix, version 8.Three factors were considered: plot, block and treatment. The comparison of means between these factors was performed with the Tukey test with a statistical significance of (p)≤0.05.

Results and discussion

The absence of tillage in the conservation agriculture systems presumably would increase the soil apparent density. Although Table 2 shows that there not was important differences in the value of this soil property between the 2 soil management systems studied, just like the data observed by Alvarez and Steinbach (2009).

Table 2 Apparent density of the different experimental fields and depths sampled.

	0-6 cm		10-25 cm	
	CC	CT	CC	CT
C3	1.49	1.46	1.45	1.51
C5	1.42	1.32	1.45	1.45
J2	1.58	1.52	1.43	1.41
S2	1.68	1.52	1.42	1.52
H2	1.65	1.67	1.64	1.52

CC showed a small increased of the values of this property in the first depth studied. In the 5 experimental fields, the apparent density experienced a mean increase of 4% in the covered area. The CT systems produced a more homogeneous distribution of it, coinciding with the results published by Birkás et al. (2004), who observed that conservation agriculture systems present a compaction peak at a depth of 3 cm.

Although the low increase of surface compaction in the cover crops treatments could produced a rise of the erosion rate (Fullen, 1985), the protection provided by the plant residue against the erosive action of the raindrops reduced the soil loss. For all the cases studied, except C3, the reductions in erosion provided by the CC were higher than 80%, and presented significant differences, Figure 1. The same results were measured by different authors in the same semiarid conditions (De la Rosa et al. 2005, Francia et al. 2006, Durán et al. 2009). In the first field, the decrease was not so important because of it was an ecological grove and the farmer applied vinasse, a liquid organic fertilizer, which is a product of grape fermentation. Its application required deep plowing and its subsequent injection into the soil so the ground cover was not so important.

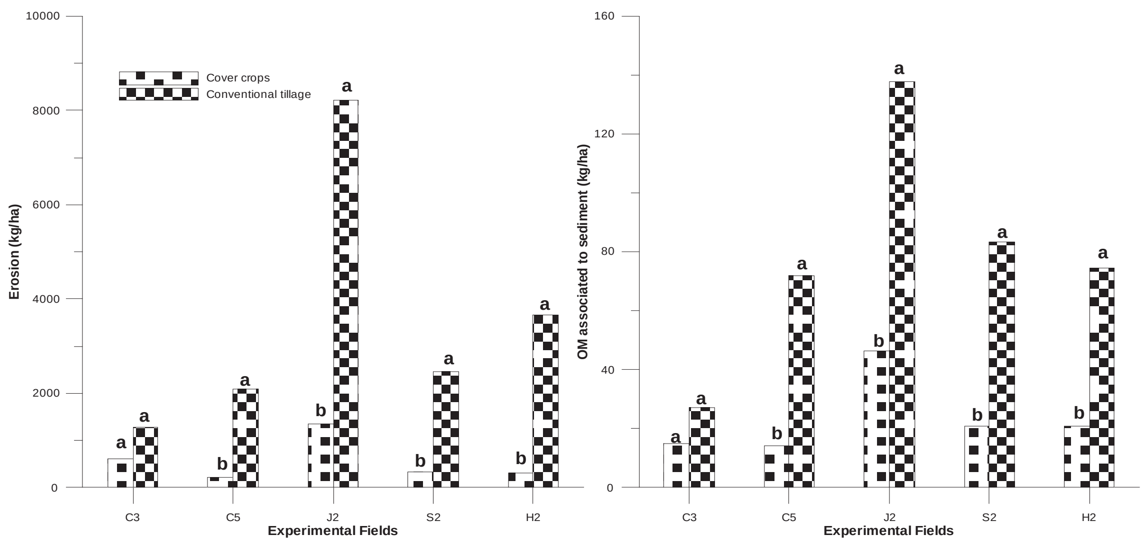

Figure 1 Mean annual erosion and OM losses associated with the sediment. Different letters indicate significant differences for p≤0.05.

The annual reduction in the OM losses in the sediment was not so high, especially in C3 that provided an average decrease of 45%. The other fields presented significant differences for this soil property. Furthermore a positive relationship was observed between the soil loss and output of OM for both management systems. As, systems that reduce erosion would presumably cause a decreased in the output of C from agricultural ecosystems, see Figure 2. The data showed that for the CC, the erosion was always below 1 t ha^{-1} and the OM losses less than 40 kg ha^{-1}. The adjustment of the function was quite good with a R^2 of 0.83. For CT the erosion and OM losses were significantly higher than in CC and the dispersion of the data was also bigger than the measured in the conservative systems. It is important to remark the huge erosion and OM losses measured in some rainfall events, very common in these region and crops. Other authors as Vanwalleghem et al. (2008) measured an erosion rates of more than 400 t ha^{-1} during high intensity events in similar conditions.

