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The influence of a shift from conventional to organic olive farming on soil management and erosion risk in southern Spain

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Abstract

Natural resource conservation should be fundamental to organic agriculture, including the prevention of soil erosion. Soil erosion in the olive orchards of southern Spain is recognized as a serious problem causing environmental, economic and social repercussions, both on and off-site. This study describes the changes in soil management practices that accompanied a shift from conventional to organic olive farming and the corresponding effect of those management practices on erosion risk in the province of Córdoba, Andalusia. Interviews with 107 farmers were carried out in two different geographic areas to assess the socio-economic factors influencing farm management decision-making, and on-farm erosion risk evaluations and soil data (organic matter, aggregate stability, infiltration and vegetative ground cover) were taken on 25 farms to assess the effects of those decisions on soil erosion risk. Results from this study show that the shift to organic farming in olive orchards in the province of Córdoba has been accompanied by increased protection of the soil and lowered erosion risk. The most important changes in soil management practices associated with the transition from conventional to organic agriculture were the reduction in tillage and the increase in management systems that incorporate a vegetative cover controlled either by grazing livestock or mowing. However, the shift to organic farming has had more impact in the south of the province than in the north where farm management systems have historically led to less erosion.

Key words: organic farming, erosion, soil management, socio-economic influences

Introduction

A shift from conventional to organic agriculture should promote the conservation of natural resources and the development and use of sustainable farming practices, not just the prohibition of synthetic fertilizers and pesticides[1]. Soil and water are the world's most important natural resources, and their careful management should be paramount in organic agriculture. In the erosion-prone Mediterranean region, prioritizing soil conservation is key to sustainable farming, where soil organic matter (SOM) levels are inherently low[2], and the loss of existing organic matter contributes to a rapid decline of soil fertility, degradation of soil structure, and an increased risk of erosion[3].

The severe problems of soil erosion become evident on a drive along any road in the olive-producing areas of Andalusia, southern Spain, where olive trees dominate the landscape in an impressive monoculture that occupies 1.5 Mha, or 17% of the total surface area of Andalusia[4]. In a region often subjected to torrential rainstorms, the most common soil management practice among olive farmers over the past few decades has been to maintain bare soil year-round, underneath and between olive trees, by means of frequent tillage and/or use of herbicides. These practices have led to serious problems of erosion, soil compaction, loss of soil fertility, sedimentation of waterways and contamination of potable water sources[5–7]. Soil degradation problems are expected to worsen as the total area of land devoted to olive production in Andalusia has

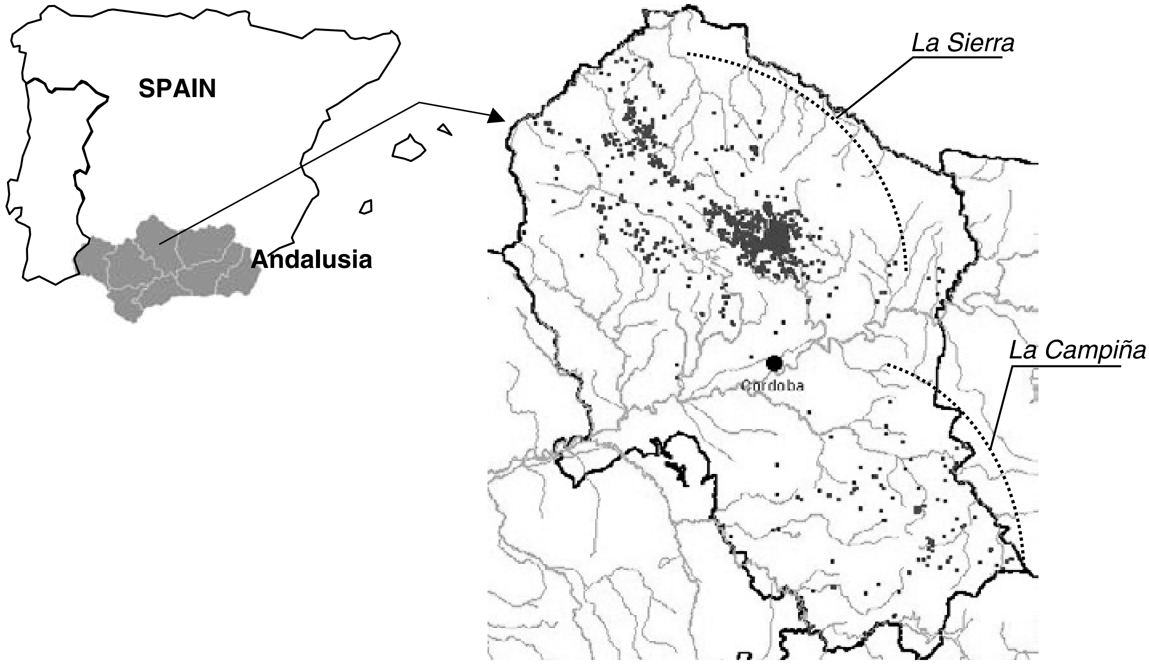

Figure 1. Location of all organic farms and the two study areas in the province of Cordoba.

rapidly expanded and cultivation has intensified in response to farm mechanization, new harvesting technologies and European Commission policies promoting productivity increases[2,8]. Small farmers on marginal lands have found themselves unable to compete with the new mechanized production systems because of their higher production costs and lower yields. Bleak economic prospects, among other factors, have led these farmers to adopt alternatives to conventional olive growing, such as organic production[9].

