ANSWERS TO REFEREE 1

GENERAL COMMENTS:

Q1. This study compares vegetation biodiversity metrics, soil degradation variables, and environmental factors for two olive orchard catchments in Spain with differing environmental characteristics and vegetation management regimes. The study is innovative and multidisciplinary by evaluating biodiversity metrics relative to environmental conditions and management practices. The primary goal was to evaluate the potential for biodiversity metrics for spontaneous grass cover to serve as indicators of soil degradation. A second goal was to determine whether biodiversity differences between the two sites could be accounted for primarily by differences in site characteristics or by differences in vegetation management regimes. The study found that the site with the greater biodiversity was the site with greater soil loss and lower soil organic content. Thus, the authors concluded that biodiversity metrics have little utility as an indicator of soil degradation. The study also concludes that the differences in biodiversity metrics between the two sites were likely associated with differences in site conditions rather than with differences in tillage practices.

Unfortunately, the study was not designed to test the hypotheses. That is, there is no way of statistically testing an association between two variables (e.g., a diversity metric vs. a soil degradation metric) with only two sites. Likewise, there is no way to determine whether a difference in biodiversity between the two sites is associated with site conditions or with tillage practices because the two sites differed in both respects. Moreover, it's not clear that the soil loss data, which came from another study, covered the same years as the biodiversity data. Thus, the author's conclusion that biodiversity metrics "were not found to be suitable for describing soil degradation" is at best a "suggestion" this is the case. Had the authors evaluated 20 sites instead of two, the conclusion might be different. Moreover, it's possible that biodiversity metrics are indeed related to degradation metrics, but not for systems that have already developed gullies and rills such as at the CN site.

A1. We agree with the reviewer that the increase of the number of study sites would obviously improve the conclusions; however, there is clear evidence -supported by measurements taken over three years - that the biodiversity indices linked to the spontaneous grass cover in the catchment with the most intense management and the best site conditions for vegetation were the highest. In the study case, the biodiversity indices were unsuitable for describing soil quality or at least, it is worth noting the lack of correlation. This has also been described by other authors on other crops or land uses, who have pointed out that rills and gullies can contribute to the biodiversity of weeds through an active dissemination of seeds (see the Discussion).

Q2. The assertion that biodiversity differences between the two sites are better explained by differences in site conditions, and not tillage practices, is further unsupported because there is no discussion of how the authors reached this conclusion. They do not describe how one would be able to differentiate between site effects versus tillage effects, and they do not discuss the possibility that tillage practices were the cause of biodiversity differences. They simply make assertions that the differences are due to site conditions,

A2. We do not agree with the reviewer. In Chapter 2.1. and Table 1, the notable differences in the environment and management can be found. It is crucial to stress when illustrating the differences that the annual mean yield in CN is 8000 kg.ha^{-1}.year^{-1} whereas in PG it is only 1300 kg.ha^{-1}.year^{-1}. In addition, we discuss the different environmental features in Chapter 3.1, while in the General Discussion, we try to explain why in CN, a richer distribution of seeds was observed.

"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".

"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".

Q3. Despite the above shortcomings, I think there is value in the data obtained in the study. Detailed studies of agroecosystems are scarce relative to the immense array of systems that exist. Moreover, such studies can be difficult to undertake such that the number of sites that can be studied may be quite limited. Thus, I think the data obtained in the present study warrant publication, but the paper would need to be recast to be more of a comparative case study and less of a hypothesis-testing study. In any event, the conclusions would need to be tempered given the small sample size.

A3. Thank you very much - we have changed our conclusions following your comment.

"Therefore, biodiversity indicators associated to spontaneous grass cover were not appropriate to describe the soil situation in the study areas. More effort to increase the number of study sites should be applied to evaluate if under more similar environmental conditions, the weight of the management in the olive orchards might determine the biodiversity indices of grass spontaneous cover".

Specific Comments

Q4. The hypotheses and objectives (Lines 86-94) are confusing and inadequately developed. What is meant by "starting hypothesis" relative to a real one? Also, "wider ecological niches" is unclear, and there is no linkage made between this term and the biodiversity metrics selected. Regarding the second hypothesis about interactions of soil and management better explaining diversity differences than environmental site conditions (Lines 88-89), there is no explanation of how one would make this distinction. For clarification of objective 1, I think you mean "biodiversity indices for spontaneous grass cover". For 2, "as a result of" should be "relative to". Also, it is unclear what "soil management" refers to. For 3, this could be better stated as "to evaluate the relevance of biodiversity indices as indicators for …."

A4. We have clarified the points indicated by the reviewer.

"The main hypothesis of this study was that richer ecological niches mean lower risks of soil degradation in terms of indicators such as organic matter decline, bulk density and runoff coefficients and soil losses. This would be associated to an optimum space taking derived from the presence of distinct species. 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) due to minor soil disturbances which might produce conditions which bring it closer to natural systems".

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

Q5. The choice of diversity metrics seems reasonable, but it is not apparent why the authors restricted their analysis to site-level metrics and did not include any plot-level metrics. The data were collected at the plot level so it would have been easy to at least

calculate species richness for each plot. Comparing metrics at the plot scale would provide a rigorous test of whether the metrics at this scale differed between the two sites, whereas for the metrics calculated at the site scale in the study, differences between the sites cannot be statistically tested because the sample size is only 3 (i.e., 3 years).
A5. We tried this but the differences between the plots are too low. The number of species in each plot varies between 0- 3 or 4 species, and so the statistics mean, medians and coefficient of variation are very close and cannot be used to determine differences.