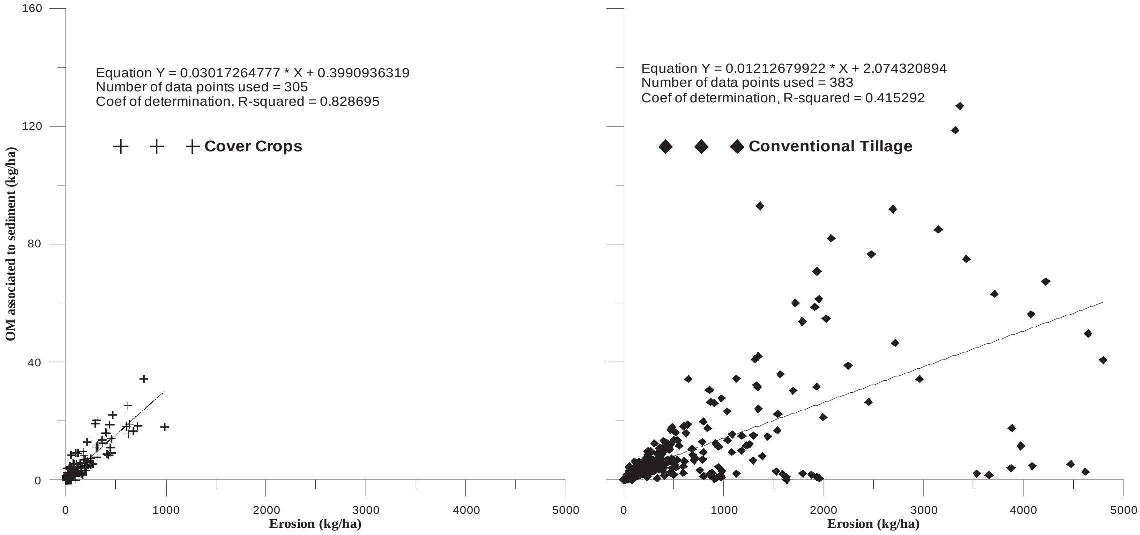

Figure 2 Correlation between erosion and OM losses.

The C contributions brought about by the presence of plant residue on the surface and the lower OM output, increased the OM concentration in the soil under CC systems. As observed in Table 3, in the first depth sampled (0-2 cm), 4 out of 5 fields showed statistically significant differences in favor of this system. For all treatments in the first 5 cm, the soil under conservation systems presented an OM concentrations above 2%. This value is the amount recommended in this region as the minimum for integrated production systems (Consejería de Agricultura y Pesca, 2002). These results are similar to those obtained by Castro et al. (2008) and Gómez et al. (2009) in olive groves in Andalusia.

Table 3 Spatial variation of the OM content (%) versus depth for the 2006-2007 sampling campaign. Different letters indicate significant differences for *$p \le 0.05$ and ** $p \le 0.01$.

		Season 2006-07				
		0-2 cm	2-5 cm	5-10 cm	10-25 cm	0-25 cm
C3	CC	2.59±0.68 a*	1.69±0.79 a*	1.20±0.82 a*	0.91±0.90 a*	1.2±0.76 a*
	CT	1.64±0.52 a*	1.22±0.47 a*	1.19±0.52 a*	0.49±0.56 a*	0.81± 0.25 a*
C5	CC	5.52±0.76 a**	5.11±1.09 a*	3.43±0.69 a**	2.52±0,97 a*	3.25±0.54 a*
	CT	2.54±0.51 b**	2.61±0.19 b*	2.27±0.65 b**	1.73±0.60 a*	2.01±0.47 b*
J2	CC	5.90±2.40 a*	2.40±1.11 a*	1.30±0.72 a*	1.29±0.84 a*	1.80±0.44 a*
	CT	2.48±0.45 b*	1.56±0.72 a*	1.20±0.13 a*	1.01±0.10 a*	1.23±0.11 a*
S2	CC	3.93±0.76 a**	2.86±0.40 a*	2.67±0.43 a*	2.08±0.60 a*	2.44±0.42 a*
	CT	2.60±0.65 b**	2.66±0.27 a*	2.75±0.59 a*	2.10±0.08 a*	2.34±0.12 a*
H1	CC	3.41±0.73 a*	2.50±0.34 a*	2.02±0.78 a*	1.69±0.30 b*	1.99±0.39 a*
	CT	2.53±0.12 a*	2.30±0.24 a*	2.21±0.21 a*	2.12±0.31 a*	2.19±0.25 a*
H2	CC	4.69±0.94 a*	3.02±0.20 a*	3.20±1.06 a*	2.39±0.11 a*	2.81±0.25 a**
	CT	2.02±0.28 b*	2.14±0.22 b*	1.89±0.12 a*	1.91±0.18 b*	1.94±0.12 b**

