Exploring the linkage between spontaneous grass cover biodiversity and soil degradation in two olive orchard microcatchments with contrasting environmental and management conditions

E.V. Taguas[(*1)], C. Arroyo[(1)], A. Lora[(1)], G. Guzmán[(1)], K. Vanderlinden[(2)] and J.A. Gómez[(3)]

(1) School of Agronomy and Forestry Engineering- University of Cordoba. Campus Rabanales. Leonardo Da Vinci building. 14071 Córdoba (Spain). Ph. +34 957 218533; E-mail: o72arbac@uco.es, evtaguas@uco.es(*), cr1logoa@uco.es, g92gudim@uco.es.

(2) IFAPA, Centro Las Torres-Tomejil-Ctra. Sevilla-Cazalla, km 12.2- 41200 Alcalá del Río (Seville), Spain. E-mail: karl.vanderlinden@juntadeandalucia.es.

(3) Institute of Sustainable Agriculture (CSIC). Avenida Alameda del Obispo s/n 14004. Córdoba (Spain). E-mail: joseagomez@ias.csic.es.

Abstract. Spontaneous grass covers are an inexpensive soil erosion control measure in olive orchards. Olive farmers allow grass to grow on sloping terrain to comply with the basic environmental standards derived from the Common Agricultural Policy (CAP). However, to date there are few studies assessing the environmental quality and extent of such covers. In this study, we described the biodiversity indices associated to spontaneous grass cover in two contrasting olive orchards in order to compare them and to evaluate its relevance as an indicator of soil degradation. In addition, biodiversity patterns and their relationships with environmental factors such as soil type and properties, precipitation, topography and soil management were analyzed.

Different grass cover biodiversity indices were evaluated in two olive orchard catchments under conventional tillage and no tillage with grass cover, during 3 hydrological years (2011-2013). Seasonal samples of vegetal material and pictures in a permanent grid (4 samples/ha) were taken to characterize the temporal variations of the number of species, frequency, diversity and transformed Shannon's and Pielou's indices.

Sorensen's index obtained in two olive orchard catchments showed notable differences in composition, probably linked with the different site conditions. The catchment with the best site conditions (deeper soil and higher precipitation) and the highest biodiversity indices showed soil losses over 10 $t.ha^{-1}$ and management practices more intense. In absolute terms, the diversity indices of vegetation were reasonably high in both catchments, despite the fact that agricultural activity usually severely limits the landscape and the variety of species. Finally, a significantly higher content of organic matter in the first 10 cm of soil was found in the catchment with worse site conditions, average annual soil losses of 2 $t{\cdot}ha^{-1}$ and the least intense management. Therefore, the biodiversity indicators associated to spontaneous grass cover were not found to be suitable for describing the soil degradation in the study catchments.

Key words: olive orchard; spontaneous grass cover, biodiversity, management; soil degradation.

1. Introduction

Soil degradation is defined as the deterioration and loss of soil functions, involving processes such as soil erosion, sedimentation problems, climate change, watershed functions and changes in natural habitats leading to loss of genetic stock and biodiversity (Chen et al., 2002). The agricultural intensification of 20th century Europe has led in general terms to a widespread decline in farmland biodiversity across many taxa (Benton et al., 2003). The new 2020 Biodiversity Strategy (European Commission, 2011; 2011/2307 INI) aims to improve the contribution of fisheries and agricultural and forestry sectors to biodiversity. In addition, the Multi-annual Financial Framework for 2014–2020 offers significant opportunities to improve synergies not only in soil biodiversity but also with respect to other degradation processes such as soil loss (European Commission, 2014).

An area of over 2.5 Mha is dedicated to olive cultivation in Spain (MAGRAMA, 2013), which represents about 41% of the world olive production. Olive harvesting and its associated agri-food industries are especially important in rural areas from a socio-economical viewpoint. Over 60% of the area dedicated to olives is located in Andalusia, the southernmost region of the country. A high risk of soil degradation has been described by different authors such as Goméz-Limón et al., (2009) and Gómez et al., (2014) as the result of the interaction of climatological and topographical factors and/or inappropriate soil management. Olive trees have traditionally been cropped under rainfed conditions and on sloping areas where other crops are difficult to grow; they usually provide very low yields or require large investments in order to exploit them properly. The characteristics of the Mediterranean type of climate, where long dry periods alternate with intense rainfall events, in conjunction with soil management systems that pursue bare soils to minimize water competition by weeds entail a high susceptibility to severe water erosion of the soil. Therefore, the use of cover crops has been promoted for soil protection, given their proven effectiveness in controlling water erosion (Gómez et al., 2004; Gómez et al. 2009a, 2009b; Márquez-García et al., 2013; Taguas et al., 2013 among others). In fact, growing in between the olive tree rows is currently a compulsory requirement if the mean slope of the plot is over 15%, according to cross-compliance rules (European Commision, 2014). Spontaneous covers are usually irregular and develop slowly, but tend to achieve a significant gowth during spring which may result in greater competition for water and nutrients during the most critical periods of the olive growing cycle. However, due to its zero cost, it is a common alternative in low production olive farms (e.g. Taguas et al., 2013). Furthermore, additional advantages of spontaneous covers in terms of biodiversity, carbon sequestration and landscape improvement, etc, might make it worth to study their potential contribution.

The study of spontaneous grass cover and their interactions with soil have been traditionally associated with the improvement in crop yield (e.g. Graziani et al., 2012; Kamoshita et al., 2014;) or habitat and species conservation (e.g. Albrecth, 2003; Hyvönen and Huusela-Veistola, 2008; Aavik and Liira, 2009) in agronomical and ecological terms, respectively. However, their importance as indicators of soil loss and degradation has scarcely been explored. In this context, monitoring is a critical aspect in efforts to protect and manage biodiversity (Lamb et al., 2009). One key drawback for the proper implementation of protection policies is the lack of a well-defined quantitative measure or indicator of biodiversity (Büchs, 2003; Spangenberg, 2007; Moonen and Barberi, 2008). The distinction between the use of biotic indicators and biodiversity indicators to determine the state of the environmental aspects of different systems is not usually clear. Measuring the diversity of process-related indicators may be a good way of measuring how well agro-ecosystems react against environmental changes (Moonen and Barberi, 2008). Bastida et al. (2008) pointed out that biological indicators of soil quality were more sensitive to changes than chemical and physical indicators and that they could give a broader picture of soil quality. The bio-indicators of soil quality are commonly associated to the biological activity of their microorganisms; however, spontaneous grass cover biodiversity may be a simpler way to measure the risk of soil degradation, given that richer and more complex ecological niches might produce more efficient cover and soil protection, as well as habitat and food opportunities for other elements of the trophic chain, such as birds or reptiles.