Q6. The terminology and metrics of interest for soil are confusing. The title addresses "soil degradation", yet the text sometimes refers to "soil quality" and once to "soil situation." In one place the text states the metrics of soil degradation of interest are soil loss, soil organic content, and runoff, but in other places it refers just to soil loss or soil loss and organic matter. It is also confusing when the text refers to "soil loss and soil degradation" (e.g., Lines 70, 94), implying that soil loss is something different from soil degradation. When the text compares biodiversity metrics versus soil metrics, it doesn't present all the soil degradation metrics at one time, so it is confusing to the reader whether the differences in biodiversity metrics between the sites are in the same direction as the several soil degradation metrics or not.
A6. The term "soil situation" has been replaced by "soil degradation state" following your suggestion. We have clarified the hypothesis to show that the degradation metrics are organic matter decline, bulk density and runoff coefficients and soil losses (See Chapter 1 and A4).
Soil loss is a type of soil degradation. Following your advice, we have kept "soil degradation" in Lines 70-71 and 96.

Q7. The Results section is full of inferences and comparisons to other studies. The Results section should just contain findings of the study. Perhaps the journal would allow a combined "Results and Discussion" section followed by a "General Discussion" section, in which case the problem could be resolved by simply renaming the section headings.
A7. We have changed the titles following your advice.

Q8. There is quite a bit of unclear text and awkward writing and grammar. I have attempted to improve some of this below.
A8. All the versions of this manuscript as well as the Revision Notes were reviewed by an English language expert.

Specific Comments by Line Number

Q9. Line 15. Specify country or institution behind Common Agricultural Policy.
A9. We have added (European Commission) to clarify the term.

Q10. Lines 15-16. Unclear what is meant by environmental quality of such covers.
A10. We have modified the sentence to clarify the meaning.
"However, to date there are few studies assessing the environmental quality considering such covers"

Q11. Lines 16-18. Confusing. Consider "we measured biodiversity indices for spontaneous grass cover in two olive orchards with contrasting site conditions and management regimes in order to evaluate the potential for biodiversity metrics to serve as an indicator of soil degradation."
A11. Thank you, we have included the proposed sentence.

Q12. Line 17. Unclear what “biodiversity patterns” refers to.
A12. We have clarified the sentence, we have substituted “biodiversity pattern” for “the differences and temporal variability of biodiversity indicators”.

Q13. Line 23, and elsewhere. “Pictures” should be “photographs”.
A13. We have included this change.

Q14. Line 24. “frequency” of what? Unclear what “diversity” refers to. The topic of the paragraph is biodiversity indices. “Transformed” should be “modified”, as described in text.
A14. We referred to distribution (absolute frequency) of life forms (biological spectrum) in the study catchments (Fig.3). “Diversity” is associated with the present species showed in Table 5. Following your suggestion, we have included the term “modified”.

Q15. Line 26: Consider: “Sorensen’s index showed strong differences in species composition for the grass covers in the two olive orchard catchments.”
A15. We have changed the sentence following your suggestion.

Q16. Line 27: What is the rationale for asserting that the differences in species composition were due to site conditions rather than management regimes? The previous paragraph stated the difference between the two catchments was in tillage practice, not site conditions.
A16. The explanation is shown in the following paragraph (deeper soil and more precipitation). In addition, in Line 17, we mentioned “two contrasting olive orchards", whereas in Line 19, we stated that we studied the influence on environmental factors (see the abstract).

Q17. Lines 27-29. An important point implied here is that the site with higher biodiversity indices had greater soil loss. This does not become apparent, however, until the value for soil loss is provided for the other site several Lines below. The statement should be revised to make clear which site had the higher soil loss. There should be a clear statement relating biodiversity difference between the two sites with the difference in the two soil degradation metrics between the two sites in one sentence so the mismatch is clear and not spread among a lot of other text.
A17. We have modified the sentence to clarify the content.

“The catchment (CN) with the best site conditions (deeper soil and higher precipitation) and most intense management practices presented the highest biodiversity indices as well as the highest soil losses (over 10 $t.ha^{-1}$).”

Q18. Lines 29-30. Regarding “were reasonably high”, text needs to make clear what this is in comparison to.
A18. We have added the term “for agricultural systems” in order to improve the readability.

Q19. Line 32. Define “worse site conditions”.
A19. We have added “in term of water deficit” to clarify the sentence.

Q20. Line 33. “biodiversity indicators” should be “biodiversity indices”. None of the indices were shown to “indicate” anything.
A20. We have changed this.

Q21. Line 33-34. This sentence indicates this inference is a firm conclusion of the study, whereas this was certainly not a firm conclusion. The study compared only two sites, so

at best the findings "suggest" that biodiversity indices "were not found to be suitable…." (see General Comments)
A21. We agree with this, and have modified the conclusions accordingly (see A1). However, in the abstract, we mentioned that the indices were not suitable "in the study catchments".

Q22. Line 34. The "soil degradation" metrics included in the study need to be specified (see comments above)
A22. We meant all the biodiversity indices cited in the previous paragraph. We have added "considered in this study" to clarify this point.

Q23. Line 38. "sedimentation problems" is vague.
A23. We have added sedimentation "in flood plains and reservoirs".

Q24. Line 43. Specify what program/country "Multi-annual Financial Framework" belongs to.
A24. We have added this Cross-compliance information. Agriculture and Rural Development.

Q25. Line 50. "Different" should be "multiple."
A25. We have changed this.

Q26. Lines 54-56. Reference needed.
A26. We have included the following reference (Gómez et al. 2014a)

José A. Gómez, Juan Infante-Amate, Manuel González de Molina, Tom Vanwalleghem, Encarnación V. Taguas, Ignacio Lorite. 2014. Review: Olive Cultivation, its Impact on Soil Erosion and its Progression into Yield Impacts in Southern Spain in the Past as a Key to a Future of Increasing Climate Uncertainty. Agriculture 2014a, 4(2), 170-198.

Q27. Lines 64-66. Unclear statement. "landscape improvement" unclear. "etc" should be deleted.
A27.We have removed "etc" and we have clarified that we meant "aesthetic improvement of the landscape".