As the profile depth increased, the differences in the content of this compound in the soils subject to the different treatments decreased. In fact, below 10 cm, statistically significant differences were observed in only in one of the fields (H2).

Therefore, a greater increase in OM is produced under conservation agriculture systems in the surface layers, as reported by Jarecki and Lal (2005). For the total sampling depth, CC always presented more OM than CT, except in S2 that had very similar values. Only in C5 and H2 appeared statistically significant differences. These results coincide with those obtained by other authors in olive groves (Hernández et al., 2005; Gómez et al., 2009; Ramos et al., 2010).

Table 4 CO_2 equivalent fixation (Mg ha^{-1}) for the different depths sampled and experimental fields.

		2003-04	2006-07				
		Depth (cm)					
Field	System	0-25	0-2	2-5	5-10	10-25	Δ 0-25
	CC	82.74	16.32	15.98	18.91	42.72	**11.19**
C3	CT	85.01	10.56	11.77	19.15	23.96	**-19.58**
	Difference	-2.27	5.76	4.21	-0.24	18.76	**30.77**
	CC	178.19	31.45	43.69	48.88	126.96	**64.16**
C5	CT	186.00	15.57	24.01	34.80	81.24	**-30.39**
	Difference	-7.81	15.89	19.69	14.08	45.82	**94.55**
	CC	78.28	38.73	23.62	21.33	59.73	**64.13**
J2	CT	79.88	16.93	15.95	21.24	46.11	**19.58**
	Difference	-1.60	21.80	7.67	0.09	13.62	**44.55**
	CC	127.80	25.80	28.15	43.80	95.64	**65.59**
S2	CT	139.89	18.87	28.95	49.87	103.36	**61.16**
	Difference	-12.09	6.93	-0.80	-6.07	-7.72	**4.43**
	CC	127.80	33.42	32.27	56.99	117.85	**112.52**
H2	CT	132.59	14.57	23.14	34.07	101.44	**40.63**
	Difference	-4.79	18.85	9.13	22.92	16.19	**71.89**
	Average difference		**13.85**	**7.98**	**6.16**	**17.33**	**49.24**
	Average/cm		**6.92**	**2.66**	**1.23**	**1.16**	**1.97**

Table 4 shows the CO_2 equivalent accumulated in the soil at the begening of the study and after 4 years. At the season 2003-04 the amount of this compound accumulated in the soil was similar for both management systems and the differences observed were always less than 10%, with a mean of 4.3% between the 5 fields.

For total profile sampled, after 4 years in the 5 experimental fields, CC increased the CO_2 equivalent content with respect to the reference period (2003); with a mean increase of 15.9 Mg ha^{-1}year^{-1}. CT also increased the sink effect of this compound in 3 of the 5 fields. However, overall, a lesser increase was measured, 3.6 Mg ha^{-1}year^{-1}.

In relation to the increase in CO_2 equivalent provided by the cover with respect to tillage during the 4 study years, it was observed that conservation systems increased the content of this compound by 1.97 Mg ha^{-1} cm^{-1} with respect to CT. These data are higher than those obtained by Gómez et al. (2009); 1.23 Mg ha^{-1} cm^{-1} in a 7-year experiment, as the maximum sink effect is reached during the fifth year after the application of conservation agriculture, with the fixation speed decreasing from there (West and Six, 2007). Also were slightly greater than those indicated by Sombrero and De Benito (2010) for extensive crops, 1.59 Mg ha^{-1} cm^{-1}; although the depth sampled by them was greater, 30 cm. The values were also much higher than those showed by Ordóñez et al. (2007b). Who obtained an increase of 0.75 Mg ha^{-1} cm^{-1}, due to a longer study duration, 11 years, and depth sampled, 52 cm.