The starting hypothesis of this study was that wider ecological niches mean lower risks of soil degradation in terms of organic matter decline and soil losses. In addition, we postulate that the interactions of soil and management explain better the diversity of spontaneous grass covers than the environmental site conditions (annual/seasonal patterns).

The specific objectives of this work were 1) to describe and compare the biodiversity indicators associated with spontaneous grass covers in two olive orchards with contrasting management intensities, environmental conditions and yields; 2) to analyze the temporal patterns of these indices, as a result of meteorological conditions and soil management; and 3) to evaluate their relevance as indicators for soil quality, in terms of soil loss and soil degradation.

2. Materials and methods

2.1. Study sites

The study catchments are located in the province of Córdoba (Fig. 1, Table 1), in Southern Spain. Both were described in detail by Gómez et al. (2014) and Taguas et al. (2013) to evaluate the erosive patterns for the periods 2006-2011 and 2005-2011, respectively. The results were considered an accurate representation of the soil degradation state.

The “Conchuela” catchment (CN; 37.6 ºN, -5.0 ºW, Spain) is situated in a fertile area along the old terraces of the River Guadalquivir. The drainage area of the catchment is 8.0 ha, and it presents an average elevation of 142 m and a mean slope equal to 9%. The climate is classified as Mediterranean with an average annual precipitation of 642 mm, which is mainly concentrated from October to March (about 76% of the precipitation). The average annual temperature is 17.5 ºC. The maximum daily mean temperature is usually recorded in July (27.8 ºC) while the minimum is generally observed in January (8.1 ºC). The soil is a Vertisol, according to the FAO classification (FAO, 2006). It is a deep soil, very plastic when wet, but when dry, the presence of cracks induces high infiltration rates. The predominant soil texture is clay-loam (Table 1). The olive trees were planted in 1993 with 6 × 7 m tree spacing. The mean olive yield in the catchment is 8000 $kg \cdot ha^{-1}$ During the study period, the farmer allowed the growth of grass spontaneous cover in the lanes from the end of winter until April. Herbicide (glyphosate and oxifluorfen) treatments were applied to control their growth in the tree line from March to September (Table 2). Occasionally surface tillage was made at selected locations within the catchment to cover rills and small gullies obstructing machinery traffic within the orchard. Mowing in the tree lane was performed in areas of excessive grass cover from late winter to early spring. Harvesting is semimechanized using tree-vibrators from late autumn to mid-winter, depending on weather conditions and when the fruit ripens (Gómez et al., 2014; Table 2).

The “Puente Genil” catchment (PG; 37.4 ºN, −4.8 ºW) represented a marginal olive orchard with a very low production. Management operations are kept to a minimum in order to reduce costs. It is located in an area with a long tradition of olive cropping in the upper reaches of the Guadalquivir Valley. The catchment has a drainage area of 6.1 ha and the mean elevation is 239 m. The average slope is equal to 15 %. As for the climate type, the catchment is located in a Mediterranean area with a mean annual precipitation is of 400 mm. The average temperature in the hottest month (July) is 26.5 ºC, while in the coldest month (January) it is 8.4 ºC. The main soil category of the catchment is Cambisol (FAO classification; FAO, 2006) with sandy-loam texture (Table 1 and 3). Calcic parental material is located at different points of the catchment with a very shallow soil, mainly on the Western hillslope (Fig. 1b). In contrast, on the Eastern hillslope, soil depth is more than 3 m. The areas closer to the catchment outlet are old terraces with abundant coarse calcarean material. The mean olive yield is 1300 $kg{\cdot}ha^{-1}$. The olive trees´ age is 17 years. They were planted on a 7 m × 7 m grid. No-tillage with spontaneous grass cover growing from winter to spring was the management type corresponding with the first few years. Spontaneous grass is removed once (only in spring) or twice a year (September or October and March, April or May), mechanically or using phytosanitary products under the canopies (or combining both; see also Taguas et al., 2013). The details of the management applied during the study period are summarized in Table 2.

2.2. Spontaneous grass cover sampling

Four spontaneous grass cover surveys were performed per year (1 per season) during 2011, 2012 and 2013. Survey dates were based on the preceding meteorological conditions that determined the germination periods, as well as the development of the spontaneous grass cover. A grid was established in each catchment (Fig. 1) with a sampling density between 4 and 6 points/ha. In each geo-referenced grid point, a 0.5 × 0.5-m frame was used to delimit the survey area (Fig. 2). These sampling points were always placed in the lanes between the lines of trees, away from the olive canopy and the areas of drip irrigation and herbicide application. Plant samples were taken in order to identify the species present at each grid point. In addition, pictures of each point were taken (Reflex Olympus E-420, ED 14-42 mm; height 1.4 m-1.7 m; Fig. 2) to check the annual and seasonal differences of the grass spontaneous cover.

2.3. Data Analyses: biodiversity indices, meteorological variables and soil quality indicators

2.3.1. Biodiversity indices

The indices considered to evaluate the biodiversity associated to the grass spontaneous grass cover were richness (*R*), Sorensen’s index (*Is*), transformed Shannon’s (*Hmod*) and Pielou’s indices (*Jmod*), absolute and relative frequency of occurrence and biological spectrum. *R* was determined for the total number of species found per catchment per season and per point. Firstly, in each sample point of the grid (Fig. 1 and

Fig 2a and 2b), the species present were identified with pictures and vegetal material, and then the total number species in each catchment (on a seasonal and annual scale) were calculated.

Is indicates the degree of similarity of two samples (study sites) as regards the species composition (Eq. 1). It ranges from 0 to 1, where 0 means that both samples are completely different and 1 completely equal.

$$Is = \frac{2 \cdot C}{A+B} \quad \text{(Eq. 1)}$$

Where: *A* is the number of species identified in PG, *B* the number of species identified in CN, and *C* is the number of species common to both study sites.

Shannon's index, *H*, (Eq. 2; Shannon and Weaver, 1949) indicates the probability of finding an individual within an ecosystem. It usually produces values of between 1.5 and 4.5. Minimum values are obtained when most of the individuals belong to the same species or to a limited group of (less diverse) species, while the highest values are produced in communities where all the species have the same number of individuals.

$$H = \sum_{i:1..n} (p_i \cdot Ln\ (p_i)) \quad \text{(Eq. 2)}$$

Where: $p_i = n_i / N$; n_i is the number of individuals corresponding to the species *i*, and *N* is the total number of individuals. In this case, a modification of Shannon's index, *Hmod*, was used to simplify the analysis, based on the evaluation of pictures.. Therefore, n_i was substituted by the number of grid points where a species was present and *N*, the total number of grid points considered. The suitability of the transformations associated to *Hmod* and *Jmod* was verified with the samples taken in spring 2013 in both catchments.