Q28. Lines 67-84. This paragraph is confusing. The topic starts with spontaneous grass covers, then indicators of soil loss and degradation, then biodiversity, then implementation of protection policies. Paragraph should be revised to make the main point first (topic sentence) and follow this with explanatory material.
We have changed the structure and the content of the paragraph in order to improve the readability.

"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 degradation has scarcely been explored.
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 indicate the risk of soil degradation, given that richer and more complex ecological niches might produce more vegetal biomass, efficient cover and eventually, soil protection, as well as habitat and food opportunities for other elements of the trophic chain, such as birds or reptiles. In addition, one key drawback for the proper implementation of environmental protection policies is the lack of a well-defined quantitative measure or indicator of biodiversity which was suitable to describe, compare or measure possible changes (Büchs, 2003; Spangenberg, 2007; Moonen and Barberi, 2008). The use of biological indices –in this case associated to grass spontaneous cover- might be helpful because they are more sensitive to changes than chemical and physical soil indicators and because they could give a broader picture of soil quality (Bastida et al, 2008)."

Q29. Line 73. "protection" of what?
A29. We have included environmental protection policies to clarify the sentence.

Q30. Line 81. paper is exploring use of biodiversity metrics to reflect (indicate) soil degradation, not "measure" soil degradation as written here.
We have substituted the term "measure" by "indicate" following the reviewer´s advice.

Q31. Line 82. Unclear what "richer and more complex ecological niches" means. Also unclear is "efficient cover and soil protection."
We have improve the sentence.

"…given that richer and more complex ecological niches might produce more vegetal biomass, efficient cover and eventually, soil protection, as well as habitat and food opportunities for other elements of the trophic chain, such as birds or reptiles".

Q32. Lines 86-90. See comments above
A32. See A4

Q33. Line 100. "were considered" by whom?
A33. We referred to the studies by Gómez et al. (2014b) and Taguas et al. (2013). We have completed the sentence in order to clarify this point.

Gómez, J.A., Vanwalleghem, T., De Hoces, A., Taguas, E.V. 2014. Hydrological and erosive response of a small catchment under olive cultivation in a vertic soil during a five-year period: Implications for sustainability. Agriculture, Ecosystems and Environment 188: 229–244, 2014b.

Taguas, E.V., Ayuso, J.L., Pérez, R., Giráldez, J.V. and Gómez J.A: Intra and inter-annual variability of runoff and sediment yield of an olive micro-catchment with soil protection by natural ground cover in Southern Spain. Geoderma, 206, 49-62, 2013.

Q34. Lines 102 – 135. It is unclear what the source is for the information provided about the two study sites. Citations should be provided.
A34. The sources are the same as for A33. We have included the references in the text (See Chapter 2.1.)

Q35. Lines 145-150. "pictures" should be "photographs." Unclear what "to check"means.
A35. We have changed the terms "pictures" and "check" to "photograph" and "observe".

Q36. Lines 152-153. "absolute and relative frequency of occurrence": I don't recall these data do not appear in the manuscript.
A36. Please see Figure 3, where the absolute frequency of life forms is presented and compared.

Q37. Lines 154. "species" refers to grasses and forbs?
A37. Yes, we have added these terms to improve the readability.

Q38. Line 158. "both samples" should be "the two samples"
A38. We have changed the words following your suggestion.

Q39. Line 163. H does not represent probability. Probability would be between 0 and 1 only.
A39. We have improved the definition.

"Shannon's index, *H*, (Eq. 2; Shannon and Weaver, 1949) represents the uncertainty associated to the prediction of species identity of an individual taken from a sample".

40. Line 165. "unclear "to a limited group…species"
A40. We mean "small" group. We have changed this word.

Q41. Line 167. H is also increased by number of species, not just evenness of species.
A41. We agree with the reviewer. However, we consider our explanation suitable because if the total abundance of species is concentrated on one type, and the other species are very rare (even if there are many of them), Shannon´s index approaches zero.

Q42. Line 172. Unclear what "based on the evaluation of pictures" means.
A42. It was explained in the following sentence. We have added "presented each grid point of those considered in the catchment sample (see Fig. 1 and 2)" to clarify the content.

Q43. Lines 173-175. Unclear what "suitability" refers to and what "verified" means? Also, it's confusing that Jmod is addressed here but is not defined until below.
A43. Please see A42: we changed the number of species for the number of grid points where a species was present as well as total number of individuals by the total number of grid points considered. The suitability of these changes was verified with the samples taken in spring 2013 in both catchments. We have removed Jmod from the paragraph.

Q44. Line 177. Change "which would describe" to "with 1 describing"
A44. We have made this change.

Q45. Line 182. Revise second sentence to "Jmod is obtained by substituting Hmod for H (Equ.3)."
A45. We have made this change.

Q46. Line 192. Who runs gauging stations?
A46. The reference is shown at the end of the paragraph (CSIC, 2014).
CSIC, Estaciones Agrometeorológicas del Instituto de Agricultura Sostenible. http://www.uco.es/grupos/meteo/. Accessed in November 2014.

Q47. Line 199. Focus of study is on soil degradation, not soil quality.
A47. We agree with you. However, these variables are also considered indicators of soil quality by different authors (Bastida et al., 2008), so we would like to keep the sentence.

Q48. Line 199-200. Give years. It's important to know whether these 5 years overlapped the 3 years of the present study.
A48. This information was shown in the first paragraph of Chapter 2.1., so we do not consider it necessary to repeat it.

Q49. Line 215. Unclear what "checked for the weighted values" means.
A49. The analysis was carried out with the mean values of the variables P, ETP and Tm corresponding to the 5, 15, 30, 60, 365 days previous to the sample date. We have clarified this in the text.