Regulations for the certification of organic agriculture prohibit the use of herbicides or chemical fertilizers; therefore the change in the type of inputs used on the farm is inherent to the shift to organic farming. However, the changes in soil management practices and the effects on soil fertility and soil erosion risk are not as evident or well understood[10], nor are soil management practices regulated under organic certification. In conventional agriculture, degradation of soil structure and function due to tillage or erosion is often combated by further cultivation and application of additional inputs rather than remedial or preventative measures[11]. In organic farming, however, the dependence on additional inputs to make up for the loss of the natural fertility of the soil is unsustainable, and is more costly than in conventional farming, given the limited access to and laborious application of manure and high costs of organic fertilizer products[12]. Soil management practices on organic farms should encompass maintenance of the natural fertility of the soil and prevention of soil degradation[1].

Soil erodibility, defined as soil susceptibility to detachment and transport by agents of erosion, is highly influenced by soil management[13]. Farmers' management decisions affect soil surface dynamics, such as soil compaction caused by machinery or overgrazing, or protection of the soil by a vegetative cover[14]. The state of the soil surface in turn affects the hydrology of the orchard, determining water balance, runoff generation and soil erosion[14]. Surface compaction and surface sealing decrease rainwater infiltration[7], causing increased surface runoff and elevated risk of erosion[3]. The presence of a vegetative cover not only protects the soil surface, but also significantly increases the formation of SOM and the biological activity in soil, thereby improving soil aggregate stability and preventing the formation of a surface seal[15]. Vegetation also increases infiltration due to the increase of soil macroporosity, causing a decrease in surface runoff[16], and consequently a decrease in erosion risk.

Improved understanding of the relationship between farmers' decision-making about soil management practices and the risk of soil erosion can facilitate the development of appropriate soil conservation policies. This relationship needs to be examined from two perspectives: the rationale behind soil management decisions and the effect those decisions have on soil erosion risk. Little research has been done on the relationship between organic production systems and soil erosion[10], especially in the Mediterranean basin, and no previous studies have been conducted about soil erosion in the organic olive orchards of Andalusia, where the organic movement is relatively young, founded officially in 1991. There are over 32,000 ha devoted to organic olive production in Andalusia at present, accounting for 38% of the total area devoted to organic agriculture[17]. The majority of organic olive orchards in Andalusia, more than 17,000 ha, are located in Córdoba[4], mostly in the north of the province (Fig. 1).

We conducted a field study with three objectives: (1) to describe the change in soil management practices that have accompanied the shift from conventional to organic farming; (2) to analyze the soil management practices of organic olive farms in the Córdoba province as influenced by farm size, economic dependence on farm and geographic location; and (3) to investigate the relationship between soil management practices and erosion risk on organic olive orchards in the province of Córdoba.

Materials and Methods

Study sites

Two geographic areas in the province of Córdoba were identified for our study, the olive growing area in the north of the province that we refer to as '*la Sierra*', and the olive growing area in the south that we refer to as '*la Campiña*' (Fig. 1). These two areas were selected to best represent the agricultural systems in the province due to their differing management systems, agro-economy, soil type and topography.

La Sierra is a mountainous area characterized by steep slopes of up to 70% and shallow soils of dominant associations Xerochrept/Haploxeralf and Xerochrept/Xerorthent/Xerumbrept[18] developed on slates of the Precambrian and of the Carboniferous periods[19]. Farmers in this area have traditionally carried out low-input management systems, using animal traction for tillage, and livestock in the olive orchards as a sylvopastoral system that offers natural weed control and soil fertilization. These orchards are very old (more than 100 years), planted approximately 8 m × 8 m to 10 m × 10 m, generally with only one trunk per tree, and are almost entirely rain-fed[4]. It is not common for farmers to plant a cover crop in addition to the natural vegetation. Farmers till on average once a year with either animal traction or chisel or disk plows. Tillage operations are generally carried out once after the first rains in the fall (October) and/or in February–March after the harvest and tree pruning is finished. When tillage is carried out by animal traction, contour plowing is almost universal. When mechanical traction is used, farmers till in the direction of the slope or in a crossed pattern as to avoid tipping the tractor. This low-tech management system is due to the steep slopes and inherent low productivity of the orchards. Conversion to organic farming has been successful in this area in part due to the easy transition from the traditional management system to an organic system and the relative importance of the subsidies available for organic production compared to the income derived from the sale of olives[12]. In 2003, agricultural subsidies for organic farming in the province of Córdoba reached 3.7 million euros, almost entirely dedicated to olive farmers. This was equivalent to approximately an average of 150 euros per ha of olive orchards[17], in addition to the standard subsidies per kg of oil given to all producers. Without these subsidies, net farm profit would be negative in many areas of *la Sierra*[4].

The second study area, *la Campiña*, is characterized by rolling plains with moderate slopes generally below 25%, and deeper soils of dominant association Xerochrept/Xerorthent/Chromoxerert[18] developed mainly on marls and limestone–marl alternations of the Neogene period[19]. Farmers in this area generally carry out an intensive, high-input, high-tech management system on more productive farms compared to their northern counterparts. Orchards in *la Campiña* are newer than in *la Sierra*, and the surface area devoted to olive orchards is increasing[4]. Trees are planted from 12 m × 12 m in the most traditional orchards with three trunks per tree, to 6 m × 8 m (or 6 m) in the newer orchards with only one trunk per tree, and a significantly larger percentage of orchards are irrigated[4]. Farmers till on average three times a year with disk or chisel plows. Tillage operations are carried out after the first fall rains (October), to prepare the ground before the harvest (November–December), after the harvest and tree pruning (February–March) and sometimes again in mid-spring (April–May). Contour plowing is not commonly implemented, and on sloped farms tillage is often performed in the direction of maximum slope. The adoption of organic agriculture has been much less widespread in this area due to the relative unimportance of the subsidies compared to the income derived from the sale of olives[4].

Average annual precipitation is around 700 mm in *la Sierra* and 600 mm in *la Campiña*, in a typical Mediterranean distribution, with the rainfall concentrated mostly between November and March[19].

Farmer interviews

Semi-structured interviews were conducted with 107 randomly chosen organic olive farmers within the province of Córdoba to determine soil management practices, farm size and economic dependence on the farm. These 107 farms represent 9% of all of the organic olive farmers, in both geographic areas.