Pielou's equity index (Eq. 3; Pielou, 1969) measures the ratio of the observed diversity and the maximum expected diversity. It varies between 0 and 1, which would describe systems where all species are equally abundant.

$$J = \frac{H}{Ln(S)} \quad \text{(Eq. 3)}$$

Where:

H is Shannon´s index and *S* is the number of species. If *H* (Eq. 3) is substituted by *Hmod*, then *Jmod* is obtained.

Finally, the biological spectrum or life-form (Raunkiaer, 1934) was identified for each species according to its behavior during the unfavorable season (June-September): Epiphytes; Phanerophytes Chamaephytes; Hemicryptophytes: Therophytes; Cryptophytes.

2.3.2. Meteorological variables to describe temporal variability of biodiversity indicators.

The cumulative precipitation (*P*), cumulative reference evapotranspiration (*ETP*) and average minimum daily temperatures (*Tm*) were considered in order to evaluate their influence on the biodiversity indices. The daily precipitation was recorded in the gauging stations of the catchments, while the daily values of

ETP and *Tm* were collected from "La Reina" and "Santaella-CSIC" meteorological stations for CN and PG, respectively (CSIC, 2014).

2.3.3. Soil degradation indicators: soil loss, runoff, organic matter and bulk density.

The relationships between the mean values of soil losses, runoff coefficients and organic matter content (0-10 cm) in the catchments with *R, Jmod* and *Hmod* were explored to discuss the role of biodiversity indices as a proxy of soil quality indicators. Soil loss (*SL*) and runoff coefficient (*Rc*) were measured in the catchments over 5 years (Taguas et al., 2013; Gómez et al., 2014).

The samples for organic matter (*OM*) analysis were taken between 0-10 cm combining the inter-row and the area under the tree canopies obtained on regular grids with a density of 6-10 samples/ha. The number of samples was 90 and 65 in CN and PG, respectively. The Walkley-Black procedure (Nelson and Sommers, 1982) with samples (2 mm sieve) was followed to determine the organic matter content. Bulk density (*BD*) was measured on the same grid using undisturbed soil cores of approximately 250 cm^3. The differences in grid and number of samples are due to the tree spacing in the catchments.

2.3.4. Statistical analyses

Basic statistics (mean, standard deviation and coefficient of variation) were evaluated for the annual values of *R*, *Jmod*, *Hmod*, *Is* as well as *Tm, ETP* and *P*. In the case of *Is*, the average seasonal values were calculated to observe the possible differences in the study sites over the year. The histograms of the biological spectrum measured in the catchments for the study period were also compared.

In addition, in order to evaluate the influence of the meteorological variables on the biodiversity indices *Hmod*, *Jmod* and *R,* a correlation analysis was carried out with meteorological features: *P*, *ETP* and *Tm*. These were checked for the weighted values for the previous 5, 15, 30, 60 and 365 days.

As for soil properties *OM* and *BD*, box and whisker plots and t-test for independent samples were used to determine whether there were significant differences between the study sites. For *SL* and *R*c, only box and whisker plots were represented because the number of samples was 5. These properties were compared with the biodiversity indices to qualitatively describe the correlation degree.

3. Results

3.1. Variability of the biodiversity indicators

The mean values of *R*, *Hmod* and *Jmod,* were higher in CN than in PG, which probably shows that site-specific conditions have greater importance than long term management effects (Table 4). A lower diversity was identified in PG, which was probably associated with worse environmental conditions in terms of water deficit, as compared to CN (Table 4), coupled with coarser soil texture and lower soil water holding capacity (Table 3). Precipitation was on average 25% lower in PG while *ETP* was slightly higher, with respect to CN (Table 4). The soils at PG were also shallower than at CN and of coarser texture (Table 3), leading to a smaller water storage capacity which might limit the development of vegetation in PG.

With the exception of *Jmod*, the highest coefficients of variation were also observed in PG. Despite the extremely simplified landscapes of both catchments, *Hmod*-values were notably high for agricultural systems, particularly in the driest year (2011) with values near to 2.2 and 1.9 in CN and PG, respectively (Table 4). On the other hand, *Jmod*-values indicated that there were no dominant species in either of the catchments. These features are common in Mediterranean environments, characterized by a high inter-annual and intra-annual variability of precipitation and temperature, with a wide range of colonizing species awaiting their optimal development conditions without any clear dominant pattern. In spite of the selective herbicide treatments (Table 2), differences in *Jmod* between both catchments were small. In addition, they were notably higher than the values quantified for olive orchards with cover crops with leguminous species (Guzmán and Forester, 2007).

Sorensen´s index numerically illustrated the notable differences of species existing in the catchments (Tables 4-5 and Fig. 3). It is worth noting how winter was the period when the floristic composition was the most similar while the spring, the most different. Although close species spectra were found (Fig. 3), a different floristic catalogue was observed in both catchments, and the lack of Monocotyledonous in PG is remarkable (Table 5). From the soil protection point of view, the current spectrum is not appropriate because most of the species are not permanently present for a long period of the year. However, most of the species constitute the nutritional base for insects and birds. Enrichment of the biological spectrum with Hemicryptophytes and Chamaephytes is suggested in locations where e.g. hedges are compatible with agricultural operations (Guzmán and Foraster, 2007).

The coefficients of correlation between weather variables (*Tm, ETP and P*) and seasonal biodiversity indicators (*Hmod*, *Jmod* and *R*) were in general low (Table 6). Significant correlations were only found for PG as a result of the shallow sandy soil with short-term water availability controlling vegetation. In contrast, the deeper clay soil at CN (Table 1, 3) enhanced long-term water availability and weakened the correlations between weather variables and biodiversity indicators. Significant negative correlations for *ETP15, ETP60* (and *Tm60*) are related to water stress, whereas the positive correlations for short-term indicators such as *Tm15* and *ETP5* might indicate optimal conditions for the seed germination and the growth of grass.