Q50. Lines 216-217. Sample size should be provided here or in figures.
A50. This information is presented in Chapter 2.3.3., where the details of samples of soil properties are explained**.**

Q51. Lines 224-227. The basis for these inferences is not clear. An objective of the paper was to differentiate between site effects and tillage effects, yet the latter possibility is not even mentioned here. Also, "water deficit" is not represented in Table 4.
A51. We agree with the reviewer that our study has some constraints derived from the scale and the number of microcatchments, but our findings are based on the environmental features measured in the catchments (see Chapter 2.1. and Tables 1) and the knowledge of management operations in the catchment (Table 2). Therefore, we consider our inference to be clear. On the other hand, water deficit

might be obtained from the ETP/P relationship. Both variables were shown in Table 4, so we do not consider it appropriate to include this factor here.

Q52. Line 232. It doesn't seem noteworthy to claim a difference between the sites in coefficient of variation. There were only 3 variables, so the fact that two were higher in one site does not represent a pattern.
A52. We agree with the reviewer. However, we did not describe any pattern, only the values of Table 4. We have added the term "Table 4" in order to clarify the information.

Q53. Line 233. "notably high". What is the basis for this assertion? References should be provided.
A53. As references, Guzmán and Forester (2007) observed for olive orchards with leguminous cover crops H-values close to 1.2, whereas in natural systems of Mediterranean semi-arid areas, H-values were approximately equal to 1 (Kawada et al.,2012). Under conventional cereal crops, Armengot et al. (2013) quantified a mean H-value of 1.5 for 11 fields in Catalonia (Spain), while for a pine afforestation located in a semi-arid catchment in Southwestern Spain, Bonet et al. (2004) came up with H-values of 2.8. These references were included.

Q54. Line 235. State how Jmod indicates no dominant species, i.e., values were generally much closer to 1 than to 0.
A54. We have included this comment**.**

Q55. Line 236. "These features". Which features?
A55. We referred "the lack of a dominant species". We have included the complete term.

Q56. Lines 236-238. Statement needs a reference. Also, "wide range of colonizing species" is unclear, as is "without any clear dominant pattern."
We agree with the reviewer that the sentence was not appropriate. We have modified the statement to clarify its content.

"The lack of a dominant species is frequent in Mediterranean agricultural areas, where a high inter-annual and intra-annual variability of precipitation and temperature produce a wide range of colonizing species awaiting their optimal development conditions".

Q57. Line 242. State how values show this, i.e., values were generally much closer to 0 than to 1.
A57. We have clarified the sentence.

Q58. Line 243-244. Drop "It is worth noting how". Give the mean values for winter and spring.
A58. We have included the values following your suggestion.

Q59. Lines 244-245. Unclear.
A59. We have improved the sentence to indicate the similarity of the life forms in the catchments, despite the fact that different species were found.

"Although similar distributions of life forms were found (Fig. 3), a different catalogue of species was observed in both catchments, where the lack of Monocotyledonous in PG is remarkable (Table 5)."

Q60. Lines 252-255. Unclear how such firm conclusions (e.g., "as a result of") are reached here with a sample size of 2 sites.
A60. I am afraid we do not understand this comment because the results of Table 6 are described simply.

On the other hand, it should be considered that we have compared the data of 12 samples (4 seasonal samples per year) with the weather variables for each site

Q61. Line 264. BD was NOT significant. Table shows p = 0.077
A61. We agree with the reviewer and we have modified the comment to clarify this aspect.

"The differences in OM between the catchments were significant as is shown in Table 7 and Fig. 4a (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), although they were not significant (Table 7 and Fig. 4b; BD-CN= 1.57 $g.cm^{-3}$ and BD-PG=1.50 $g.cm^{-3}$)".

Q62. Lines 266-268. Much emphasis is given to the differences between sites in soil loss and runoff, yet the differences do not appear to be significant.
A62. The significance test was not carried out because the sample size was very low (n=5 in CN and n=6 in PG). However, the differences can be clearly appreciated in Figure 4c) and 4d).

Q63. Line 271. Why is runoff not listed? It was one of the soil degradation metrics.
A63. We included the runoff coefficient because it provides more information than the runoff only. In addition, the mean annual precipitation is shown in Table 1, and so we do not consider necessary.

Q64. Lines 273-274: The meaning of the following terms is unclear and it's also unclear how they were represented in the study: "wider ecological niche", "efficient occupation of space" and "efficiency in the flow control"
A64. We have changed the paragraph in order to clarify its content.

"The role of cover crops in soil erosion is related with the dissipation of energy from rainfall and runoff and with the increase of infiltration, which reduces the sediment transport. It was expected that a wider ecological niche would allow for a more efficient occupation of space with probably more biomass, as well as a higher efficiency in the runoff control on the hillslopes".

Q65. Line 277-278. "impinge the spontaneous grass cover seedbank growth" is awkward.
A65. We have clarified the sentence.
"Lewis et al. (2013) highlighted the potential for soil erosion to disseminate the spontaneous grass cover seedbank and to improve the biodiversity indicators in agro-ecosystems of Northern Europe".

Q66. Line 280-284. I do not understand, possibly because I am not a soil scientist.
A66. The objective is to illustrate that higher erosion rates can indicate more efficient seed dissemination. The sediment delivery ratio gives information about the redistribution of sediment in the catchments. According to the bibliography, in PG, the mean annual value of sediment redistribution is close to 96% (Taguas et al., 2011) whereas in CN, it is equal to 10% (Burguet, 2015).

Q67. Line 291. Seems like "as used at CN" should be added to end of sentence after "orchards."
A67. This was not exactly applied in CN (see Table 2).

Q68. Lines 301-302. But text indicated CN had the more extensive management than PG.
A68. The most extensive management corresponds with PG. We have included a small clarification in Table 2.

Q69. Line 310. Number of species is a metric of biodiversity so it is unclear what is meant by "number of …. species and biodiversity".
A69. We agree with the reviewer - we have removed "and biodiversity".

