



Plant-conservative agriculture of acid and degraded Raña-grassland enhances diversity of the common soil mites (Oribatida)

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Abstract

The seminatural prairie of the Raña of Cañamero (Spain) is a degraded and unproductive agrosystem with acid and stony soils, and low coverage of xerophytic grasses. In a project about secondary reversion of the raña-prairie to a more productive cropland, an experimental field (EF) was established to assess the effect on plot-productivity of the interaction between correction of soil pH (liming) with three cropping systems: a no-tilled and annually fertilized and improved prairies, and a conventionally-tilled forage crop. The EF model of management was designed as plant-conservative, because no herbicide was applied after seeding to preserve the post-emergence of wild herbs and the natural grass diversity of the prairie. Between 2008 and 2012, we analysed the effect of managing factors (initial conventional-tillage, fertilization, liming and cropping) and agricultural predictors (pH, C:N ratio, soil bulk density and herbaceous biomass) on the alpha(α)-diversity of one of the major group of soil animals, the oribatids. In relation to the raña-prairie, all EF-plots improved their soil bulk density (ρ_s) and herbaceous biomass (t/ha), and enhanced desirable α -diversity values (richness, abundance and community equity). We conclude that the plant-conservative model: i) do not affect statistically the species richness of the prairie; ii) the desirable α -diversity responses are negatively correlated with soil bulk density and positively with herbaceous biomass, and iii) the low input or minimum intervention model, of an initial and conventional till and annual fertilisation, is the threshold and optimal model of agricultural management to improving oribatids diversity of the raña-soil.

Additional key words: Acari; agriculture practices; oribatids; soil biodiversity; Ultisols.

Abbreviations used. D_j (α -diversity; dominance index); D^2 (β -similarity statistic; squared distance between groups); EF (experimental field); FC (EF-plot of forage crop); FP (EF-plot of fertilized prairie); GLM (general linear model of variance analysis); H_j (α -diversity index of equity); IP (EF-plot of improved prairie); MCFs (mean cumulative functions of total richness); N (α -diversity; cumulative abundance); NF (natural field; control plots); N_j (α -diversity; sample abundance); NL (EF-plot without pH-amendment); ρ_s (soil bulk density); S_e (α -diversity; expected total richness); SF (EF-plot amended with sugar foam); SP (EF-plot amended with sugar foam plus phosphogypsum).

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Introduction

The Raña of Cañamero is one of the typical digitiform or fan-like uplands in the Iberian Peninsula, dated in a Middle-posterior Pliocene with a subtropical climate. Ancient raña-surfaces are formed by alluvial sediments from quartzite massifs located between river basins, the Villuercas Mountains (Espejo-Serrano, 1978). Currently and into the proper xeric regime of the Mediterranean subregion, the raña-environment is relatively humid by its Atlantic influence (annual rain-

fall about 900 mm). The soil is classified into ultisols as Typical Palexerult (Soil Survey Staff, 2014), with plinthic segregation of the horizon Bt (Peregrina, 2005), and the soil epipedon is fragile with high content in gravel, and acid (pH \approx 5) with high soluble aluminium content (González-Fernández *et al.*, 2008).

In the middle of the twentieth century, the dominant raña-forest of cork oak's *Quercus suber* L. was primarily converted into silvopastoral systems of *Quercus silex* L., pastures and cereal lands of *Secale cereale* (L). Traditional agriculture in the raña-land was deter-

minant into the soil impoverishment, the posterior abandonment of the land use and its natural reconversion into prairies steppe/savannah-type. The raña-prairie is an unproductive agrosystem with a low forage production -about 1.6 t/ha (Pedro González-Fernández; unpublished data)- of xerophytic grasses (Fig. 1A). Liming, or pH-amendment practices, promote fertility and productivity of acid soils (Manoj-Kumar *et al.*, 2012), and reduce its erodibility (Rhoton, 2000). For raña-soils, phosphogypsum, red gypsum and sugar foam are alternatives to lime and mine gypsum to alleviate soil acidity and related aluminium phytotoxicity (González-Fernández *et al.*, 2003; García Navarro *et al.*, 2009).

Agrosystems need a model of productivity that ensures its sustainability (Marshall, 1993; Convention on Biological Diversity, 2010; De Vries *et al.*, 2013). For our knowledge, there are no references about the diversity of soil animals in raña-environment and the effect of the agriculture practices in the local populations of soil animals.

Within the soil biotic-net and its inhabiting mesofauna (invertebrates with a breadth < 2 mm), mites belonging to Oribatida Duges, 1834 or oribatids are common residents and dominants in the upper layers of soils and organic horizons (Wallwork, 1976; Coleman, 2001). Oribatids are detritivorous and microphytophagous, primary and secondary decomposers in the soil's food web (Woolley, 1960; Schneider *et al.*, 2004) and therefore, are involved in the cycle and mineralisation of organic matter and in the formation and stability of fertile soils (Butcher *et al.*, 1971; Petersen & Luxton, 1982; Seastedt, 1984; Osler & Sommerkorn, 2007). By their demographic behaviour, are k-strategists with a low growth rate of population and a poor dispersal capacity (Luxton, 1981; Beckmann, 1988). For the last reasons, the oribatids diversity, based on

the species abundance data, constitute a direct and feasible parameter to biodiversity in soils (Linden *et al.*, 1994; Behan-Pelletier, 1999; André *et al.*, 2002; Gergócs & Hufnagel, 2009), and are useful to analyse the biological response to a soil disturbance, at local and medium or long-term levels (Beckmann, 1988).

In 2002, a project was started about the promotion of the fertility and consequent productivity of the raña-prairie. The selected model of agriculture was defined as plant-conservative, because herbicidal treatments were excluded to preserve the grass diversity of the prairie, and in contraposition to largely applied soil-conservative models where chemical herbicides are required (*e.g.* no-till and direct seeding). This paper aims to evaluate the effect of selected agricultural practices (conventional tillage, liming and cropping) on the diversity of soil animals of the prairie, estimated by the oribatid mites demography, and to obtain a model of agricultural practices that integrates a more efficient plant productivity and preservation of the soil biodiversity of the raña-prairie.