3.2. Relationships between biodiversity indices and indicators of soil quality

In addition to *R*, *Jmod* and *Hmod*, the mean annual values of *SL* and *Rc*, measurements of *OM* and *BD* are also shown in Table 7 and Figure 4. *R, Jmod* and *Hmod* were not correlated with soil indicators. The highest values of soil losses and the lowest values of organic matter were found in CN. The differences in *OM* and *BD* between the catchments were significant as is shown in Table 7 and Fig. 4a-b (average OM-CN=1.249 $g.cm^{-3}$; average OM-PG=1.479 $g.cm^{-3}$). A large quantity of coarse elements was found in PG, which must be taken into account when understanding the differences in BD (Table 7). Substantial higher mean soil loss in CN(16.1 $t{\cdot}ha^{-1}$) was found with respect to PG (1.8 $t{\cdot}ha^{-1}$; Fig. 4c), Likewise, the mean *Rc* in CN(15.3%) tripled the value of PG (5.1%; Fig. 4d),

4. Discussion

Indicators of spontaneous grass cover biodiversity were not correlated with soil losses and organic matter. The role of cover crops in soil erosion is related with dissipation of energy from rainfall and runoff. It was expected that a wider ecological niche would allow for a more efficient occupation of space and a higher efficiency in the flow control on the hillslopes. However, in CN, other factors such as precipitation, soil hydrologic characteristics and the possible dominance of concentrated flow (gullies and rills; Gómez et al., 2014) accounted for higher soil losses and runoff coefficient (much higher than PG values). Lewis et al. (2013) highlighted the potential for soil erosion to impinge the spontaneous grass cover seedbank growth and to improve the biodiversity in agro-ecosystems of Northern Europe. In natural Mediterranean systems Cerdá and García-Fayos (2002) and García-Fayos et al., (2010) described the susceptibility to seed removal by water erosion according to seed and landscape features. In this context, an annual sediment delivery ratio of 4% was found in PG using the SEDD model (Taguas el al, 2011) while in Conchuela, the value was over 90% indicating an efficient rate of transport, as calculated by Burguet (2015). Both the different values of soil losses and the annual sediment delivery ratios might illustrate the very different sediment dynamics which contribute towards explaining the greater biodiversity in CN.

As for the values of organic matter content, these might be explained by the management systems. No tillage operations were applied in PG from 2005 and machinery traffic was usually minimal (Table 2), which implies less mechanical soil disturbance than in CN, where productive farm management is carried out. In two sites with a silt loam texture in the Ebro Valley in Spain, Fernández-Ugalde et al. (2009) also described an increase in soil organic carbon content associated with non-tillage practices.

It is important not to confuse non-tillage allowing spontaneous grass cover vegetation, as used in PG, with non-tillage management with herbicide to maintain bare soil in olive orchards. The later led to larger soil losses, runoff coefficients and soil compaction as compared to conventional tillage and cover crops as was described by Gómez et al., (2004), however, larger carbon and organic matter contents were found in the topsoil, particularly under the canopy (Gómez et al., 1999). As for surface tillage operations in CN, Márquez-García (2013) also found lower values of organic carbon in the topsoil of olive orchards under conventional tillage as compared to cover crops (spontaneous and sown). Near the study catchments, in other agricultural land uses under conservation agriculture, smaller amounts of crop residues, lower soil water contents and larger CO_2 emissions were observed in managements where tillage operations were applied (Cid, 2013).

Despite the annual and seasonal variations of meteorological conditions, overall a larger availability of water was observed in CN, as a result of the higher annual precipitation and the notably deeper soil. More extensive management did not lead to greater spontaneous grass cover biodiversity in PG compared to CN. Benton et al. (2003) highlighted the importance of differential seed or edaphic factors contributing distinctly to plant growth and to patchiness in the presence of insects. Similarly, Albrecht and Mattheis (1998) found that a management change from conventional to integrated farming in dicotyledonous crops in Germany did not lead to a substantial increment of rare species number of spontaneous grass cover.

Hyvönen et al. (2003) found that differences in spontaneous grass cover species numbers between organically and conventionally cropped fields in Finland were small. Similar results were highlighted under Mediterranean conditions by Graziani et al. (2012) for a sequence of six rotations in Italy. They found that the number of spontaneous grass cover species and biodiversity were only slightly higher in organic systems as compared to low-input conventional systems.

Although single measures, such as the application of fertilizers or certain herbicides, may lead to a strong correlation with species diversity, such as the case of monocotyledoneous in CN, no clear sensitivity to the management was found, as described by Albrecht (2003) in Germany or Pysek et al. (2005) in Central Europe for different crops. This is likely to be a result of the site conditions in CN being substantially better for vegetation growth, which becomes evident from the olive yields at both catchments (CN, 5000-8000 kg ha^{-1} and PG < 2000 kg ha^{-1}). In fact, crop yield was also used with other soil properties (such as bulk density, water retention, pH, electrical conductivity, plant-available nutrients, organic matter, microbial biomass, soil enzymes) by Masto et al. (2007) to define a soil quality index in an agricultural area with a rotation of maize, pearl millet, wheat and cowpea in India. In addition, it is a common agronomical factor of soil quality for farmers, which is well-correlated with biodiversity indices of spontaneous grass cover. On the other hand, the traditional metrics used in this study to measure biodiversity - widely used in ecological studies since it is simple to calculate and understand and has been used for a long time (Lamb et al., 2009) – have been criticized because they provide a limited part of the information (Magurran, 2004) and may be unsuitable for monitoring biodiversity intactness (Lamb et al., 2009). These traditional indices, for example, cannot indicate the presence of non-native species or rare plants. In this case, the details of the species shown in Table 5 complete the information provided by the biodiversity indices and allow us to confirm the short-term environmental advantages of the vegetation growth found in CN, which is likely to be linked to greater water availability.

5. Conclusions

Sorensen's index for two olive orchard catchments in the province of Cordoba (Spain) showed notable differences in composition, which were probably associated with the different site conditions. Although CN had a more intense management, its better site conditions (higher precipitation, deeper soils and less steep slopes) can explain the higher values in richness, Pielou's index and Shannon's index. Water stress is a limiting factor for the development of vegetation in the Mediterranean area, so the notable differences in annual precipitation (400 mm in PG versus 600 mm in Conchuela) account for the differences observed. In addition, a more active sediment transport dynamic might contribute to seed dispersal and to increasing the biodiversity indices.

In absolute terms, the diversity indices were high in both catchments, in spite of the major simplifications derived from the agricultural systems. This can be related with the typical Mediterranean dynamics where temporal variability allows different individual species to be incorporated each year according to certain climatological features. The impact of land-use and management in both catchments explains the dominance of short cycle Therophytes, Hemicryptophites and Cryptophytes, which are extremely resistant to mechanical/chemical treatments, since their buds are kept underground. On the other hand, Therophytes and Hemicryptophytes do not provide efficient soil protection, since their aerial parts are not present during autumn and winter seasons. However, these species are ecologically important for feeding numerous insects and local birds such as partridge (*Alectoris rufa* L).