Conclusions

Under our rainfed semiarid conditions CC showed as an effectiveness environmentally management system. Erosion decreased by an average of 80.5% and OM losses associated to sediments decreased by 67.7%. In addition, the depth sampled, 0-25 cm, experienced a mean increase in OM of 38.1% with respect to CT, with a more marked rise in the first 10 centimeters of soil, where it reached 47.5%.

The CC system increased the sink capacity of carbon fivefold with respect to CT, achieving an increase in CO_2 equivalent fixation with respect to the conventional system of 12.3 Mg $ha^{-1}year^{-1}$ for the total depth sampled. According to the MARM (Spanish Ministry of Environment and Rural and Marine Affairs) (2011a), the CO_2 equivalent emissions in Andalusia for the year 2008 were 58188 Gg, exceeding the maximum permissible value by 15819 Gg, required to fulfill the commitments made by this region in reference to the Kyoto protocol. According to the data obtained and taking into account the actual CC area of 518659 ha (MARM, 2011b) in Andalusian olive groves, these soil conservation systems could annually fix 40.4% of the total gases needed to fulfill the commitments signed.

Acknowledgements

The authors would like to acknowledge the support given by the Department of Innovation, Science and Enterprises of the Autonomous Government of Andalusia for their financial support through the Project of Excellence RNM 03-205 and to the project RTA2010-00026-C02 funded by INIA in the framework of the “National Subprogramme of Agricultural Resources and Technologies with the Autonomous Communities” under the National Plan for Research, Development and Technological Innovation (I+D+I) and co-financed by the European Union via FEDER funds.

6.References

- Alvarez R, Steinbach H.S (2009). A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crops yield in the Argentine Pampas. Soil. Till. Res. 104, 1-15
- Birkás M, Jolánkai M, Gyuricza C, Percze A (2004) Tillage effects on compaction, earthworms and other soil quality indicators in Hungary. Soil Till. Res. 78: 185-196
- Castro J, Fernández-Ordoño E, Rodríguez C, Lallena AM (2008) Effects of different olive-grove management systems on the organic carbon and nitrogen content of the soil in Jaén (Spain). Soil Till Res 98:56-57
- Consejería de agricultura y Pesca, Junta de Andalucía (2002) Boletín oficial de la Junta de Andalucía, 88: 14359
- Consejería de Agricultura y Pesca, Junta de Andalucía (2003) El olivar andaluz. Servicio de publicaciomnes y divulgación (eds) Seville. Spain
- Consejería de Agricultura y Pesca, Junta de Andalucía (2011) Agricultural statistics available at: http://www.juntadeandalucia.es/agriculturaypesca/portal/export/sites/default/comun/galerias/galeriaDescargas/cap/servicioestadisticas/estadisticasagrarias/avances/PRESENTACIxN_AFORO_OLIVAR_2010-2011.pdf (accessed 09-02-2011)
- De la Rosa D, Díaz-Pereira E, Mayol F, Czyz E A, Dexter A R, Dumitru E, Enache R, Fleige H, Horn R, Rajkay K, Simota C (2005) Part 2. Soil erosion as a function of soil type and agricultural management in a Sevilla olive area, southern Spain. Soil Till. Res. 82:19-28
- Durán V, Rodríguez C, Arroyo L, Martínez A, Francia J, Cárceles B (2009) Soil conservation measures in rainfed olive orchards in South-Easter Spain: impacts pf plant strips on soil water dynamics. Pedosphere. 19: 453-464
- Francia J R, Durán V, Martínez A (2006) Environmental impact from mountainous olive orchards under different soil-management systems (SE Spain). Sci. Total Environ. 358: 46-60
- Franzluebbers AJ (2002) Soil organic matter stratification ratio as an indicator of soil quality. Soil Till Res 66:95-106
- Fullen MA (1985) Compaction, hydrological processes and soil erosion on loamy soil sands in East Shropshire, England. Soil Till Res 6: 17-29
- Gómez JA (2005a) Effects of soil management on soil physical properties and infiltration in olive orchards-implications for yield. In: Benites J. (eds) Integrated soil and water management for orchard development. FAO. Rome. 65:70
- Gómez JA, Sobrinho TA, Giráldez, JV, Fereres E (2009) Soil management effects on runoff, erosion and soil properties in an olive grove of Southern Spain. Soil Till Res 102: 5-13