Material and methods

Experimental design

The experiment was carried out on an agricultural farm in the Raña of Cañamero (Cáceres, Spain; 39°19'7.76" N, 5°19'26.44" W). The selected site, designed as natural field (NF), was an old cropfield into the farm, without any agricultural management or treatment since 1999 and naturally reconverted to a seminatural prairie of wild herbs (Fig. 1A). During the sampling period 2008-2012, three separated blocks with three plots of 0.1-ha each were delimited as experimental controls.

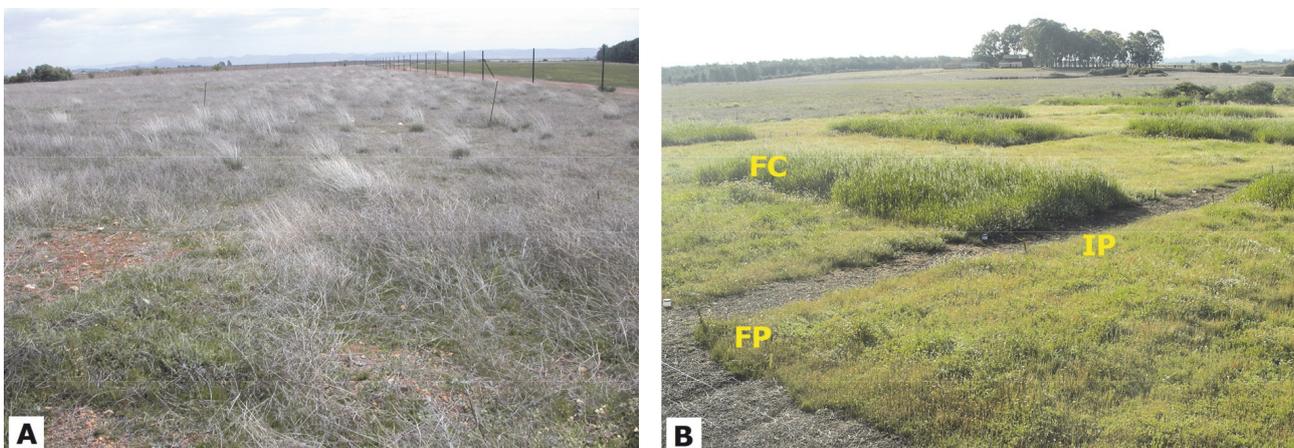


Figure 1. Natural field in late March-2008 (A); experimental field in late April-2008 (B). FP, fertilized prairie; IP, improved prairie; FC, forage crop.

In autumn 2002, an experimental field (EF) into NF was fenced, conventionally tilled at 20 cm deep with a manual rotavator and divided into 36 (9×4) square units (plots) of 40 m² separated by 1.5-m corridors (Fig. 1B). The two-factorial split plot design was set up by grouping the plots into 3 type-blocks repeated 4 times and with 3 plots into each block. For the lime-factor (blocks), each type-block received alternatively an initial and equivalent dose of the three amendments: SF, 4000 kg/ha of sugar foam; SP, 4000 kg/ha of sugar foam plus 7200 kg/ha of phosphogypsum; and NL, control without amendment.

For the crop-factor (plots), each plot into-block received alternatively one of the three cropping treatments:

- FP) fertilized prairie, with spontaneous growth of wild herbs, without tillage in years 2003-2011 and supplied in the preparation for planting with a mineral fertilizer N – P (as P₂O₅) – K (as K₂O) at equivalent dosage 70-70-70 kg/ha and annual fertilisation P – K at 70-70 kg/ha;
- IP) improved prairie; sown land in 2002 with 28 kg/ha of pasture crops mixture (*Trifolium subterraneum* L., *T. vesiculosum* Savi, *T. michelianum* Savi; *Biserrula pelecinus* L., *Ornithopus compressus* L., *Lolium rigidum* (Gaudin) and *Dactylis glomerata* L.; 8:3:3:3:3:4:4). No-tillage and fertilisation equal to FP; and
- FC) forage crop; sown land in period 2002-2003 with 210 kg/ha of a mixture of cereals (*Secale cereale* L., *Avena sativa* L. and *Triticosecale* Wittmack; 1:1:1) and in later years 2004-2011, with 150 kg/ha of the same grain mix plus 60 kg/ha of the legume *Vicia villosa* Roth. Annual conventional tillage 20 cm depth and equal fertilisation to FP in the preparation for planting and annual N – P – K at 35-75-75 kg/ha.

The EF field was designed as plant-conservative and for this, during the experimental period, any herbicidal treatment or till to control the post-emergence of wild herbs was applied.

Sampling

During the sampling period of years 2008-2012, soil samples were extracted by soil corers to obtain soil surface cylinders of 10 cm height and 5.82 cm diameter.

Analyses of soil variables was set up on sieved and dried soil samples of each plot, without materials >2 mm and 3-4% of residual moisture. In 2008, we measured

the soil pH of plots (pH-meter; aqueous suspension 1:2.5) and obtained the rate between carbon and nitrogen (C:N; dry combustion analyzer, LECO CN TruSpec St. Joseph, MI, USA). In 2012, the soil bulk density (ρ_s) was obtained as estimator of density and relative porosity of the soil (Blake & Hartge, 1986). For this purpose, in each plot a volume of soil ($V_c=265.7$ cm³) was extracted, weighed the fractions of fine soil (materials <2 mm; W_s) and gravel (W_g) and measured the volume occupied by the gravel in water (V_g). The ρ_s value refers to the volume occupied by the soil mass and estimated by its weight [$\rho_s=(W_s-W_g)/(V_c-W_g)$, in g/cm³; gravel: $\rho_g=2.62$ g/cm³, water: $\rho_w=1.00$ g/cm³].

At harvest of the years 2011 and 2012, the herbaceous production of two 1-m² squares in each plot was weighed and estimated the gross or whole herbaceous biomass in t/ha. In forage crop (EF-FC)-plots, the wild herbs were previously discarded and referring the values as net forage production.