Higher contents of organic matter were determined in PG, the catchment with the worst site conditions in terms of water availability and the least intense management. Additionally, low soil losses have been measured in this catchment. Therefore, biodiversity indicators associated to spontaneous grass cover were not appropriate to describe the soil situation.

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TABLES

Table 1. Summary of the main environmental features in the study catchments

Name	La Conchuela	Arroyo Blanco
Location	Córdoba	Puente Genil (Córdoba)
Drainage area (ha)	8.0	6.1
Mean elevation (m)	142	239
Mean slope (%)	9	15
Mean annual precipitation (mm)	642	400
Max. and min. daily average temperatures	27.8º July/8.1º January	26.5º July/ 8.4º January
Soil type (FAO; see details in Table 3)	Vertisol	Cambisol
Texture	Clay-loam	Sandy-loam
OM content (%, topsoil)	1.1	1.4
Mean olive yield (kg/ha)	8000	1300
Management (see details in Table 2)	Spontaneous grass cover controlled with a combination of mowing, and occasional herbicide application	Non-tillage with a spontaneous grass cover

Table 2. Management operations applied during the study periods in both catchments.

Catchment	Month	2011	2012	2013
Con	January		Harvesting: Mechanical vibrators combined with a buggy with an umbrella to collect the olives.	Harvesting: Mechanical vibrators combined with a buggy with an umbrella to collect the olives.
	February			
	March	Herbicide treatments around trees (glyphosate and oxifluorfen in infested areas)		Herbicide treatments around trees (glyphosate and oxifluorfen in infested areas) Mowing of lane areas
	April	Mowing of lane areas	Herbicide treatments around trees (glyphosate and oxifluorfen in infested areas) Mowing of lane areas	
	May	Drip irrigation	Drip irrigation	Drip irrigation
	June	Drip irrigation	Drip irrigation	Drip irrigation
	July	Drip irrigation Herbicide treatments around trees (glyphosate and oxifluorfen in infested areas)	Drip irrigation	Drip irrigation Herbicide treatments around trees (glyphosate and oxifluorfen in infested areas)
	August	Drip irrigation	Drip irrigation Herbicide treatments around trees (glyphosate and oxifluorfen in infested areas)	Drip irrigation
	September	Drip irrigation	Drip irrigation	Drip irrigation
	October			
	November			
	December	Harvesting: Mechanical vibrators combined with a buggy with an umbrella to collect the olives.	Harvesting: Mechanical vibrators combined with a buggy with an umbrella to collect the olives.	
PG	January			
	February			
	March			
	April	4 tractor passes to mechanically clear the spontaneous grass cover.		
	May	Foliar fertilization (N, Mg & Fe)	4 tractor passes to mechanically clear the spontaneous grass cover Herbicide treatments around trees (glyphosate)	
	June			
	July			
	August			
	September			4 tractor passes to mechanically clear the spontaneous grass cover. Herbicide treatments around trees (glyphosate)
	October			
	November	Harvesting: Mechanical vibrators combined with a buggy with an umbrella	Harvesting: Mechanical vibrators combined with a buggy with an umbrella	Harvesting: Mechanical vibrators combined with a buggy with an umbrella

December	to collect the olives.	to collect the olives.	to collect the olives.

Table 3. Soil properties in two profiles of the catchments (PG= Puente Genil; CN= Conchuela)

Catchment	*Horizon*	*Width (cm)*	*Coarse elements (%)*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*Texture class*	*pH*	*OM (%)*
PG	A	10	22.7	59.5	35.2	5.3	Sandy-loam	8.8	1.59
	C	40	24.4	60.8	34.3	4.9	Sandy-loam	8.8	1.59
CN	A	0-56	0.36	5.9	45.1	49.0	Clay	8.6	0.96
	B	56-110	0.00	5.9	46.4	47.7	Clay	8.7	0.53
	BC	110-138	0.00	-	-	-	Clay-loam	-	-
	C	>138	0.00	-	-	-	Clay-loam	-	-

Table 4. Annual values of biodiversity indices: Richness (*R*), modified Shannon's (*Hmod*) and Pielou's indices (*Jmod*) and seasonal Sorensen's indices (*Is*); and meteorological attributes: average minimum temperature (*Tm*), annual evapotranspiration (*ETP*) and precipitation (*P*) for both catchments. (CV=coefficient of variation).

Index	Catchment/ Season	2011	2012	2013	Mean	St. Dev.	CV(%)
	CN	23	26	28	25.7	2.5	9.7
R	**PG**	24	14	24	20.7	5.8	28.0
	CN	2.194	1.947	1.826	1.989	0.187	9.4
Hmod	**PG**	1.880	1.213	1.751	1.614	0.354	21.9
	CN	0.897	0.839	0.850	0.862	0.031	3.6
Jmod	**PG**	0.840	0.834	0.817	0.830	0.012	1.4
	Winter	0.231	0.571	0.333	0.378	0.174	46.0
Is	**Spring**	0.231	0.100	0.087	0.139	0.080	57.6
	Summer	0.320	0.000	0.363	0.228	0.198	86.8
	Sutumn	0.166	0.333	0.000	0.166	0.167	100.6
	CN	11.7	11.6	11.1	11.5	0.3	2.6
Tm (ºC)	**PG**	12.4	11.6	11.7	11.9	0.4	3.4
	CN	1270.5	1310.2	1230.4	1270.4	39.9	3.1
ETP (mm)	**PG**	1383.7	1359.8	1355.1	1366.2	15.3	1.1
	CN	401	610	621.1	544	124	22.8
P (mm)	**PG**	376.8	434.4	423.8	411.7	30.7	7.5

Table 5. Species identified in the study catchments present in Puente Genil (PG), Conchuela (CN) or both catchments (Both) for the study period.