Soil management practices were divided into five categories covering all major soil management practices existing in organic olive orchards in the study areas (n = number of farms): (1) mowing (M), a mechanical form of weed management requiring mowing on average twice in the spring ($n = 10$); (2) intensive tillage (IT), tillage more than once a year ($n = 7$); (3) tillage (T), once or less than once a year ($n = 22$); (4) mixed system of tillage and livestock (TL), which implies tillage once or less than once a year and pasture animals as a form of weed control ($n = 37$); and (5) livestock (L), pasture animals as the sole form of weed control ($n = 31$). In this case, a livestock grazing system implies either owning the animals or leasing out grazing rights for other farmers' animals. The most common grazing animals are sheep.

We defined economic dependence on the farm in terms of the importance of income from olive cultivation (including subsidies) to overall family income. Three levels of economic dependence and three options for farmers not economically dependent on their olive orchards were defined, based on the information gathered in a preliminary study to best represent the most important groups within the local olive farmers. The levels of economic dependence are: (1) total dependence on olives as the only source of income; (2) dependence on olive farming together with another source of income from an agricultural activity such as animal products (meat, cheese and milk) and other crops, or from providing agricultural services such as a tractor service, or olive milling; and (3) dependence on the farm together with another source of income from a non-agricultural source, such as a job in a city or town. The three options for farmers not economically dependent on olives reflect their motivations for maintaining olive production: (1) for cultural reasons; (2) for the extra income it provides from the harvest and the subsidies; and (3) both for cultural reasons and for the extra income. Farm size was divided into five groups: less than 5 ha, 5–20 ha, 20–50 ha, 50–100 ha and greater than 100 ha.

Measurement of soil characteristics

Fieldwork was conducted during the rainy season (mid-January to mid-March) over 2 years (2003–2004). Twenty-five farms were sampled, ten in *la Sierra* and 15 in *la Campiña*. More farms were sampled in *la Campiña* to represent better the greater heterogeneity (soil, socio-economic factors, etc.) in organic olive farms compared to farms in *la Sierra*[4,19]. To compare the condition of the soils under cultivation with undisturbed soil, measurements were taken in two locations on each farm: on a slope between two rows of trees within the orchard and on an adjacent slope in a nearby, undisturbed area whenever possible. In each location, the sample plot considered was a rectangular area in the middle of the slope (250 m^2); sample plots in the undisturbed locations were of equal size. While conducting fieldwork, it became evident that apart from the five soil management categories mentioned above, it was necessary to create another category given that some farmers claimed to carry out a mowing (M) system, but their farms had reached such a state of soil degradation that little or no vegetation grew. We refer to this group of farms as ‘bare soil’ (BS). We refer to the results from the undisturbed areas as ‘natural soil’ (NS) ($n = 14$). In total, the soil measurements are divided into seven categories.

Vegetative ground cover (VGC), SOM, cation exchange capacity (CEC), texture, aggregate stability, infiltration and slope were measured on each sample area of the 25 farms studied. In order to determine SOM, CEC, texture and aggregate stability, a composite sample of 30 sub-samples was taken (0–10 cm depth) in each sample plot. VGC was measured by estimating percentage of the soil covered by vegetation or vegetative residues in a 0.5 m × 0.5 m square, divided into four equal sections, in a total of 16 random locations in each sample plot, based on a percentage ground cover diagram from Herweg[20]. SOM was determined using the Walkley–Black method[21]. CEC was measured using the ammonium replacement method[22]. Texture was measured with the hydrometer method[23]. Aggregate stability was measured as percentage water-stable aggregates (WSA) of aggregates between 0.25 and 2 mm diameter[24]. Slope was measured with a pocket inclinometer. Olive tree canopy cover was determined by measuring the area projected onto the ground by the canopy (ten trees in each farm) in relation to the plantation density.

In 2003, infiltration was measured using the US Department of Agriculture (USDA) infiltration test[24] based on a simplified single ring test. In each sample plot, five rings (22 cm in diameter) were inserted 5 cm into the ground, 17 mm of water was applied and infiltration rate was measured when it became constant, following the USDA methodology[24]. In 2004, we modified the methodology for use on farms with steep slopes where water did not cover the whole soil surface area inside the ring. In this case, water was applied using perforated buckets as simplified rainfall simulators at a rate of 236 mm h^{-1}. Each ring had a tube built in at ground level that allowed for collection of the runoff. The results of the 2004 tests were standardized to the 2003 tests.

Erosion risk of the farms was assessed using a visual assessment derived from a methodology developed by Morgan[13], based on erosion symptoms. The assessment is scaled from 0 to 5, with 0 for no visual symptoms of erosion and 5 for a farm with serious rills, gullies, compaction, surface sealing or large areas with bare soil.

During the two study years (September 2002 to August 2004), the annual precipitation recorded on farms evaluated was 545 and 726 mm in *la Sierra*, and 534 and 568 mm in *la Campiña*.

Results

Changes in soil management from conventional to organic farming

Accompanying the shift from conventional to organic farming, there was a 46% decrease in farms managed with tillage (T and IT) and a 74% increase in the use of a sylvopastoral system (L and TL) despite the fact that these changes were not required by the regulations of organic certification (Fig. 2). Approximately two-thirds of the farmers who tilled intensively (IT) changed management practices when they converted to organic farming; one-half of the farmers that previously tilled intensively changed to a mowing system, and all of the farmers who previously mowed maintained their management system (Table 1). The only farmers that changed over to an IT system were those who previously used herbicides (Table 1).