Sampling for oribatids was carried out in two different spring days of years 2008, 2011 and 2012. Each day of sampling, one soil core sample (surface 26.60 cm², 10 cm depth) was extracted in all NF-plots (sample size, n=54) and in the EF field, in 24 of the 36 plots randomly selected in each day of sampling and to finally obtain an equal number of 4 samples for each one of the 36 plot-repetitions during the entire experimental period (sample size, n= 144).

The oribatids were extracted from fresh and whole samples by Berlese-Tullgreen funnel method (Walter & Krantz, 2009), by exposing each sample in one funnel, during ten days to 42 w halogen bulb lamp and at a distance of 25 cm. The recovered adults were counted under stereomicroscope, and sample specimens were cleared in lactic microscopic preparations and identified to species level following published keys (Balogh & Mahunka, 1983; Pérez-Íñigo, 1993; Pérez-Íñigo, 1997; Subías & Arillo, 2001) and reference descriptions.

Data analysis

Statistical analyses (Minitab Inc., 2013) were carried out from the data matrix (i-variables, j-plots) of agricultural data (i-variables pH, C:N, and t/ha), abundance data (n_{ij} , number of individuals of each i-species of oribatids) and alpha (α)-diversity values of richness (S_j , total number of species), abundance (N_j , total number of oribatids) and indexes of community structure of Shannon's or Shannon-Wiener's equity (H_j) (Spellerberg & Fedor, 2003) and Simpson's dominance (D_j) (Simpson, 1949). In order to reduce data variability by influence of the year of sampling, species aggregation and null samples ($N_j=0$), and to allow para-

metric comparisons between factorial groups and responses, data values used were the averages of each plot-repetition during the entire experimental period (NF, n=9 plots; EF, n=36 plots).

The statistical analyses were made by the following procedures:

- First, we obtained the mean cumulative functions (MCFs, trend test of Laplace) of observed cumulative richness (S_o , ΣS_i) versus soil sample size (soil surface, in cm^2) and expected richness (S_e) versus cumulative abundance (N) or oribatids sample size (N ; $N=\Sigma N_i$) obtained by the rarefaction method (McAleece *et al.*, 1997), and comparing groups (Chi-square test).
- Then we fitted the α -parameters to a non-linear function (Anderson-Darling test for a maximum likelihood, $p>0.05$).
- Multiple regression equations ($\hat{y}=b_0 + b_1x_1 + b_2x_2 + \dots + b_nx_n$) were obtained to calculate the regression coefficients ($b_{0 \rightarrow n}$) associated to the categorical factors of management ($x_{1 \rightarrow n}$) and the fitted value of each agricultural or α -response (\hat{y}) in a crossed and nested model Field-Crop(Field)-Lime(Field)-Crop*Lime (F-test for variance and t-test for coefficients).

- We obtained the correlation coefficients and applied a model of general regression between the agricultural predictors and α -responses.
- Finally, we compared the diversity among groups or beta-similarity by multivariate analyses (discriminant and of two first principal components), and referring the β -statistic to the squared distance between cluster centroids (D^2).

Results

Table 1 shows the descriptive statistics for agricultural responses and estimated GLM coefficients associated to plot-treatments. Field factor (EF treatment) affects pH, bulk density and herbaceous biomass ($p<0.001$), and there is no evidence of effect on C:N ratio ($p>0.05$). The pH increase was associated exclusively with lime, and the reduction of bulk density and increase of vegetal biomass with crop. Into EF, there were no plot differences in all responses related to crop and lime interaction ($p>0.05$).

A total of 13698 oribatids belonging to 34 species were collected (Table 2). In NF, 22/34 of the species were detected, *Cosmochthonius reticulatus* and *Minunthozetes* sp. were unique species and *Oribatula*

Table 1. Effect of selected agricultural practices in the agricultural parameters and associated coefficients in the fitted equations of the General Linear Model of variance analysis (GLM).

Plot (Field-Crop-Lime)	Observed (mean \pm SE)			
	pH	C:N	ρ_s	t/ha
NF	4.89 \pm 0.07 (n=9)	17.98 \pm 0.52 (n=9)	0.87 \pm 0.05 (n=9)	1.88 \pm 0.12 (n=18)
EF-FP-NL	5.03 \pm 0.19 (n=4)	19.52 \pm 0.93 (n=4)	0.64 \pm 0.08 (n=4)	5.54 \pm 0.90 (n=8)
EF-FP-SF	5.59 \pm 0.11 (n=4)	19.46 \pm 1.73 (n=4)	0.67 \pm 0.06 (n=4)	7.51 \pm 0.54 (n=8)
EF-FP-SP	5.85 \pm 0.05 (n=4)	18.67 \pm 1.72 (n=4)	0.63 \pm 0.08 (n=4)	7.25 \pm 0.40 (n=8)
EF-IP-NL	4.88 \pm 0.15 (n=4)	18.15 \pm 1.20 (n=4)	0.63 \pm 0.07 (n=4)	6.80 \pm 0.74 (n=8)
EF-IP-SF	5.69 \pm 0.13 (n=4)	19.13 \pm 0.77 (n=4)	0.48 \pm 0.02 (n=4)	7.58 \pm 0.66 (n=8)
EF-IP-SP	5.68 \pm 0.11 (n=4)	17.67 \pm 0.58 (n=4)	0.55 \pm 0.04 (n=4)	7.98 \pm 0.53 (n=8)
EF-FC-NL	4.99 \pm 0.07 (n=4)	18.10 \pm 0.91 (n=4)	0.61 \pm 0.04 (n=4)	10.02 \pm 1.14 (n=8)
EF-FC-SF	5.66 \pm 0.09 (n=4)	17.19 \pm 0.78 (n=4)	0.50 \pm 0.03 (n=4)	11.23 \pm 1.69 (n=8)
EF-FC-SP	5.82 \pm 0.05 (n=4)	18.28 \pm 1.11 (n=4)	0.58 \pm 0.03 (n=4)	9.54 \pm 1.30 (n=8)
Factor	GLM coefficient (\pm SE)			
Constant	5.18 \pm 0.04***	18.22 \pm 0.40***	0.73 \pm 0.02***	5.02 \pm 0.32***
Field (EF)	0.28 \pm 0.04***	NS	-0.14 \pm 0.02***	3.14 \pm 0.32***
Crop (IP)	NS	NS	NS	1.39 \pm 0.40**
Crop (FC)	NS	NS	0.06 \pm 0.03*	2.10 \pm 0.40***
Lime (SF)	0.18 \pm 0.05**	NS	NS	NS
Lime (SP)	0.50 \pm 0.07***	NS	NS	NS
Crop*Lime	NS	NS	NS	NS
σ ; R^2	0.23; 79.98%	2.15; 0.00%	0.12; 46.92%	1.70; 73.75%