Q70. Line 312-314. Confusing sentence. The assertion for why there were not monocotyledons at CN needs to be made. “measures” seems like incorrect word. What “management” action is referred to?
A70. Some herbicides select monocotyledonous plants. However, there is no apparent dominance of species despite its continuous use. We have modified the sentence to clarify its content.

“Although single steps, such as the application of fertilizers or certain herbicides, may lead to the dominance of some species such as in the case of monocotyledoneous in CN (Table 5), 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”.

Q71. Line 320-322. Specify what “it” refers to. Provide reference.
A71. We referred to the “yield”. We have corrected the sentence.

Q72. Lines 327-329. What does “this case” refer to? “complete the information” is unclear. “allow us to confirm…..CN” is unclear.
A72. We have modified the text.

“Additionally to the yield, *R, Hmod, Jmod* and *Is*, the group of species shown in Table 5 supports short-term environmental advantages of the vegetation growth found in CN, which is likely to be linked to greater water availability despite a more intense management”.

Q73. Line 338. Specify site you are referring to.
A73. We meant CN. Our apologies.

Q74. Line 340. “high” relative to what?
A74. We have clarified that we meant Shannon´s index and Pielou´s index (see also A53).

Q75. Line 352. Focus of study was on soil degradation, not “soil situation” which is vague.
A75. We have clarified the sentence. See also A3.

Q76. Table 1. Arroyo Blanco is not the site name used in the text. Provide site abbreviations (CN, PG).
A76. We have included the abbreviations.

Q77. Table 3. Define OM
A77. We have clarified that OM is the organic matter content.

Q78. Table 7. Specify sample size.
A78. We have done this.

Q79. Figure 1. Lettering has poor resolution, and scale is unreadable. Arroyo Blanco label does not correspond to site name used in text or in figure legend.
A79. We have included an image with a better resolution and we have clarified the legend.

Q80. Fig. 2. Identify which site is shown in c.
A80. The information was included. The picture was taken in CN.

Q81. Fig. 3. Legend: "Number of species by life form ….."
A81. We have made this change.

Q82. Figure 4. Specify sample size for each variable. State which data came from another study and give reference. Mean +- 1.96 SE is not really appropriate given the same size was so small. It would be more meaningful to use the appropriate t value (mean +- t*SE). State which data came from another study and give reference.
A82. We have included the information required. However for BD and OM, the sample sizes were 65 in PG and 95 in CN, and so t=1.96 is suitable. In the case of *rc* and soil loss, it is debatable, but we would like to keep the uniformity in the presentation and not to change the graphs.

I hope these comments will be useful to the authors.
Thank you so much for your rigorous review and your helpful comments.

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

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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- European Commission). However, to date there are few studies assessing the environmental quality considering such covers. In this study, we measured biodiversity indices for spontaneous grass cover in two olive orchards with contrasting site conditions and management regimes in order to evaluate the potential for biodiversity metrics to serve as an indicator of soil degradation. In addition, the differences and temporal variability of biodiversity indicators 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 photographs in a permanent grid (4 samples/ha) were taken to characterize the temporal variations of the number of species, frequency of life forms, diversity and modified Shannon's and Pielou's indices.

Sorensen's index showed strong differences in species composition for the grass covers in the two olive orchard catchments probably linked with the different site conditions. The catchment (CN) with the best site conditions (deeper soil and higher precipitation) and most intense management presented the highest biodiversity indices as well as the highest soil losses (over 10 $t.ha^{-1}$). In absolute terms, the diversity indices of vegetation were reasonably high for agricultural systems in both catchments, despite the fact that management activities usually severely limit 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 in terms of water deficit, average annual soil losses of 2 $t{\cdot}ha^{-1}$ and the least intense management. Therefore, the biodiversity indices considered in this study to evaluate 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 in flood plains and reservoirs, 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 (Cross-compliance. Agriculture and Rural Development; 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 multiple authors such as Goméz-Limón et al., (2009) and Gómez et al., (2014a) 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 (Gómez et al., 2014a). 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 the aesthetic improvement of the landscape 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 degradation has scarcely been explored.

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 indicate the risk of soil degradation, given that richer and more complex ecological niches might produce more vegetal biomass, efficient cover and eventually, soil protection, as well as habitat and food opportunities for other elements of the trophic chain, such as birds or reptiles. In addition, one key drawback for the proper implementation of environmental protection policies is the lack of a well-defined quantitative measure or indicator of biodiversity which was suitable to describe, compare or measure possible changes (Büchs, 2003; Spangenberg, 2007; Moonen and Barberi, 2008). The use of biological indices –in this case associated to grass spontaneous cover- might be helpful because they are more sensitive to changes than chemical and because physical soil indicators and that they could give a broader picture of soil quality (Bastida et al, 2008).

The main hypothesis of this study was that richer ecological niches mean lower risks of soil degradation in terms of indicators such as organic matter decline, bulk density and runoff coefficients and soil losses. This would be associated to an optimum space taking derived from the presence of distinct species. 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) due to minor soil disturbances which might produce conditions which bring it closer to natural systems.

The specific objectives of this work were 1) to describe and compare the biodiversity indices for spontaneous grass covers in two olive orchards with contrasting management intensities, environmental conditions and yields; 2) to analyze the temporal patterns of these indices, relative to meteorological conditions and soil management; and 3) to evaluate the relevance of biodiversity indices as indicators for soil quality, in terms of 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. (2014b) and Taguas et al. (2013) to evaluate the erosive patterns for the periods 2006-2011 and 2005-2011, respectively. The results of those studies 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 (Gómez et al. (2014b). 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., 2014b; 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 (Taguas et al. 2013). 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, photographs of each point were taken (Reflex Olympus E-420, ED 14-42 mm; height 1.4 m-1.7 m; Fig. 2) to observe 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 frequency of occurrence and biological spectrum. *R* was determined for the total number of grasses and forbs 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 the two samples are completely different and 1 completely equal.