- Hernández AJ, Lacasta C, Pastor J (2005) Effects of different management practices on soil conservation and water in a rainfed olive orchard. Agric Water Manag 77: 232-248
- International Olive Oil Council (2011) Statistics available at: http://www.internationaloliveoil.org (accessed 09-02-11)
- Jarecki M, Lal R (2005) Soil organic carbon sequestration rates in two long-term no till experiments in Ohio. Soil Sci 170:280-291
- Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Sci 304: 1623-1627
- Mckibben B (2007) La crisis del carbono. National Geographic Society 21-5: 2-7
- Ministerio de Medio Ambiente y Medio Rural y Marino (MARM) (2010) Encuesta sobre superficies y rendimientos de cultivo. Resultados nacionales y autonómicos 2009. http://www.mapa.es/es/estadistica/pags/encuestacultivos/resultados.htm (accessed 12-01-2011)
- Ministerio de Medio Ambiente y Medio Rural y Marino (2011a) Emisiones de GEI por comunidades autónomas a partir del inventario español serie 1990-2008 http://www.mma.es/secciones/calidad_contaminacion/atmosfera/emisiones/inventario.htm (accessed 04-07-2011)
- Ministerio de Medio Ambiente y Medio Rural y Marino (2011b) Encuesta sobre superficies y rendimientos de cultivo. Resultados nacionales y autonómicos 2010.http://www.mapa.es/es/estadistica/pags/encuestacultivos/resultados.htm (accessed 04-07-2011)
- Moreno M, Garcia S, Cañizares R, Castro J, Benítez E (2009) Rainfed olive farming in south-eastern Spain: Long-term effect of soil management on biological indicators of soil quality. Agric Ecosyst Environ 131: 333-339
- Ordóñez R, Rodríguez-Lizana A, Espejo AJ, González P, Saavedra M (2007a) Soil and available phosphorus losses in ecological olive groves. Eur J Agron 27: 144-153
- Ordóñez R, González P, Giráldez JV and Perea F (2007b) Soil properties and crop yields after 21 years of direct drilling trials in southern Spain. Soil Till Res 94: 47-54
- Ovando P, Caparrós A (2009) Land use and carbon mitigation in Europe: a survey of the potentials of different alternatives. Energy Policy 37:992-1003
- Pastor M (2004) Sistemas de manejo de suelo. In: Barranco D, Fernández-Escobar R and Rallo L (eds) El cultivo del olivo. Mundi Prensa. Madrid. Spain. 231-285
- Paul E, Follet SW, Leavitt A, Halvorson GA, Peterson GA, Lyon DJ (1997) Radio carbon dating for determination of soil organic carbon pool sizes and dynamics. Soil Sci Soc Am J 61:1058-1067
- Pyke CR, Andelman SJ (2007) Land use and land cover tools for climate adaptation. Climatic Change 80:239-251
- Ramos ME, Benítez E, García PA, Robles AB (2010) Cover crops under different managements vs. frequent tillage in almond orchards in semiarid conditions: Effects on soil quality. App Soil Eco 44:6-14
- Rodríguez-Lizana A, Ordóñez R, Espejo-Pérez AJ, González P, Giráldez JV (2005) Estudio de la influencia de la cobertura vegetal viva en olivar en la contaminación de las aguas de escorrentía por nitratos. In: Samper J, Paz A (eds), Proceedings VII Jornadas de Investigación en la zona no saturada del suelo ZNS'05. La Coruña, Spain. 81–86
- Smith P, Andrén O, Karlsson T, Perälä P, Regina K, Rousenvells M, Van Wesemaels B (2005) Carbon sequestration potential in European croplands has been overestimated. Global Change Biol 11: 2153-2163
- Sombrero A, De Benito A (2010) Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon, Spain. Soil Till Res 107: 64-70
- Sparks DL (1996) Methods of soils analysis. Part 3, chemical methods. Soil Sci Soc Am, wisconsin
- Torn MS, Trumbore SE, Chadwick OA, Vitousek PM, Hendricks DM (1997) Mineral control of soil organic carbon storage and turnover. Nature 389:170-173
- Vamwwalleghem, T, Giraldez, JV (2008) Midiendo fuera de las parcelas de erosión: Importancia de erosión por cárcavas y regueros en cuencas de olivar. In: López JA, Rubio JC, Martín, M (eds) VII Simposio del agua en Andalucía. Jaén. Spain. 211-217
- West TO, Six J (2007) Considering the influence of sequestration duration and carbon saturation on estimates of soil carbon capacity. Climatic Change 80: 25-41