GLM ($\alpha=0.05$): not significantly different at $p>0.05$ (NS) and significantly different at $p<0.05$ (*), $p<0.01$ (**), and $p<0.001$ (***); σ : variance error; R^2 : percentage of determination; NF: natural field, EF: experimental field; FP: fertilized prairie, IP: improved prairie, FC: forage crop; NL: control without amendment, SF: sugar foam, SP: sugar foam plus phosphogypsum.

Table 2. List of oribatids and their percentage of abundance in raña-prairie fields.

Oribatida Duges, 1834	NF (%)	EF (%)
<i>Aphelacarus acarinus</i> (Berlese, 1910) (Aphelacaridae) [Aac]	0.05	0.01
<i>Brachychthonius pseudoimmaculatus</i> Subías & Gil, 1991 (Brachychthoniidae) [Bps]	–	0.01
<i>Brachychthonius hirtus</i> Moritz, 1976 (Brachychthoniidae) [Bhi]	–	0.02
<i>Sellnickochthonius cricoides</i> (WeisFogh, 1948) (Brachychthoniidae) [Scr]	–	0.03
(**) <i>Cosmochthonius (C.) reticulatus</i> Grandjean, 1947 (Cosmochthoniidae) [Cre]	0.09	–
(*) <i>Phyllozetes emmae</i> (Berlese, 1910) (Cosmochthoniidae) [Pem]	–	0.01
<i>Haplochthonius sanctaeluciae</i> Bernini, 1973 (Haplochthoniidae) [Hsa]	–	0.01
<i>Epilohmannia cylindrica cylindrica</i> (Berlese, 1904) (Epilohmanniidae) [Ecy]	0.05	0.90
<i>Acrotritia ardua ardua</i> (Koch, 1841) (Euphthiracaridae) [Aar]	–	0.01
<i>Nothrus anauniensis</i> Canestrini & Fanzago, 1876 (Malaconothridae) [Nan]	–	0.23
(**) <i>Nothrus pulchellus</i> (Berlese, 1910) (Malaconothridae) [Npu]	–	0.01
(**) <i>Neoppia discreta</i> Ruiz, Mínguez & Subías, 1988 (Oppiidae) [Ndi]	0.38	0.02
(**) <i>Discoppia (Cylindroppia) cylindrica rostroincisa</i> Subías & Rodríguez, 1986 (Oppiidae) [Dci]	–	0.02
<i>Microppia minus minus</i> (Paoli, 1908) (Oppiidae) [Mmi]	0.09	18.72
<i>Serratoppia intermedia</i> Subías & Rodríguez, 1988 (Oppiidae) [Sin]	0.99	9.03
<i>Ramusella (Rectoppia) strinatii strinatii</i> (Mahunka, 1980) (Oppiidae) [Rst]	2.13	2.28
<i>Ramuseloppia anomala</i> Subías & Rodríguez, 1986 (Oppiidae) [Ran]	6.06	6.98
<i>Hypogeoppia terricola terricola</i> Subías, 1981 (Oppiidae) [Hte]	3.12	3.47
<i>Tectocephus velatus sarekensis</i> Trägårdh, 1910 (Tectocephidae) [Tve]	0.38	5.32
<i>Scutovertex sculptus</i> Michael, 1879 (Scutoverticidae) [Ssc]	1.42	0.01
(**) <i>Bipassalozetes bidactylus</i> (Coggi, 1900) (Passalozetidae) [Bbi]	4.54	1.11
<i>Passalozetes africanus</i> Grandjean, 1932 (Passalozetidae) [Paf]	4.97	7.78
<i>Passalozetes hispanicus</i> Mihelčič, 1955 (Passalozetidae) [Phi]	1.23	0.11
(**) <i>Passalozetes ruderalis</i> Mínguez & Subías, 1983 (Passalozetidae) [Pru]	–	0.02
<i>Berlesezetes ornatissimus mirus</i> (Mihelčič, 1956) (Microzetidae) [Bor]	–	0.14
<i>Ceratozetes (C.) laticuspidatus</i> Menke, 1964 (Ceratozetidae) [Cla]	0.43	3.04
<i>Trichoribates (Latilamellobates) latilamellatus</i> Mihelčič, 1956 (Ceratozetidae) [Tla]	2.27	0.49
<i>Minunthozetes</i> sp. (Punctoribatidae) [Msp]	0.05	–
<i>Oribatula (Zygoribatula) exarata</i> Berlese, 1916 (Oribatulidae) [Oex]	67.58	23.60
<i>Scheloribates (S.) barbatulus</i> Mihelčič, 1956 (Scheloribatidae) [Sba]	2.60	5.92
<i>Lauritzenia (Incabates) sinuata</i> (Pérez-Íñigo Jr., 1990) (Haplozetidae) [Lsi]	1.04	0.46
<i>Galumna (G.) tarsipennata</i> Oudemans, 1914 (Galumnidae) [Gta]	0.43	10.06
(**) <i>Pergalumna semistriata semistriata</i> Pérez-Íñigo Jr., 1990 (Galumnidae) [Pse]	0.09	0.17
<i>Pilagalumna ornatula ornatula</i> Grandjean, 1956 (Galumnidae) [Por]	–	0.01
Individuals (N)	2123	11575
	(100%)	(100%)
Species (S _c)	22	32

Species nomenclature and systematic ordination according Subías (2015); new geographical locations according Subías *et al.* (2015), for the Extremadura Region (**) and Cáceres Province (*). Natural field (NF), experimental field (EF).