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

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) represents the uncertainty associated to the prediction of species identity of an individual taken from a sample. 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 small group of (less diverse) species, while the highest values are produced in communities where all the species have the same number of individuals. If there is only one group of species Shannon's index is equal to 0.

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

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 that presented each grid point of the considered in the catchment sample (see Fig. 1 and 2). 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* 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, with 1 describing systems where all species are equally abundant.

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

Where:

H is Shannon´s index and *S* is the number of species. If *H* (Eq. 3) is substituted for *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., 2014b).

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*. The analysis was carried out with the mean values of the variables *P*, *ETP* and *Tm* corresponding to the 5, 15, 30, 60, 365 days previous to the sample date. 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 and discussion

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 (Table 4). 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). As references, Guzmán and Forester (2007) observed for olive orchards with leguminous cover crops *H*-values close to 1.2, whereas in natural systems of Mediterranean semi-arid areas, *H*-values were approximately equal to 1 (Kawada et al.,2012). Under conventional cereal crops, Armengot et al. (2013) quantified a mean *H*-value of 1.5 for 11 fields in Catalonia (Spain) while for a pine afforestation located in a semi-arid catchment in Southwestern Spain, Bonet et al. (2004) came up with *H*-values of 2.8.

On the other hand, *Jmod*-values closed to 1, indicated that there were no dominant species in either of the catchments. The lack of a dominant species is frequent in Mediterranean agricultural areas, where a high inter-annual and intra-annual variability of precipitation and temperature produce a wide range of colonizing species awaiting their optimal development conditions. In spite of the selective herbicide treatments (Table 2), differences in *Jmod* between both catchments were small.

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 (*Is*= 0.378) while the spring, the most different (*Is*=0.139). Although similar distributions of life forms were found (Fig. 3), a different floristic catalogue of species was observed in both catchments, where 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* between the catchments were significant as is shown in Table 7 and Fig. 4a (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), although they were not significant (Table 7 and Fig. 4b; BD-CN= 1.57 g.cm^{-3} and BD-PG=1.50 g.cm^{-3}). Substantial higher mean soil loss in CN(16.1 t·ha^{-1}) was found with respect to PG (1.8 t·ha^{-1}; Fig. 4c), Likewise, the mean *Rc* in CN(15.3%) tripled the value of PG (5.1%; Fig. 4d),

4. General 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 the dissipation of energy from rainfall and runoff and with the increase of infiltration, which reduces the sediment transport. It was expected that a wider ecological niche would allow for a more efficient occupation of space with probably more biomass, as well as a higher efficiency in the runoff 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., 2014b) accounted for higher soil losses and runoff coefficient (much higher than PG values). Lewis et al. (2013) highlighted the potential for soil erosion to disseminate the spontaneous grass cover seedbank and to improve the biodiversity indicators 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) described 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 was only slightly higher in organic systems as compared to low-input conventional systems.

Although single steps, such as the application of fertilizers or certain herbicides, may lead to the dominance of some species such as in the case of monocotyledoneous in CN (Table 5), 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 fact, the yield is a common agronomical factor of soil quality for farmers, which may be 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 they are 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. Additionally to the yield, *R, Hmod, Jmod* and *Is*, the group of species shown in Table 5 support short-term environmental advantages of the vegetation growth found in CN, which is likely to be linked to greater water availability despite a more intense management.

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 CN) account for the differences observed. In addition, a more active sediment transport dynamic might contribute to seed dispersal and to increasing the biodiversity indices.

Shannon´s index and Pielou´s index were relatively 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 degradation state in the study areas. More effort to increase the number of study sites should be applied to evaluate if under more similar environmental conditions, the weight of the management in the olive orchards might determine the biodiversity indices of grass spontaneous cover.

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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 (Córdob
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 Janua
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	Extensive, non-tillage with a spontai

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

Catchment	Month	2011	2012	2013
CN	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 to collect the olives.	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.
December			

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

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.
	CN	23	26	28	25.7	2.5
R	**PG**	24	14	24	20.7	5.8
	CN	2.194	1.947	1.826	1.989	0.187
Hmod	**PG**	1.880	1.213	1.751	1.614	0.354
	CN	0.897	0.839	0.850	0.862	0.031
Jmod	**PG**	0.840	0.834	0.817	0.830	0.012
	Winter	0.231	0.571	0.333	0.378	0.174
	Spring	0.231	0.100	0.087	0.139	0.080
Is	**Summer**	0.320	0.000	0.363	0.228	0.198
	Sutumn	0.166	0.333	0.000	0.166	0.167
	CN	11.7	11.6	11.1	11.5	0.3
Tm (ºC)	**PG**	12.4	11.6	11.7	11.9	0.4
	CN	1270.5	1310.2	1230.4	1270.4	39.9
ETP (mm)	**PG**	1383.7	1359.8	1355.1	1366.2	15.3
	CN	401	610	621.1	544	124
P (mm)	**PG**	376.8	434.4	423.8	411.7	30.7

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	Locatic
	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; CN (n= 95); PG (n=65) (See also Fig. 4a)
(**) T-test showed p=0.07764; CN (n= 95); PG (n=65) (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) Arroyo Blanco in Puente Genil (PG).