Species Scientific name	Biological Spectrum	Location
Dicotyledonous		
APIACEAE(UMBELLIFERAE)		
Daucus carota L.	Hemicryptophites	CN
ASTERACEAE(COMPOSITAE)		
Anacyclus clavatus (Desf.) Pers.	Therophytes	Both
Anthemis arvensis L.	Therophytes	Both
Calendula arvensis L.	Therophytes	CN
Centaurea melitensis L.	Therophytes	Both
Cirsium arvense (L.) Scop.	Geophytes	Both
Cichorium intybus L.	Hemicryptophites	CN
Conyza sumatrensis (Retz) E. Walker	Therophytes	PG
Chrysanthemum segetum L.	Therophytes	Both
Picris echoides L.	Hemicryptophites, Therophytes	Both
Senecio vulgaris L.	Therophytes	Both
Silybum marianum (L.) Gaerth	Hemicryptophites	CN
Sonchus asper (L.) Hill	Hemicryptophites, Therophytes	Both
Sonchus oleraceus L.	Hemicryptophites, Therophytes	Both
Taraxacum officinale Weber ex F.H. Wiss	Hemicryptophites	Both
Taraxacum obovatum (Willd) D.C	Hemicryptophites	PG
Pulicaria paludosa Link	Hemicryptophites, Therophytes	Both
BORAGINACEAE		
Anchusa azurea Mill	Hemicryptophites	PG
Echium plantagineum L.	Hemicryptophites, Therophytes	Both
Heliotropium europaeum L.	Therophytes	Both
BRASICACEAE(CRUCIFERAE)		
Diplotaxis virgata (Cav) DC	Therophytes	PG
Raphanus raphanistrum L.	Geophytes, Therophytes	Both
Rapistrum rugosum(L.) Bergeret	Therophytes	Both
Sinapis arvensis L.	Therophytes	CN
CARYOPHYLLACEAE		
Spergula arvensis L.	Therophytes	PG
Stellaria media (L.) Vill	Therophytes	Both
CISTACEAE		
Fumana ericoides (cav) Gand. In Magnier	Chamaephytes	PG
CONVOLVULACEAE		
Convolvulus arvensis L.	Geophytes, Hemicryptophites	CN
CRASSULACEAE		
Umbilicus rupestris (Salisb.) Dandy	Hemicryptophites	PG
CUCURBITACEAE		
Ecballium elaterium	Hemicryptophites	CN

FABACEAE(LEGUMINOSAE)		
Ononis punescens L.	Therophytes	PG
Trifolium repens L.	Hemicryptophites	CN
Trifolium campestre Screb.	Therophytes	CN
GERANIACEAE		
Erodium cicutarium (L.) L´Her	Therophytes	Both
Erodium moschatum (L.) L´Her	Therophytes	CN
Erodium malacoides (L.) L´Her	Therophytes, Hemicryptophites	PG
Geranium molle L.	Therophytes	CN
LAMIACEAE		
Lamium amplexicaule L.	Therophytes	Both
MALVACEAE		
Malva sylvestris L.	Hemicryptophites	Both
PAPAVERACEAE		
Fumaria officinalis L.	Therophytes	CN
POLYGONACEAE		
Polygonum aviculare L.	Therophytes	PG
PRIMULACEAE		
Anagallis arvensis L.	Therophytes	Both
RANUNCULACEAE		
Ranunculus arvensis L.	Therophytes	Both
RUBIACEAE		
Galium aparine L.	Therophytes	Both
SCROPHULARIACEAE		
Veronica arvensis L.	Therophytes	PG
Veronica heredifolia L.	Therophytes	PG
URTICACEAE		
Urtica urens L.	Therophytes	PG
Monocotyledonous		
LILIACEAE		
Muscari comosum (L.) Miller	Geophytes	PG
POACEAE		
Bromus hordaceus L.	Therophytes	CN
Bromus madritensis L.	Therophytes	CN
Bromus squarrosus L.	Therophytes	CN
Hordeum murimum L.	Therophytes	CN
Hordeum leporinum (Link)	Therophytes	CN
Lolium rigidum Gaudin	Therophytes	CN
Poa annua L.	Therophytes	CN

Table 6. Matrix of correlation between diversity indices (seasonal values) and climatological features: *Hmod* = Shannon´s modified index; *Jmod* = Pielou´s modified index; *R* = richness; *P* = cumulative precipitation; *Tm*= average of minimum daily temperatures; *ETP* = cumulative evapotranspiration. Numbers indicate the interval of previous days (5, 15, 30 and 60).

		P5	*P15*	*P30*	*P60*	*Tm5*	*Tm15*	*Tm30*	*Tm60*	*ETP5*	*ETP15*	*ETP30*	*ETP60*
CN	*Hmod*	0.12	0.33	0.40	0.39	-0.28	-0.26	-0.25	-0.31	-0.35	-0.36	-0.42	-0.43
	Jmod	-0.19	-0.25	-0.20	-0.10	0.55	0.52	0.41	0.17	0.29	0.54	0.55	0.44
	R	0.35	0.52	0.49	0.45	-0.16	-0.17	-0.20	-0.29	-0.25	-0.32	-0.36	-0.37
PG	*Hmod*	0.23	0.29	0.11	0.39	-0.12	-0.05	-0.42	**-0.64**	-0.27	**-0.58**	-0.39	**-0.58**
	Jmod	-0.19	-0.29	-0.42	-0.18	0.40	**0.60**	0.29	-0.01	**0.61**	0.26	0.51	0.36
	R	0.29	0.38	0.16	0.36	-0.22	-0.09	-0.42	**-0.61**	-0.35	**-0.62**	-0.46	**-0.61**

N=12 – Bold indicates correlations are significant at $p < 0.05$

Table 7**.** Means and standard deviations of the annual biodiversity indicators and parameters of soil quality: *Hmod* = Shannon´s modified index; *Jmod* = Pielou´s modified index; *R* = richness; *OM*= organic matter content in upper horizon (0-10 cm); *BD*= bulk density of upper horizon (0-10 cm); *SL* = annual soil loss; *Rc* = runoff coefficient (ratio of the annual values of precipitation and runoff).

Catchment	Stat.	*R*	*Jmod*	*Hmod*	*OM** (%)	*BD*** ($g.cm^{-3}$)	*SL+* ($t.ha^{-1}$)	*Rc+* (%)
CN	Mean	25.7	0.86	1.99	1.25	1.57	16.1	15.3
	St. Dev.	2.5	0.03	0.19	0.37	0.19	20.8	12.7
PG	Mean	20.7	0.83	1.61	1.48	1.50	1.8	5.1
	St. Dev.	5.8	0.01	0.35	0.53	0.25	2.3	4.2

(*) T-test showed p=0.00054 (See also Fig. 4a)
(**) T-test showed p=0.07764 (See also Fig. 4b)
(+) See Figures 3c-d, T-test was not carried out because the number of samples was very low. CN(n=5 years), PG (n=6 years)