(*Zygoribatula*) *exarata* is the dominant species with nearly 2/3 of the oribatids population.

Contrary to NF findings, in EF we identified 32/34 of the species detected and two primitive oribatids (*Haplochthonius sanctaeluciae* and *Acrotritia ardua*) appeared as unique species. Additionally, *O. (Z) exarata* numbers were reduced to nearly 1/3 of the abundance and less abundant species in NF increased their numbers, as is in the extreme case of *Microppia minus* that multiplies in 208 the NF values, reaching nearly a fifth of the total individuals.

The analysis of field MCFs of richness indicates that there was a significant increment of S_c in relation to soil sample size (Fig. 2A, Laplace test, $p < 0.001$) and the lack of significance for field factor (shape \pm scale,

EF: 2.05 ± 64.15 , NF: $2, 30 \pm 154.92$; Chi-square, $p > 0.05$). Additionally, the increment of S_c is due to oribatids abundance (Fig. 2B, Laplace test, $p < 0.001$) and there was no difference between fields (EF: $1.20 \pm 2, 13$, NF: 1.21 ± 2.32 ; Chi-square, $p > 0.05$).

For the field factor, the α -responses S_j, H_j and D_j fit adequately to normal distribution and N_j to log-normal one (Table 3, Fig. 3). GLM analyses indicates that all α -parameters are influenced by field factor ($p < 0.001$) and a lack of significance of crop, lime or crop and lime interaction into EF-field (Table 3).

Sample richness was positively correlated with herbaceous biomass ($r = 0.463$, $p < 0.01$) and negatively with bulk density ($r = -0.472$); sample abundance with biomass ($r = 0.462$, $p < 0.01$); and equity and dominance

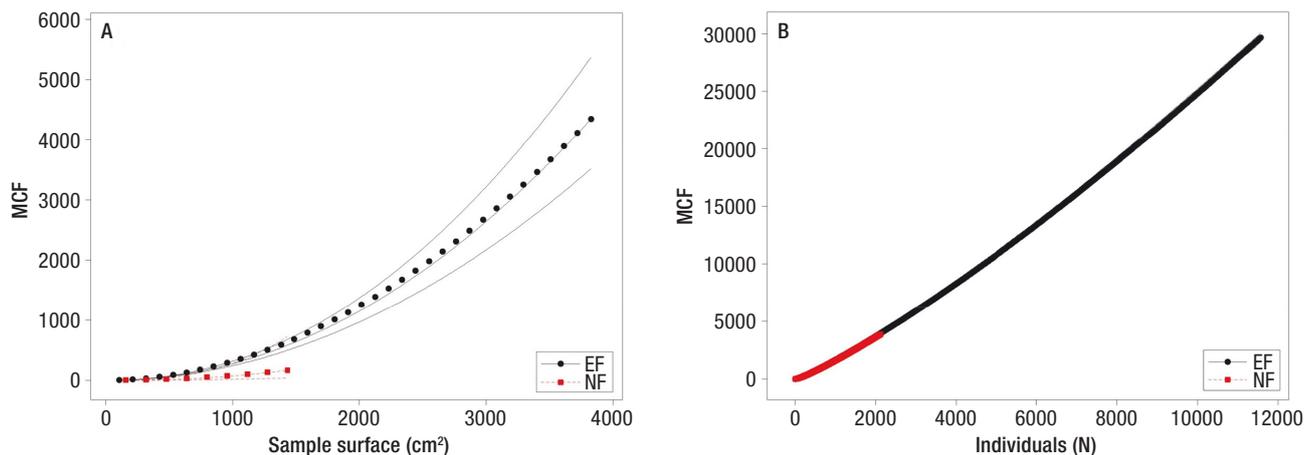


Figure 2. Species richness in raña-fields, mean cumulative functions (MCFs) and 95% confidence levels. Observed richness versus soil sample size (A). Expected richness versus oribatids cumulative abundance obtained by the rarefaction method (B). EF: experimental field, NF: natural field.

with pH, bulk density and biomass (pH: H_j , $r=0.420$ and D_j $r=-0.439$, $p<0.01$; ρ_s , H_j , $r=-0.589$ and D_j $r=0.583$, $p<0.01$; t/ha , $r=0.386$ and D_j $r=0.495$, $p<0.001$). The optimal regression equations (F and t-tests $p<0.05$, normality of standardized residuals, $p>0.05$) are:

$S_j=6.86 - 3.04 \rho_s + 0.145 t/ha$ (F, $p<0.001$; t, constant $p<0.001$, ρ_s and t/ha , $p<0.05$; $s=1.31$, $R^2=27.0\%$),

$\ln N_j=3.25 + 0.0670 t/ha$ (F-test, $p<0.01$; t-tests, constant, $p<0.001$, t/ha , $p<0.01$; $s=0.50$, $R^2=14.7\%$),
 $H_j=1.70 - 0.817 \rho_s$ (F-test, $p<0.001$; t-tests, constant, $p<0.001$, ρ_s , $p<0.001$; $s=0.19$, $R^2=33.2\%$), and
 $D_j=0.196 + 0.350 \rho_s$ (F-test, $p<0.001$; t-tests, constant, $p<0.001$, ρ_s , $p<0.001$; $s=0.08$, $R^2=32.4\%$).

Agricultural variables and α -statistics by separate do not securely discriminate fields (discriminant analysis; agricultural: 95.6% accuracy, $D^2=17.72$;

Table 3. Effect of selected agricultural practices in the alpha-diversity responses of the oribatids populations and associated coefficients in the fitted equations of the General Linear Model of variance analysis (GLM).