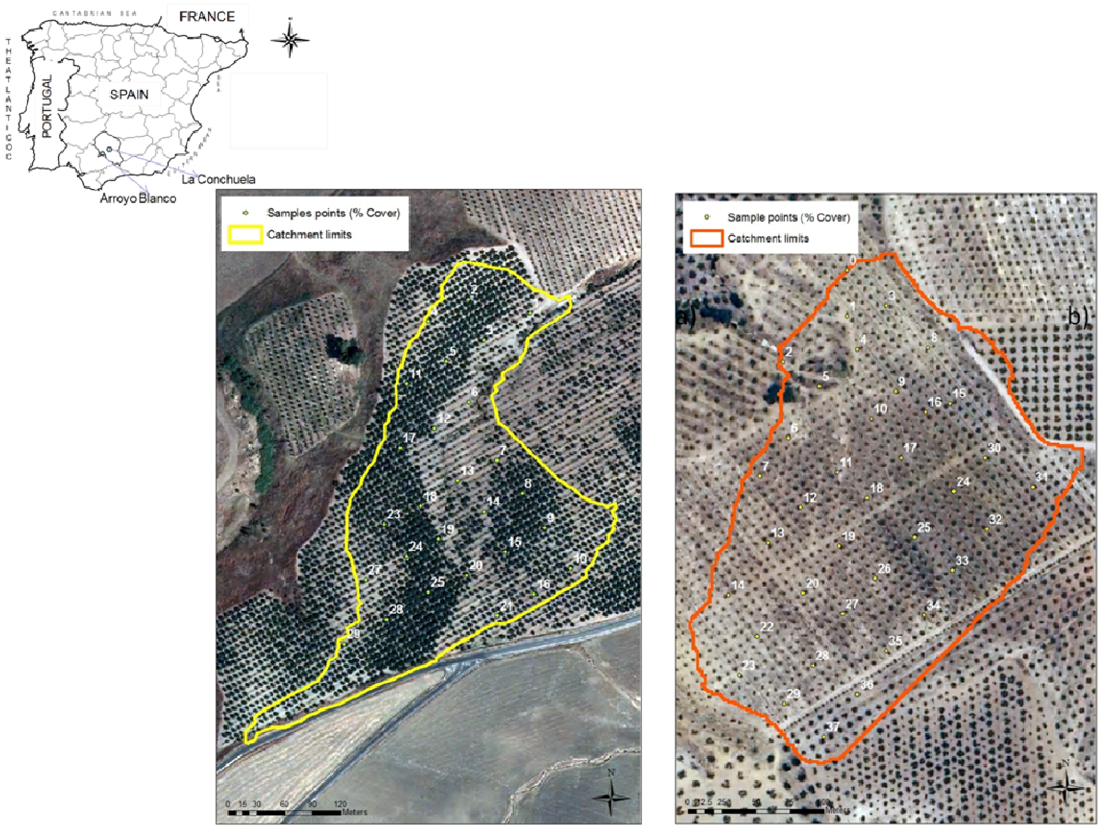


Figure 2. Examples of grass spontaneous cover sample plots and view of the catchments: a) a plot in La Conchuela; b) a plot in Puente Genil; c) gully with cover crop in CN; d) view of a hillslope in PG.

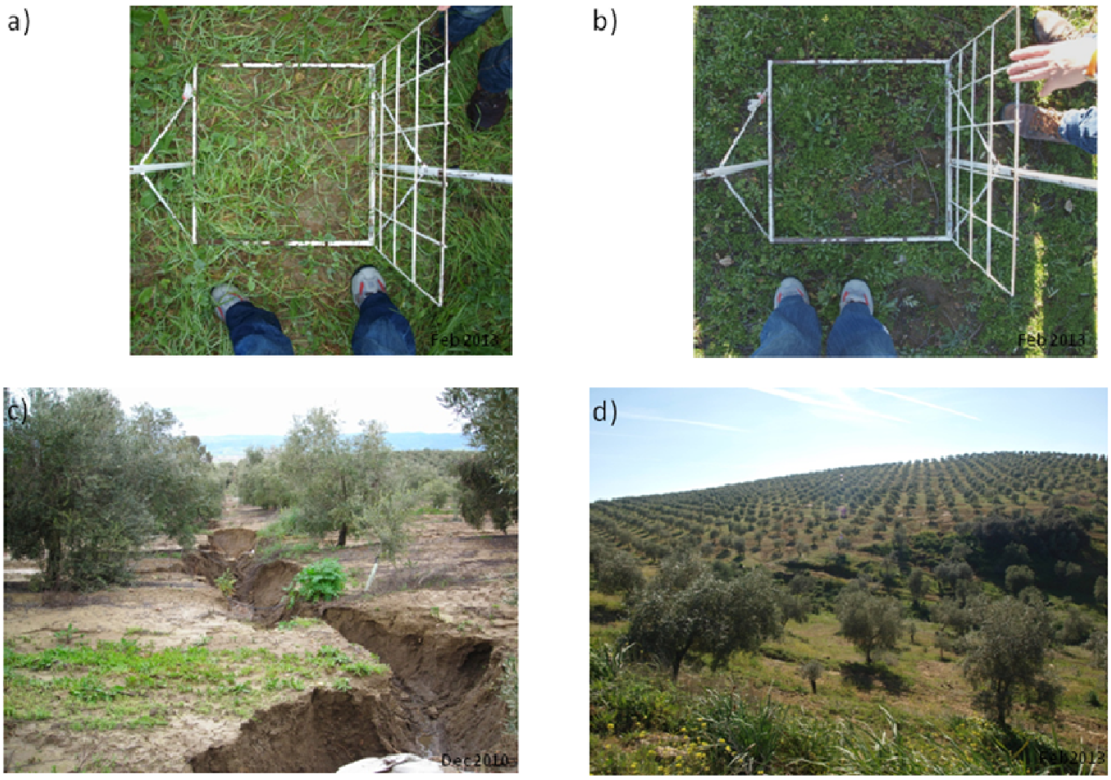
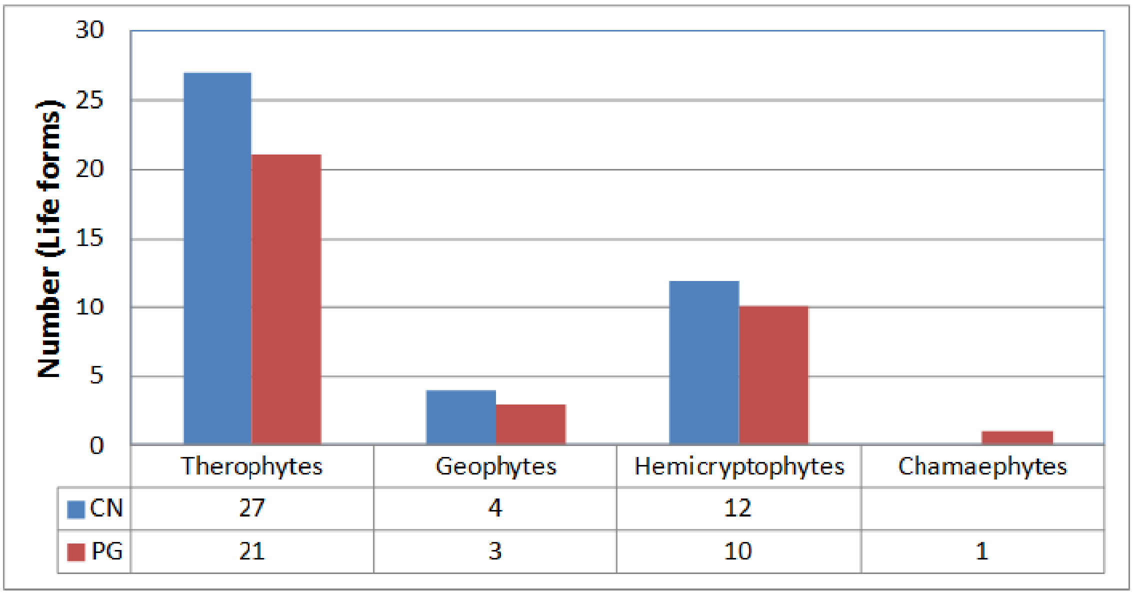