Factors influencing soil management decisions in organic farming

All of the farmers who managed their farm with mowing (M), the majority of those who tilled intensively (IT) (86%) and those who tilled and had livestock (TL) (70%) depended economically on their farm (Fig. 3). The majority of the farmers who tilled less than once a year (67%) or

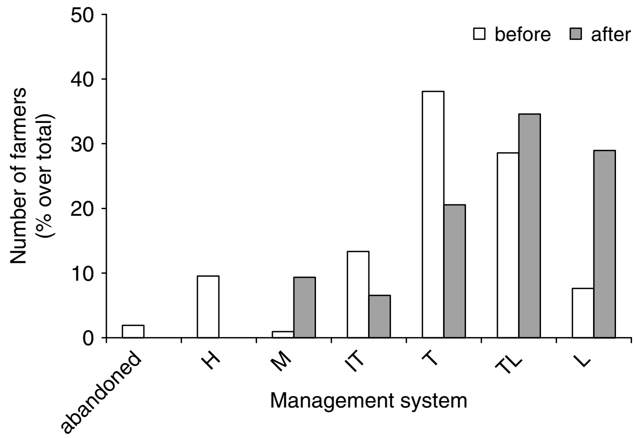

Figure 2. Soil management system before and after converting to organic farming (as % over total of farmers). H = herbicides, M = mowing, IT = intensive tillage, T = tillage once or less than once a year, TL = tillage and livestock, L = livestock.

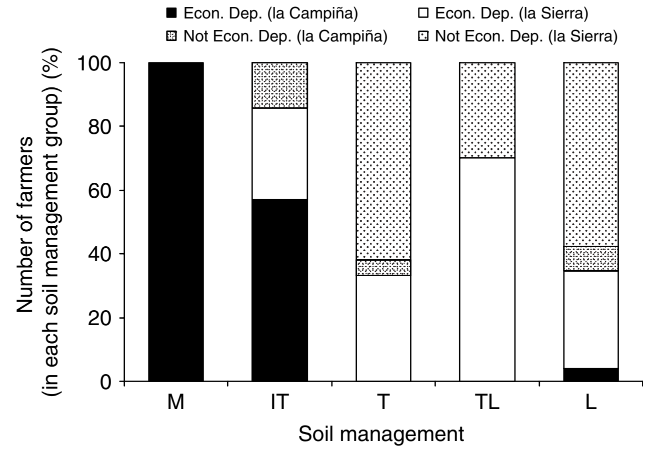

Figure 3. Relationship between soil management system and farmer's economic dependence on the farm, in *la Campiña* and *la Sierra* (as % over total of farmers for each management type). H = herbicides, M = mowing, IT = intensive tillage, T = tillage once or less than once a year, TL = tillage and livestock, L = livestock.

Table 1. Number of farmers (%) that changed soil management practices after the conversion from conventional to organic agriculture (for each management before converting to organic farming) ($n = 107$).

	After converting to organic farming				
Before converting to organic farming	**Mowing (M)**	**Intensive tillage (IT)**	**Tillage (T)**	**Tillage and livestock (TL)**	**Livestock (L)**
Abandoned	0	0	0	0	100
Herbicides	20	20	30	0	30
Mowing	**100**	0	0	0	0
Intensive tillage	50	**36**	0	0	14
Tillage	0	0	**48**	30	22
Tillage and livestock	0	0	0	**77**	23
Livestock	0	0	0	25	**75**

n = total number of farmers.
The numbers in bold represent the number of farmers who have not changed management practices.

managed their farm with livestock (L) (65%) did not depend economically on their farm (Fig. 3). Of all farmers interviewed, 43% did not depend economically on their farm, and of the farmers who did depend economically on their farm, 58% also depended on income from non-agricultural jobs (Table 2). Only 24% of all organic olive farmers depended solely on income from the olive farm and other agricultural activities. All of the farmers who depend solely on olive farming, mowed (M) (Table 2).

This relationship between soil management and economic dependence on the farm was associated with the farm size. Larger farms (more than 100 ha) were associated with mowing (M) (57%), whereas the most common management practice on small farms (less than 5 ha) was tillage (T) (52%), and on farms between 5 and 100 ha, farmers tended to use a livestock grazing system (TL or L) (Fig. 4a). The larger the farm, the more economic dependence farmers tended to have on the farm. All of the farmers with farms more than 100 ha in size and 80% of those with farms between 50 and 100 ha depended economically on their farm (Fig. 4b), whereas less than 20% of farmers with small farms (less than 5 ha) depended economically on their farm. On farms between 5 and 20 ha, economic dependency on the farm and on income from *non*-agricultural activities prevails (50%); however, on farms of 20–50 ha, economic dependence on the farm and on income from other *agricultural* activities prevails (42%) (Fig. 4b).

Results from the two geographic areas differed significantly with respect to farm size, economic dependence and management practices. In *la Campiña*, farms were larger, with an average farm size of 93 ha and 28% of all the farms having more than 100 ha, whereas in *la Sierra*, farms were smaller with an average farm size of 18 ha and 73% of the farms having less than 20 ha. Farmers in *la Campiña* tended to depend economically on their farms (78% of all the farmers) but in *la Sierra* farmers tended to rely more heavily on external forms of income (48% did not depend on the farm). In *la Campiña*, the majority of

Table 2. Main economic reasons for maintaining the olive organic orchards and associated soil management practices (as percentage of farmers over total for each economic dependence level) ($n = 107$).

Economic dependence on farm			Soil management practices: Mowing (M)	Intensive tillage (IT)	Tillage (T)	Tillage and livestock (TL)	Livestock (L)
Economic dependency	Only source of income	(1)[1]	100	0	0	0	0
	Income from other agricultural activities	(22)	18	18	14	41	9
	Income from non-agricultural jobs	(33)	9	6	12	52	21
No economic dependency	Tradition, culture, hobby	(18)	0	0	39	39	22
	Extra income (production, subsidies)	(8)	0	0	12	25	63
	Tradition and extra income	(17)	0	6	35	12	47

n = number of total farmers.
[1] Percentage of farmers in each economic dependence level.