Plot (Field-Crop-Lime)	Observed (mean \pm SE)			
	S_j	$\ln N_j$	H_j	D_j
NF (n= 9)	3.89 \pm 0.13	3.28 \pm 0.16	0.88 \pm 0.05	0.54 \pm 0.03
EF (n= 36)	6.41 \pm 1.26	3.82 \pm 0.51	1.25 \pm 0.19	0.39 \pm 0.08
EF-FP-NL (n=4)	6.53 \pm 0.76	3.85 \pm 0.19	1.28 \pm 0.12	0.39 \pm 0.04
EF-FP-SF (n=4)	7.07 \pm 0.59	4.20 \pm 0.25	1.22 \pm 0.11	0.44 \pm 0.05
EF-FP-SP (n=4)	6.63 \pm 0.93	3.58 \pm 0.25	1.33 \pm 0.13	0.38 \pm 0.05
EF-IP-NL (n=4)	7.31 \pm 0.76	4.04 \pm 0.39	1.30 \pm 0.09	0.40 \pm 0.03
EF-IP-SF (n=4)	5.88 \pm 0.83	3.46 \pm 0.37	1.32 \pm 0.12	0.30 \pm 0.04
EF-IP-SP (n=4)	6.04 \pm 0.67	3.78 \pm 0.11	1.28 \pm 0.11	0.35 \pm 0.05
EF-FC-NL (n=4)	6.20 \pm 0.51	3.87 \pm 0.15	1.14 \pm 0.05	0.43 \pm 0.02
EF-FC-SF (n=4)	6.18 \pm 0.28	4.17 \pm 0.15	1.16 \pm 0.07	0.39 \pm 0.02
EF-FC-SP (n=4)	5.83 \pm 0.28	3.40 \pm 0.18	1.23 \pm 0.05	0.41 \pm 0.03
Factor	GLM coefficient (\pm SE)			
Constant	5.15 \pm 0.22***	3.55 \pm 0.09***	1.07 \pm 0.03***	0.47 \pm 0.01***
Field (EF)	1.26 \pm 0.22***	0.27 \pm 0.09**	0.19 \pm 0.03***	-0.08 \pm 0.01***
Crop, Lime, Crop*Lime	NS	NS	NS	NS
σ ; R^2	1.17; 40.96%	0.49; 20.59%	0.19; 35.17%	0.08; 39.53%

GLM ($\alpha=0.05$): not significantly different at $p>0.05$ (NS) and significantly different at $p<0.05$ (*), $p<0.01$ (**) and $p<0.001$ (***); σ : variance error; R^2 : porcentaje de determinación; NF: natural field, EF: experimental field; FP: fertilized prairie, IP: improved prairie, FC: forage crop; NL: control without ammendment, SF: sugar foam, SP: sugar foam plus phosphogypsum.

α -statistics: 93.3% accuracy, $D^2=7.20$), and combined data discriminate securely fields ($D^2=26.48$). A greater discriminative value is offered by the species abundance matrix ($D^2=343.55$). Figure 4 shows the combined influence of α -diversity, agricultural variables and species abundance on the plots dispersion in the two principal components analysis.

Discussion

Oribatids from the Raña-prairie of Cañamero are commonly reported in the Iberian Peninsula living in a wide variety of soils in xeric habitats (Pérez-Íñigo, 1993; Pérez-Íñigo, 1997; Subías & Arillo, 2001). Fifteen species are previously cited in the related Villuer-

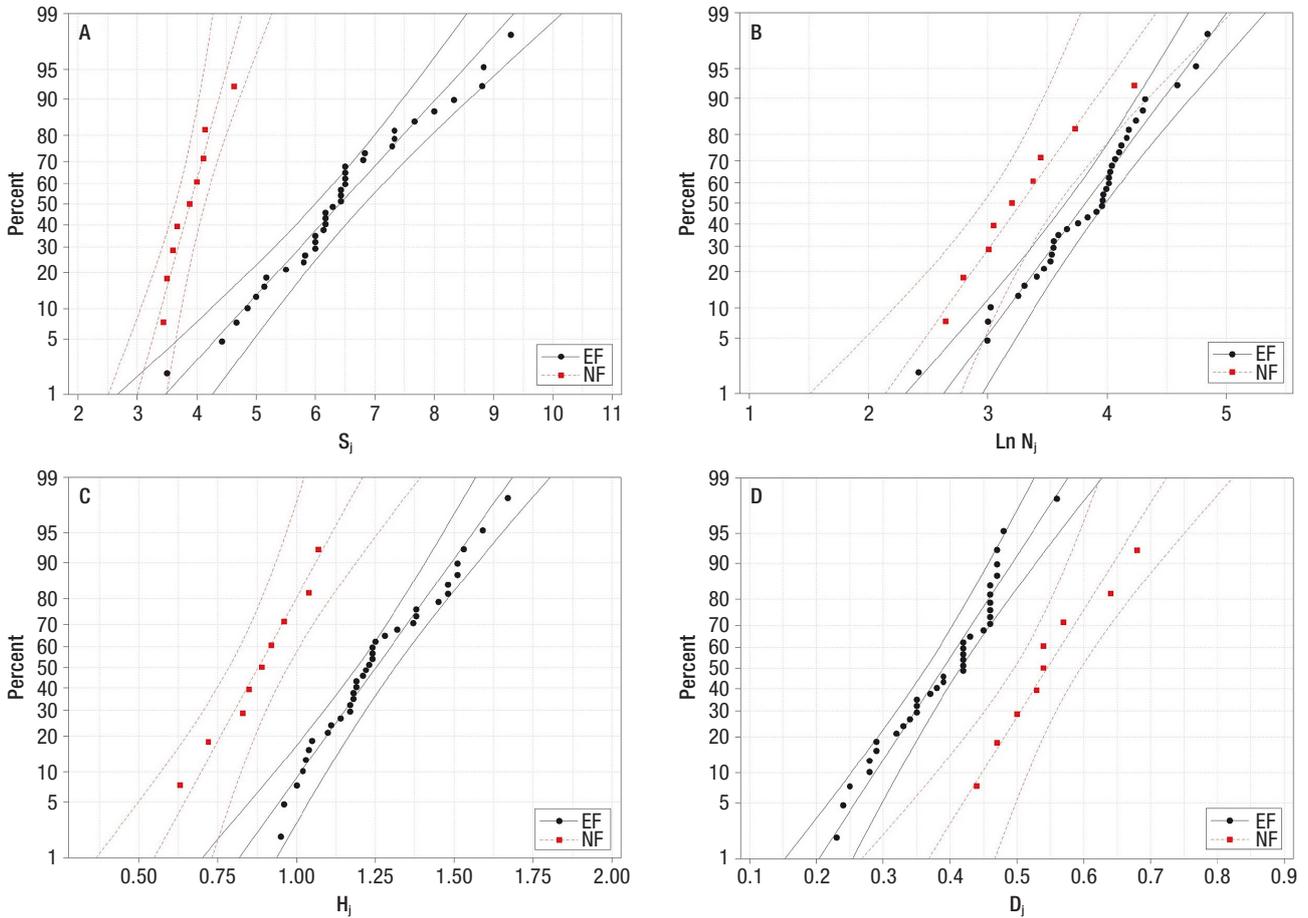


Figure 3. Fits of α -parameters and 95% confidence levels for field factor. A, C and D: normal distributions. B: log-normal distribution. EF: experimental field, NF: natural field.