FIGURES

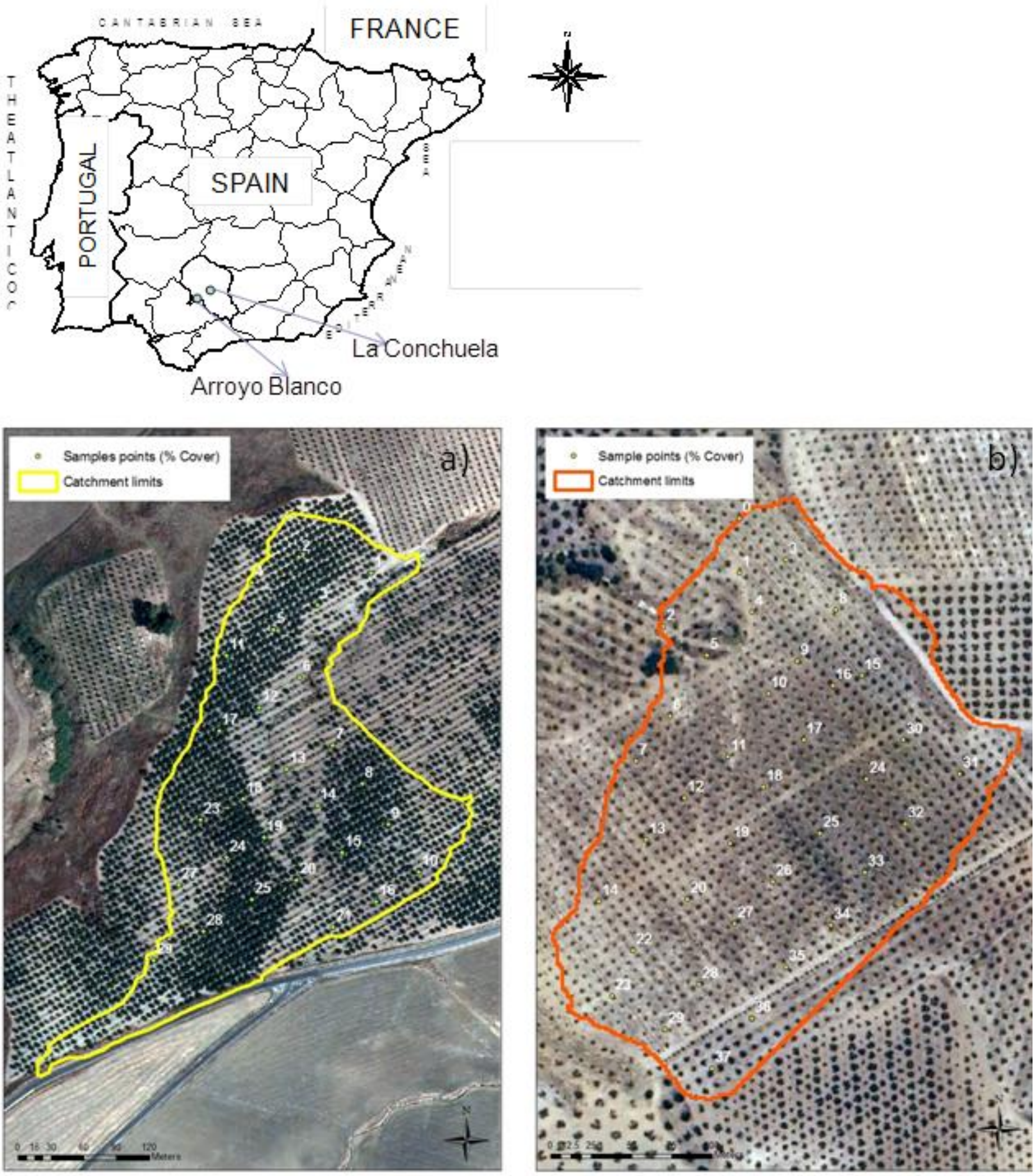

Figure 1. Locations of the study catchments and sample grids: a) La Conchuela (CN); b) Puente Genil (PG).

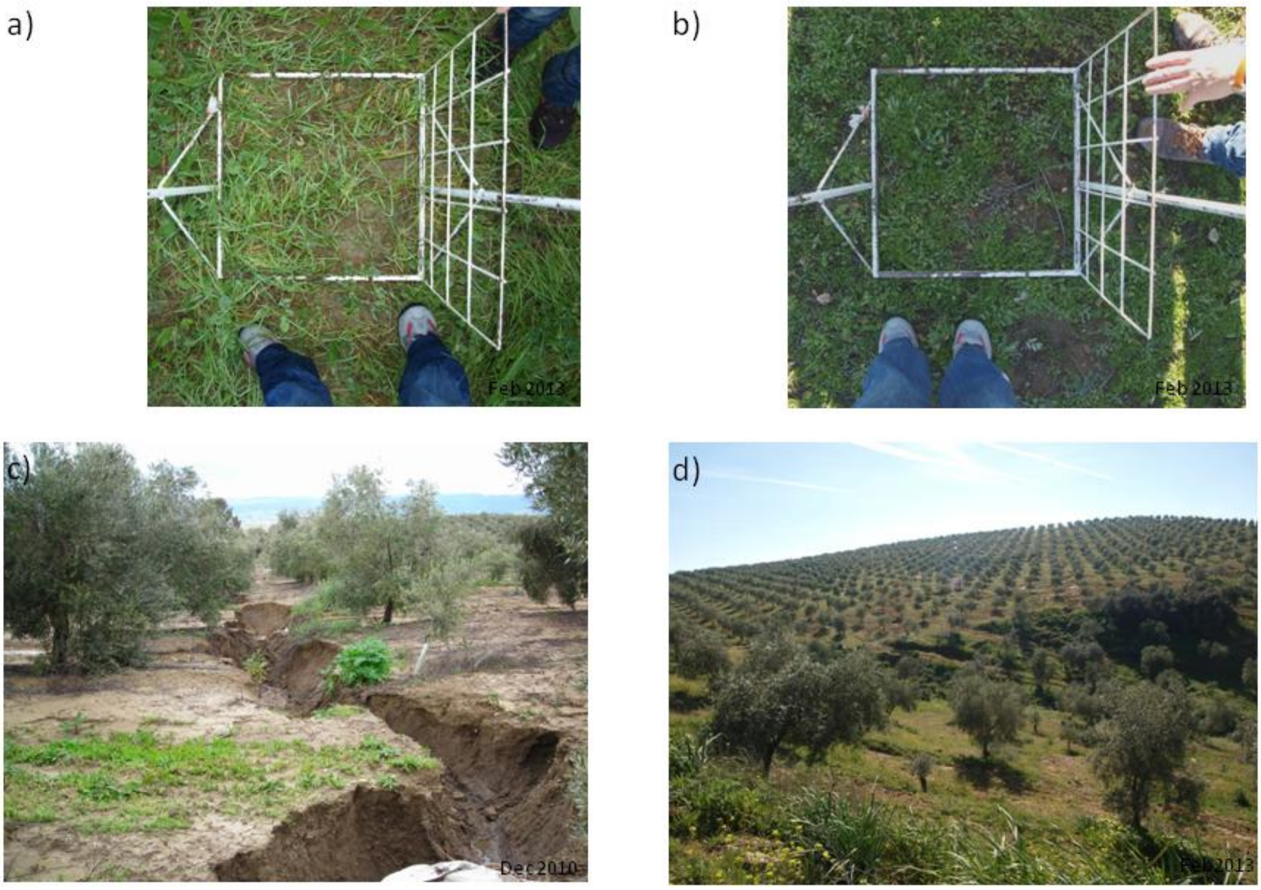

Figure 2. Examples of grass spontaneous cover sample plots and view of the catchments: a) a plot in La Conchuela; b) a plot in Puente Genil; c) gully with cover crop; d) view of a hillslope in PG.