Figure 3. Number of species by life forms (biological spectrum) in the study catchments (CN= La Conchuela; PG= Puente Genil).



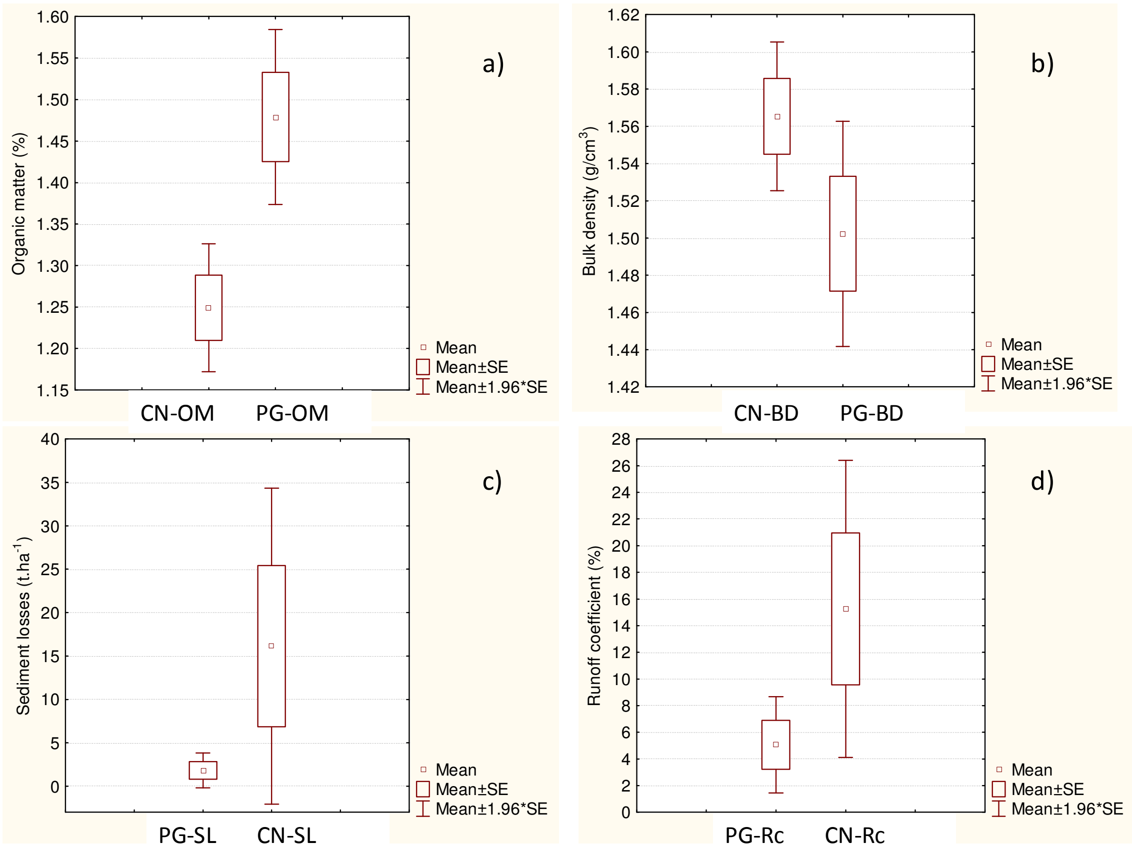


Figure 4. Box and whisker plots of the measurements of soil degradation indicators: (a) organic matter content in the upper horizon (b) bulk density in the upper horizon; (c) annual soil losses in the catchment outlets; (d) annual runoff coefficients (PG= Puente Genil; CN=La Conchuela; SE= Standard error; For (a) and (b), the sample size was 65 in PG and 95 in CN; For (c) and (d) the sample size was 6 in PG and 5 in CN; The data of (c) and (d) were described in Taguas et al. (2013) and Gómez et al. (2014b)..