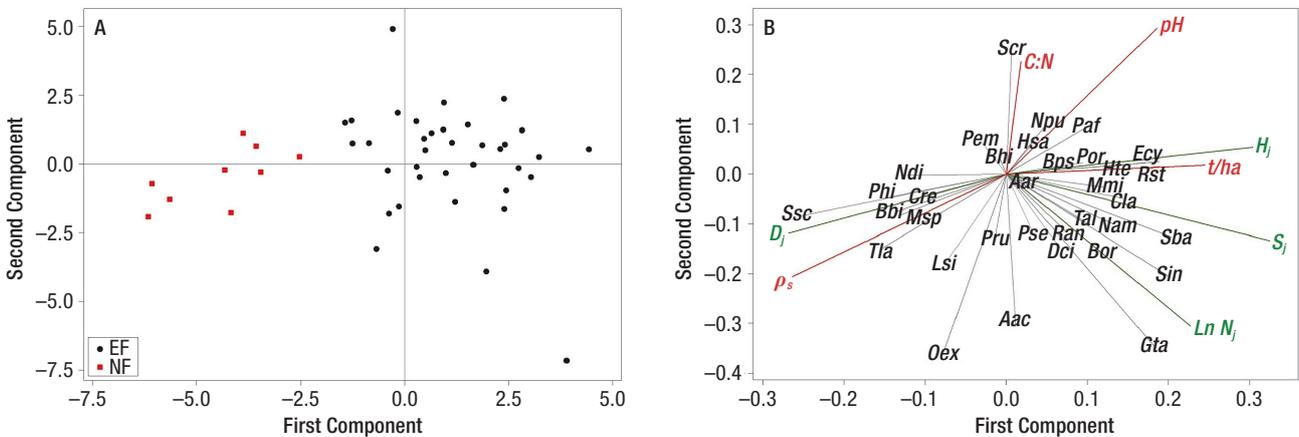


Figure 4. First two principal components graph of the combined matrix of species abundance (in black), agricultural variables (in red) and α -parameters (in green). A: scatter graph, B: eigenvectors. EF: experimental field, NF: natural field. Species abbreviations in B follow Table 2.

cas Mountains (Subías & Shtanchaeva, 2012) and 12 are new location records (Subías *et al.*, 2014).

The upper 10 cm of 0.18 m² of sampled soil of the prairie contains 22 species and 2123 individuals (S=22; converted N=11794 individuals/m²). Last data fall within the classic range for herbaceous biomes of Wallwork (Wallwork, 1980), close to desert grasslands (S=20, N=13000 individuals/m²) and lower than in temperate ones (S=44, N=32000). Comparing the data with other palearctic grasslands in Europe, the raña-prairie richness and/or abundance was: i) higher than dry and cold steppes of Northern Spain (Arroyo *et al.*, 2005); ii) similar to those of humid regions of northern Spain (Corral-Hernández & Iturrondobeitia, 2012), heathlands in the Netherlands (Kardol *et al.*, 2009), with acid soils in Scotland (Cole *et al.*, 2005), loess soils in Germany (Hülsmann & Wolters, 1998), dry alpine meadows (Schatz, 1996) and with calcareous soils in Switzerland (Baur *et al.*, 1996), and iii) less than dense prairies in wetlands of Europe (Weis-Fogh, 1948; Curry & Momen, 1988; Penttinen *et al.*, 2008).

The raña-prairie can be identified as an infertile and unproductive ecosystem of Wardle *et al.* (2004), with an acid soil, low herbaceous biomass with xerophytic condition and consequent high soil C:N ratio (Fig. 2A; Table 1). The Oribatida community is adapted to agricultural land use, data supported by the presence of four passalozetids (Table 2), species that are common in Iberian agrosystems (Pérez-Íñigo, 1993). In the raña-prairie, *O. (Z.) exarata* is the dominant species. This oribatid has a southern Palearctic distribution (Subías *et al.*, 2015), where is a common inhabitant of humid prairies (Pérez-Íñigo, 1993). This species possess a relatively thick cuticle with a striated cerotegumental layer that is distinctive of surface dwellers living in sunny habitats with poor vegetation. The strong influence of this species on the community demography is comparable to those of stony environments and mosses in steppes of Crimea (Ukraine) (Seniczak *et al.*, 2012) and for this, the relative abundance of *O. (Z.) exarata* may be an indicator for soil compaction for raña-type or humid, sunny and stony prairies in the south of Europe where this species is present. Finally, species less adapted to higher soil density and low vegetation cover have smaller populations, are aggregated in more porous and/or protected locus and their finding depends statistically on the sample size (Fig. 2).

The plant-conservative model of the experimental field, preserves the natural development of the herbaceous community by avoiding herbicide treatment, improving soil structure and increasing herbaceous coverage estimated by its aerial biomass (Table 1). As consequence, EF treatments increased samples richness and abundance and structural equity of oribatids com-

munity (Fig. 3, Table 3). In relation to NF, EF samples contain 1.65 times more species, individuals are 1.16 times more abundant, the equity index is 1.42 times higher and decrease the dominance index 1.41 times. Our results agree with the postulate that the oribatid respond to changes in soil edaphic factors and dynamics of habitat resources (Butcher *et al.*, 1971; Wardle, 2002) and their response is favourable to improving soil structure and revegetation (Dong-Hui *et al.*, 2007; Minor & Norton, 2008). The prairie-community prefers this new habitat, where the oribatids population grows; the relative abundance of *O. (Z.) exarata* decreases; new populations of small and/or delicate primitive oribatids are detected; and other oribatids less adapted to the original habitat increase their numbers, are more dispersed and establish more equitable demographic relationships.