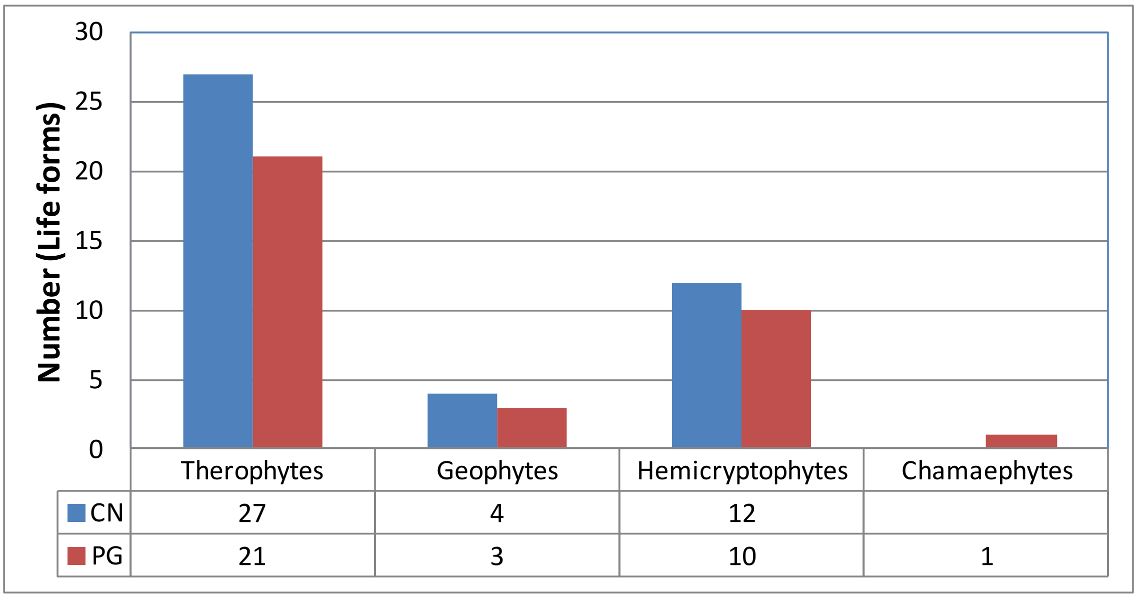

Figure 3. Distribution of life forms (biological spectrum) in the study catchments (CN= La Conchuela; PG= Puente Genil).

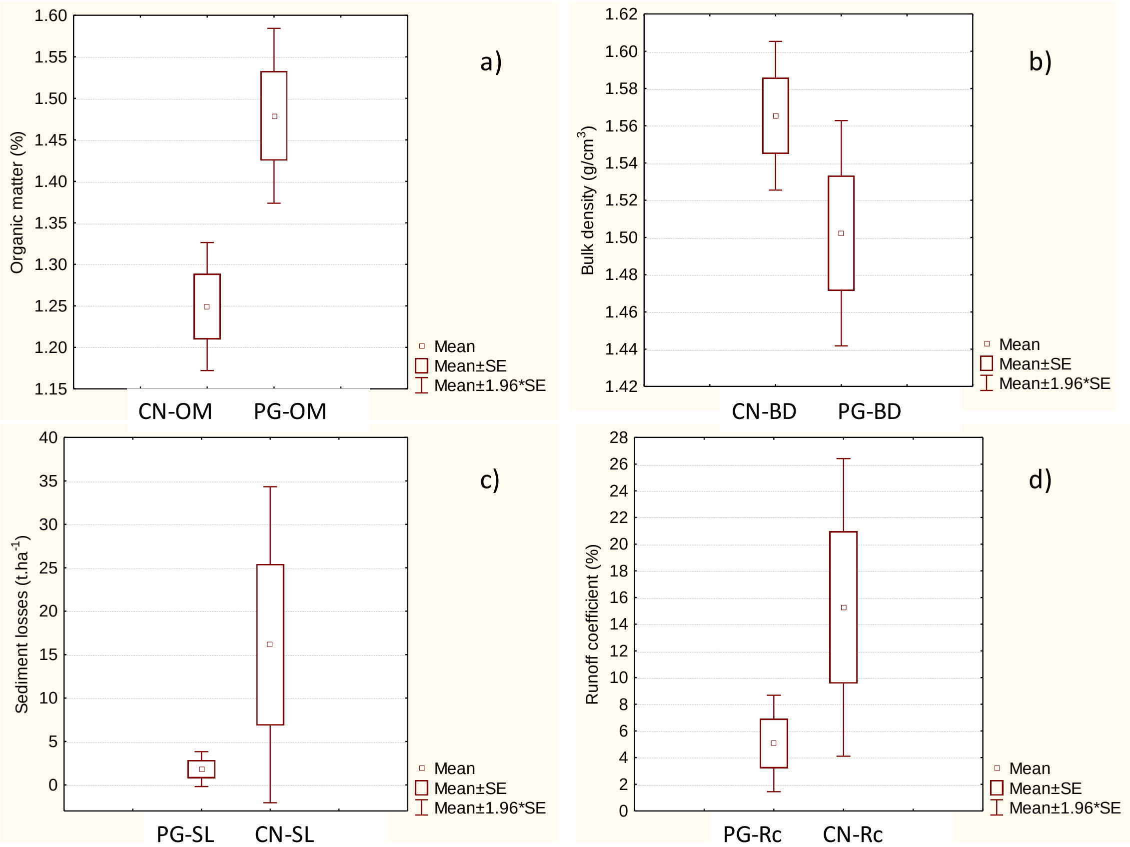

Figure 4. Box and whisker plots of the measurements of soil degradation indicators: (a) organic matter content in the upper horizon (b) bulk density in the upper horizon; (c) annual soil losses in the catchment outlets; (d) annual runoff coefficients (PG= Puente Genil; CN=La Conchuela; SE= Standard error).