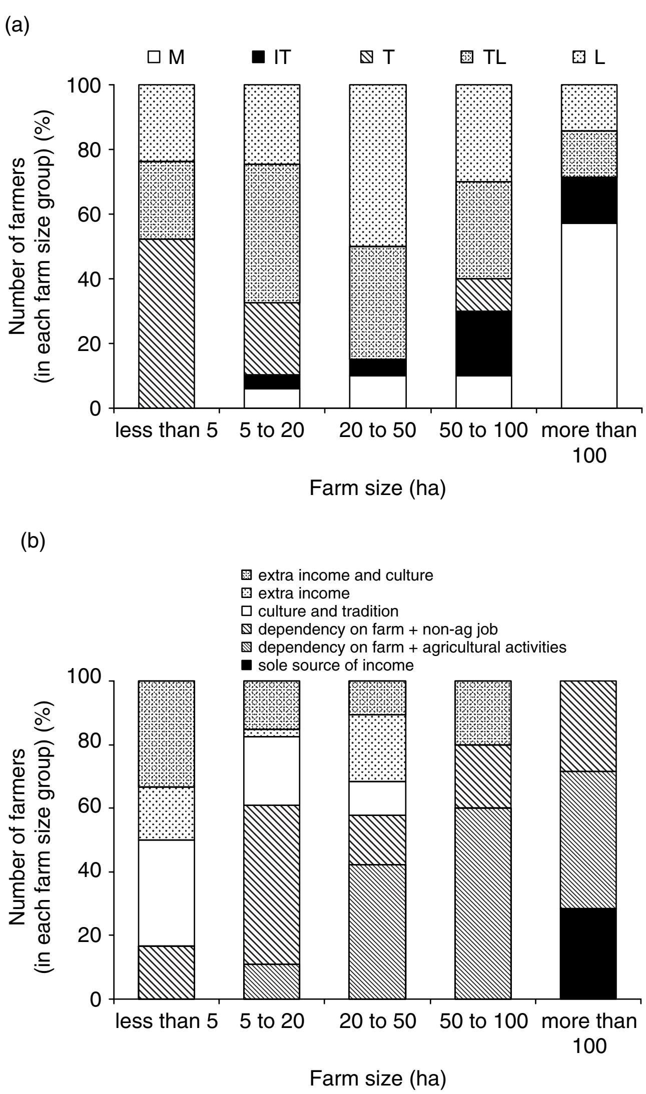

Figure 4. Distribution of (a) soil management practices, and (b) farmer's economic dependence on the farm, in each farm size group (as % over total of farmers for each farm size group). H = herbicides, M = mowing, IT = intensive tillage, T = tillage once or less than once a year, TL = tillage and livestock, L = livestock.

farmers mow (M) and till intensively (IT) (78% of the farmers), whereas in *la Sierra*, livestock (L) and TL were the most common soil management practices (73%) (Figs. 2 and 3). In *la Sierra*, farmers have farmed organically for more years, 93% of the farms are managed by family members, and farmers are on average older than in *la Campiña*. Average yields in *la Sierra* are significantly smaller than yields in *la Campiña* (Table 3).

Soil characteristics and erosion risk

The soil data taken on the 25 farms sampled are summarized in Table 4. VGC is highly related to soil management practices. The highest ground cover values are associated with L, TL, and M management systems, whereas the lowest values were found on farms with IT and BS management systems. SOM is highly associated with VGC in relation to farm management system. Despite the differences observed in SOM between management systems, these differences were not perceived in WSA, except in the BS farms with the most degraded soils that showed significantly lower WSA. However, there are important and similar differences in WSA between the natural and agricultural soils in both geographic locations (Table 4). Infiltration rates on L farms were significantly higher than the other management types, following the pattern observed in VGC and SOM results. The lowest infiltration rates were seen on farms with BS management systems due to their inherently compacted soils. Significant differences in infiltration rates were also observed between natural and agricultural soils in both geographic locations associated with higher SOM in the natural soils (Table 4).

The farms studied in *la Campiña* had principally clay loam soil textures as well as some loam soils; farms in *la Sierra* had sandy loam soil textures. CEC was directly related primarily to SOM as well as to the clay content of the soils (Table 4). The average slope for all of the sample plots in *la Campiña* was 16% (max 40%) and in *la Sierra* was 37% (max 65%). The average canopy cover on the

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Table 3. Socio-economic characteristics of olive organic farms in the two geographic areas studied (averages): olive production per tree (kg), size of farm (ha), age of farmer, experience on farm, employees on farm, and years (average) in organic farming.

Geographic area	Years in organic (mean)	Yield ($kg\,tree^{-1}$)	Size of farm (ha)	Age of farmers (mean)	Farmers with more than 10 years of experience working in the farm (%)	Farms managed by the owner or a family member (%)
La Campiña	4	35	93	38	49	62
La Sierra	6	7	18	50	67	93

Data from farmer surveys ($n = 107$), where n = total number of farmers.

Table 4. Soil characteristics[1]: VGC in winter (%), SOM (%), CEC ($cmol\,kg^{-1}$), WSA (%), and infiltration rate ($cm\,h^{-1}$) for natural and agricultural soils and for each soil management system, in the two geographic areas ($n = 25$).