By a first and strict point of view, traditional agriculture practices can decrease the heterogeneity, richness and abundance of oribatids (Edwards & Lofty, 1975; Siepel & Van de Bund, 1988; Hülsmann & Wolters, 1998; Pandit & Bhattacharya, 2000; Arroyo & Iturrondobeitia, 2006; Minor & Cianciolo, 2007). Contrasting with last assumption, the recuperation of degraded agrosystems is related to a positive and bidirectional relationship between plant biomass and soil animals (Osler & Beattie, 2001; De Deyn *et al.*, 2003; Wardle *et al.*, 2004; Gormsen, 2006; St John *et al.*, 2006). This relationship follows a chronosequence model suggested by Maharning *et al.* (2009): in the early stage of recuperation increases the species richness and later, their abundance. Oribatids follow the model of Maharning *et al.* (2009), with an apparent effect at medium and long term (Zaitsev *et al.*, 2006; Kardol *et al.*, 2009). For the last reasons, an increase of the productivity of the raña-prairie, via soil fertilisation, pH correction and/or cropping more productive herbs, results in a positive effect in oribatids populations.

Kardol *et al.* (2009) point out that the mesofaunistic restoration of degraded ecosystems depends primarily on the colonization of pioneer species from surrounding habitats. In our case of a moderately degraded agrosystem of the raña-prairie, we interpret an alternative model of in-site recolonization from the same habitat. This model, that is complementary or additive to the Kardol *et al.* (2009) model, is more consequent at short or medium-term scale with the k-strategy of population growth and low-scale capacity of dispersion in the space of the oribatids, and is supported by the statistical equality of expected and observed cumulative richness (Fig. 2). Additionally, previous authors indicated that the species richness is not determined by the identity or species composition of the herbaceous com-

munity (Osler & Beattie, 2001; Porazinska *et al.*, 2003; St John *et al.*, 2006). Our results agree with last premise: there are cumulative richness equality between fields and involving crop treatment (NF wild herbs=EF cultivated herbs; Fig. 2) and sample richness equality into EF (FP wild herbs = IP and FC wild herbs + forage crops; Table 3).

The oribatids have a specific pattern of vertical distribution in soil layers, that is related to soil depth, compaction (Price & Benham Jr, 1977; Perdue & Crossley Jr, 1990) and pore diameter (Vreeken-Buijs *et al.*, 1998; Ducarme *et al.*, 2004; Nielsen *et al.*, 2008). Bulk density is a simple and reliable estimator of the soil physical condition, of its structure, texture and porosity (Chen *et al.*, 1998; Carter & Ball, 1993) and additionally, of an available place into the soil to live for oribatids. The correlation and regression models show a direct correlation between ρ_s and α -diversity. In EF plots, increases the space for the 'structure followers' and among them, the oppiid *M. minus*. This species has great ecological plasticity and is common in open biotopes in Central and Northern Spain (Subías & Arillo, 2001; Arroyo *et al.*, 2005). *M. minus* has tendency to vertical migration and occupies deeper organic layers (Moritz, 1963), is poli- and meso-hygrophilous and in relation to pH is oligo-mesophilic (Rajski, 1968), and as is in oppiids, with a relative great capacity of population increase (Maraun & Scheu, 2000). The relative abundance of *M. minus* can be used as indicative for a more porous and plant covered raña-microhabitat.

Mineralization increases the richness and abundance of mesoarthropods in low-input grasslands (Marshall, 1977; Cole *et al.*, 2005). In our case of a seminatural and degraded raña-prairie, the low or minimum intervention model, that includes an initial tillage and annual fertilization (EF-FP-NL plots), enhances desirable α -parameters, which are positively related with herbaceous biomass. Bardgett & Cook (1998) indicate that grasslands with low human intervention are self-regulating ecosystems with an optimal biotic diversity. Additionally, in acid grasslands of Scotland, Cole *et al.* (2005) observed an independent and non-additive effect of fertilization and liming in oribatids demography. In our studied case, the minimum intervention model (plot EF-FP-NL with an unique and initial tillage and annual fertilisation) agrees with the optimum of Bardgett & Cook (1998) and, in line with Cole *et al.* (2005), suggests that above last optimal threshold of local diversity, if biomass is increased by effect of pH correction or crop, there is no apparent effect in population parameters (Table 3).

The soil pH amendment with sugar foam improves its productivity via correcting soil acidity and related

phytotoxicity of the soluble aluminium, and adding new nutrients to soil. This treatment gradually increases the pH 0.7-0.9 points between 0-856 days post-treatment and is effective up to 8-9 years (González-Fernández *et al.*, 2003, 2008). Oribatids exhibit a specific response to pH in natural (Moritz, 1963; Hågvar, 1990) and experimental conditions (Van Straalen & Verhoef, 1997). The raña-community shows adaptation to minor pH variations and its meso-acidophilic condition. Phosphogypsum was utilized as complement of sugar foam and source of phosphorus to the soil. However, this mineral contains 12.3 g/kg of fluorine, element that is phytotoxic in relation to its capacity to solubilize the soil aluminium (Mariscal-Sancho *et al.*, 2009). Oribatids are sensitive to soil contamination with heavy metals and fluorine (Vasiliu *et al.*, 1995; Ivan & Vasiliu, 2009) and in a natural grassland, a concentration of 10-15 ppm of fluorine in soil affects their abundance (Vasiliu *et al.*, 1995). In our test, the application of an equivalent dose of 0.585 kg/ha of fluorine has not valuable signification on populations demography.

Finally, we conclude that, at local-scale and from the standpoint of the oribatids, the plant-conservative model applied is a feasible solution to improve both productivity and biodiversity of degraded and unproductive prairies for extensive agriculture and/or livestock use of pasture lands.

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