Geographic area and management system	VGC (%)	SOM (%)	CEC ($cmol\,kg^{-1}$)	WSA (%)	Infiltration ($cm\,h^{-1}$)
'*La Campiña*' (clay loams and loams)					
Natural soil (NS)	n.a.	4.13 ± 1.11	18.3 ± 1.7	77.3 ± 3.2	94.4 ± 43.4
Agricultural soil (AS)	40.8 ± 8.3	1.85 ± 0.34	13.9 ± 1.1	55.7 ± 4.7	7.85 ± 1.50
'Bare soil' (BS)	21.8 ± 10.5	1.23 ± 0.38	11.8 ± 1.8	40.4 ± 3.3	2.39 ± 1.58
Mowing (M)	73.1 ± 5.6	2.44 ± 0.62	15.8 ± 1.3	60.1 ± 8.2	9.67 ± 2.47
Intensive tillage (IT)	2.7 ± 2.7	0.77 ± 0.11	11.4 ± 2.2	50.0 ± 12.0	7.28 ± 3.45
Tillage (T)	26.9 ± 12.6	2.22 ± 0.89	14.4 ± 4.4	71.1 ± 8.0	11.9 ± 2.73
'*La Sierra*' (sandy loams)					
Natural soil (NS)	n.a.	6.93 ± 1.32	19.4 ± 3.0	72.2 ± 2.7	60.0 ± 12.1
Agricultural soil (AS)	72.3 ± 8.8	2.76 ± 0.35	14.1 ± 1.4	54.2 ± 5.2	32.0 ± 10.4
Tillage (T)	18.6	1.21	7.44	33.2	44.9
Tillage and livestock (TL)	69.9 ± 9.2	2.87 ± 0.45	14.3 ± 1.8	55.1 ± 7.7	18.8 ± 2.4
Livestock (L)	95.0 ± 0.8	3.06 ± 0.59	15.9 ± 1.4	59.4 ± 3.6	54.3 ± 34.0

[1] Mean ± standard error.
n = number of farms.

farms sampled was 22% and 18% in *la Campiña* and *la Sierra*, respectively.

There were large differences in erosion risk between management systems (Fig. 5). Farms managed with IT and those with sparse vegetation cover (BS) showed higher erosion risk than those with M, L and TL management systems. Lower erosion risk was associated with higher percentage of VGC.

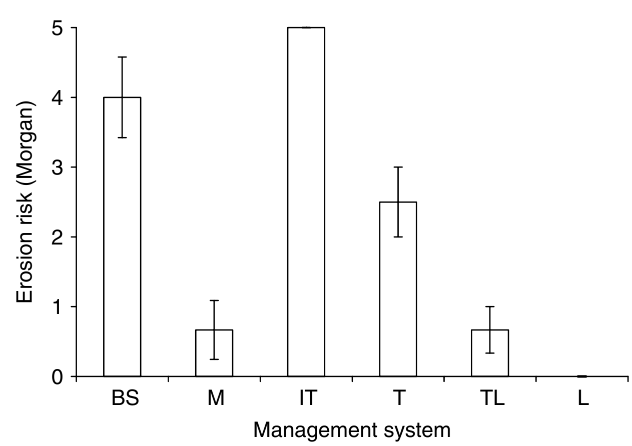

Figure 5. Erosion risk estimations based on Morgan[13] (0 = low risk, 5 = high risk).

Discussion

Our study has shown that the amount and frequency of tillage has decreased with the conversion to an organic cropping system (Fig. 2 and Table 1). Tillage in traditionally rain-fed olive orchards is considered necessary to avoid competition with the natural vegetation for water and nutrients, to reduce compaction and to improve infiltration. Control of vegetation by tillage also reduces the risk of wildfire during the dry season. Additionally, there are cultural reasons for which farmers till; many farmers still till so as not to have what their community would consider a 'dirty' orchard with weeds. While animals were the only source of power, tillage did not represent a significant threat to soil conservation in the region because of limited frequency and intensity of tillage. However, the extension of use of the tractor exacerbated soil erosion problems[5,7]. Careful management of weeds is necessary to avoid loss of production due to competition for water in a rain-fed system, but the presence of VGC is beneficial for the

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protection of the soil against erosion, and for maintaining SOM levels, and soil structure[14–16,25]. There are several studies in Andalusia[26,27] showing that it may be possible to have vegetative cover without suffering a loss of production provided that the VGC is controlled adequately. Appropriate weed control in organic farming can be achieved by mowing or by grazing livestock. The shift to an organic production system has been accompanied by an increase in mowing in *la Campiña* and an increase in livestock in *la Sierra* (Figs. 2 and 3). There has been more adoption of mowing practices in *la Campiña* due to flatter slopes that facilitate the use of machinery and higher net profits that allow for greater economic investment in this area. The lack of a grazing tradition in *la Campiña* has also contributed to the increased adoption of mowing compared to *la Sierra*.

The two distinct groups of organic farms defined in this study (*la Sierra* and *la Campiña*) are differentiated by their location, soil type, agricultural history, socio-economic situation, farm size and yield potential. It can be seen from the results of this study that soil management practices are tied to geographic location (Fig. 3) and associated with economic dependence on the farm (Table 2 and Fig. 3) which is largely determined by farm size (Fig. 4). Sole economic dependence on olive orchards is not feasible in the mountainous areas of *la Sierra*, but is more common in *la Campiña* where yields per tree for organic olive are up to five times higher (Table 3) and the farms are almost five times larger. The farmers in *la Campiña* are also younger, have been managing the farms for fewer years and are more often employees of the farm and not the owners (Table 3). In accordance with our results, studies have shown that farmers with larger farms[28–30] and younger farmers more readily adopt new technologies[28,31], in this case associated with IT and mowing. All of these factors contribute to a more mechanized and productive cropping system in *la Campiña* than in *la Sierra*.

Overall, the shift to organic olive production has resulted in a net decrease in tillage (both intensive and minimal) and use of herbicides, and in an increase in mowing and use of livestock, alone or combined with tillage to control weeds (Fig. 2 and Table 1). These changes have resulted in an increase of VGC and a corresponding decrease in soil erosion risk (Table 4 and Fig. 5). Increase in ground cover has been shown to reduce soil loss dramatically in sloping olive orchards[32–34]. It has also been shown that additional reduction in erosion risk in organic systems with vegetative cover is achieved through increased levels of soil biological activity, SOM, aggregate stability and infiltration[10,35,36]. The results from this study show that differences in SOM, infiltration rates and water aggregate stability were significant between the management systems that have low VGC (IT and BS) and the other management systems that present values closer to those shown by the natural soils (Table 4 and Fig. 5).

Even though mowing systems had a high percentage of vegetative cover, infiltration rates in *la Campiña* soils remained low (Table 4). These low infiltration rates are most likely due to soil compaction as a result of excessive traffic and the compounded effect of the easily compacted clay textures of the soils in *la Campiña*. The effects that excessive traffic has on compaction and on soil loss[37–39] were not manifested in visual signs of soil erosion on the farms with mowing (M) systems evaluated in this study, due to the positive effect of the vegetative cover[39] and therefore the risk of erosion for the farms with this management system was low (Fig. 5).

Contrary to what would be expected, our erosion assessment indicated that the farms located in the steeper *la Sierra* showed less erosion symptoms than the farms located in the flatter *la Campiña*. Soils in *la Sierra* are slightly less erodable than soils in *la Campiña*; average soil erodibility rates (as defined for RUSLE[40]) are 0.03 and $0.04\,\mathrm{t\,ha\,h\,(ha\,MJ\,mm)^{-1}}$ for *la Sierra* and *la Campiña*, respectively[41]. However, the large differences in soil erosion risk between *la Sierra* and *la Campiña* are most likely due to the prevailing management systems of grazing livestock and minimal tillage in *la Sierra*, whereas IT and heavy use of machinery on clay loam soils exacerbate erosion risk in *la Campiña*. Differences in erosion risk associated with these management practices (Fig. 5 and Table 4) are of the same magnitude or larger than the differences in soil erodibility[5] published for these soils. Even though a grazing system runs the risk of being erosive, we found that in general the farms with livestock did not show signs of overgrazing.

The shift from conventional to organic farming is still ongoing in the area, and the effects that it may have on a regional level may change with time. However, all of the farms sampled in this study have been managed organically for at least 4 years, sufficient time for soil properties to be affected.

Conclusion

This study shows that the shift to organic farming in olive orchards in the province of Córdoba has been associated with increased protection of the soil and reduced erosion risks. This was due to the decrease in soil management practices that may have a negative effect on soil conservation such as IT, and an increase in practices that have a positive effect, such as grazing livestock (L and TL), and mowing (M), systems that incorporate a VGC.

The organic farming initiative in the province of Córdoba has had a more important effect in *la Sierra* in terms of area of land affected by the change in soil erosion risk (Fig. 1). However, in *la Sierra*, the majority of the farms converted to organic are the farms that already had extensive, traditional management systems. The change in management systems and the impact on erosion risk was greater in *la Campiña*, as can be seen in the decrease in farms managed with IT, and an increase in farms managed with mowing. However, there is still an important percentage of organic olive farmers that manage their farms with IT and have high erosion risk levels. This is important in the development of agricultural policy and certification guidelines of organic farming. With respect to soil conservation, rewarding farmers for organic farming can potentially decrease soil erosion risk if soil management practices on organic farms are monitored carefully.

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References

1 El-Hage Scialabba, N. and Hattam, C. (eds). 2002. Organic Agriculture, Environment and Food Security. FAO, Rome.

2 Zalidis, G., Stamatiadis, S., Takavakoglou, V., Eskridge, K., and Misopolinos, N. 2002. Impacts of agricultural practices on soil and water quality in the Mediterranean region and proposed assessment methodology. Agriculture, Ecosystems and Environment 88(2):137–146.

3 Stanners, D. and Bourdeau, P. (eds). 1995. Europe's Environment: The Dobris Assessment. European Environment Agency, Office for Official Publications of the European Communities, Luxemburg.

4 Consejería de Agricultura y Pesca (ed.). 2003. El olivar andaluz. Servicio de Publicaciones y Divulgación, Junta de Andalucía, Sevilla, Spain.

5 Gómez, J.A., Battany, M., Renschler, C.S., and Fereres, E. 2003. Evaluating the impact of soil management on soil loss in olive orchards. Soil Use and Management 19:127–134.

6 Schoorl, J.M. and Veldkamp, A. 2001. Linking land use and landscape process modelling: a case study for the Alora region (south Spain). Agriculture, Ecosystems and Environment 85(1–3):281–292.

7 van Wesemael, B., Cammeraat, E., Mulligan, M., and Burke, S. 2003. The impact of soil properties and topography on drought vulnerability of rainfed cropping systems in southern Spain. Agriculture, Ecosystems and Environment 94:1–15.

8 de Graaff, J. and Eppink, L.A.A.J. 1999. Olive oil production and soil conservation in southern Spain, in relation to EU subsidy policies. Land Use Policy 16:259–267.

9 Alonso Mielgo, A.M., Sevilla Guzmán, E., Romera Jiménez, M., and Guzmán Casado, G. 2001. Rural development and ecological management of endogenous resources: the case of mountain olive groves in Los Pedroches comarca (Spain). Journal of Environmental Policy and Planning 3:163–175.

10 Siegrist, S., Schaub, D., Pfiffner, L., and Mader, P. 1998. Does organic agriculture reduce soil erodibility? The results of a long-term field study on loss in Switzerland. Agriculture, Ecosystems and Environment 69(3):253–264.

11 Holland, J.M. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems and Environment 103:1–25.

12 Sánchez, J.L. 2003. Evaluación de sustentabilidad de sistemas de manejo de olivares ecológicos y convencionales en Los Pedroches. Asociación Comité Andaluz de Agricultura Ecológica (CAAE), Sevilla, Spain.

13 Morgan, R.P.C. 1995. Soil Erosion and Conservation, 2nd ed. Longman Scientific and Technical, Harlow, Essex, UK.

14 Lal, R. 2001. Soil degradation by erosion. Land Degradation and Development 12:519–539.

15 Lado, M., Paz, A., and Ben-Hur, M. 2004. Organic matter and aggregate size interactions in infiltration, seal formation, and soil loss. Soil Science Society of America Journal 68:935–942.

16 Rawls, W.J. and Brakensiek, D.L. 1989. Estimation of soil water retention and hydraulic properties. In H.J. Morel-Seytoux (ed.). Unsaturated Flow in Hydrology: Theory and Practice. Kluwer Academic, Dordrecht, The Netherlands. p. 275–300.

17 Consejería de Agricultura y Pesca (ed.). 2003. El plan Andaluz de la agricultura ecológica. Servicio de Publicaciones y Divulgación, Junta de Andalucía, Sevilla, Spain.

18 Soil Survey Staff. 1999. Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. 2nd ed. Agricultural Handbook 436, SoTI Conservation Service (SCS), USDA, Washington, DC.

19 CSIC/IRNAS. 2000. SEIS.net: Sistema Español de Información de Suelos sobre Internet. Available at Web site http://leu.irnase.csic.es/mimam/seisnet.htm (verified 25 February 2005).

20 Herweg, K. 1996. A field manual for assessment of current erosion damage. Soil Conservation Research Programme, Ethiopia and Centre for Development and Environment, University of Berne, Switzerland.

21 Nelson, D.W. and Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In A.L. Page, R.H. Miller, and D.R. Keeney (eds). Methods of Soil Analysis. Part 2. ASA and SSSA, Madison, WI. p. 539–579.

22 Rhoades, J.D. 1982. Cation exchange capacity. In A.L. Page, R.H. Miller, and D.R. Keeney (eds). Methods of Soil Analysis. Part 2. ASA and SSSA, Madison, WI. p. 149–157.

23 Bouyoucos, G.J. 1962. Hydrometer method used for making particle size analyses of soils. Agronomy Journal 54:464–465.

24 USDA. 1999. The Soil Quality Test Kit Guide. USDA-NRCS (Natural Resources Conservation Service), Washington, DC. Available at Web site http://soils.usda.gov/sqi/soil_quality/assessment/kit2.html (verified 25 February 2005).

25 De Ploey, J. 1989. Erosional systems: a perspective for erosion control in European loess areas. Soil Technology Series 1:93–102.

26 Castro Nieto, G. 2004. La cubierta vegetal en el olivar: determinación experimental del uso de agua y de su influencia sobre los procesos de infiltración, escorrentía y erosión. Trabajo Profesional Fin de Carrera, University of Cordoba, Córdoba, Spain.

27 Pastor, M. 1990. Non-tillage and other methods of reduced tillage in olive cultivation. Olivae 34:18–30.

28 Ogunlana, E.A. 2004. The technology adoption behaviour of women farmers: the case of alley farming in Nigeria. Renewable Agriculture and Food Systems 19(1):57–65.

29 Cramb, R.A. and Nelson, R.A. 1998. Investigating constraints to the adoption of recommended soil conservation technology in the Philippines. In F.W.T. Penning de Vries, F. Agus, and J. Kerr (eds). Soil Erosion at Multiple Scales: Principles and Methods for Assessing Causes and Impacts. CAB International, Wallingford, UK. p. 99–120.

30 Rawal, T. 1981. An analysis of factors affecting the adoption of modern varieties in Nepal. Research Paper Series. 11. Agricultural Projects Service Center, Nepal.

31 Feder, G.R., Just, R.E., and Zilberman, D. 1985. Adoption of agricultural innovations in developing countries: a

survey. Economic Development and Cultural Change 33(2):255–298.

32 Gómez, J.A., Romero, P., Giráldez, J.V., and Fereres, E. 2004. Experimental assessment of runoff and soil erosion in an olive grove on a Vertic soil in southern Spain as affected by soil management. Soil Use and Management 20:426–431.

33 Gómez, J.A., Orgaz, F., Villalobos, F.J., and Fereres, E. 2002. Analysis of effects of soil management on runoff generation in olive orchards using a physically based model. Soil Use and Management 18:191–198.

34 Francia, J.R., Martínez Raya, A., and Ruíz Gutiérrez, S. 2000. Erosión en suelos de olivar en fuertes pendientes: comportamientos de distintos manejos de suelo. Edafología 7:147–155.

35 Schjonning, P., Elmholt, S., Munkholm, L.J., and Debosz, K. 2002. Soil quality aspects of humid sandy loams as influenced by organic and conventional long-term management. Agriculture, Ecosystems and Environment 88:195–214.

36 Tan, C.S., Drury, C.F., Reynolds, W.D., Gaynor, J.D., Zhang, T.Q., and Ng, H.Y. 2002. Effect of long-term conventional tillage and no-tillage systems on soil and water quality at the field scale. Water Science and Technology 46(6–7): 183–190.

37 Hussain, I., Olson, K.R., and Siemens, J.C. 1998. Long-term tillage effects on physical properties of eroded soil. Soil Science 163:970–981.

38 Ferreras, L.A., Costa, J.L., García, F.O., and Pecorari, C. 2000. Effect of no-tillage on some soil physical properties of a structural degraded Petrocalcic Paleudoll of the southern 'Pampa' of Argentina. Soil and Tillage Research 54:31–39.

39 Raper, R.L., Reeves, D.W., Burmester, C.H., and Schwab, E.B. 2000. Tillage depth, tillage timing, and cover crop effects on cotton yield, soil strength, and tillage energy. Applied Engineering in Agriculture 16:379–385.

40 Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., and Yoder, D.C. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with The Revised Universal Soil Loss Equation (RUSLE). Agricultural Handbook 703, Agricultural Research Service (ARS), USDA, Washington, DC.

41 ICONA. 1977. Mapas de estados erosivos: cuenca hidrográfica del Guadalquivir. Ministerio de Agricultura, Pesca y Alimentación, Madrid, Spain.