1 **Bosch-Serra, A.D.^{1*}, Padró, R¹, Boixadera-Bosch, R¹, Orobitg, J¹, Yagüe, M-R¹**
2 **2014. Tillage and slurry over-fertilization affect oribatid mite communities in a**
3 **semiarid Mediterranean environment. *Applied Soil Ecology* 34:124-**
4 **139.doi.org/10.1016/j.apsoil.2014.06.010**

5
6
7
8
9
10 ¹*Department of Environment and Soil Sciences, University of Lleida,*
11 *Avda. Alcalde Rovira Roure 191, E-25198 Lleida, Spain.*

12 *Corresponding author contact information: Àngela D. Bosch-Serra
13 Tel: +34 973702899, Fax: +34 973702613, E-mail: angela.bosch@macs.udl.cat

Abstract

Fertilization with animal residues together with no-tillage is being widely used in dryland Mediterranean agriculture. The aim of this work is to assess the potential impacts of these combined management practices on oribatid mite species, and to evaluate their potential use as bioindicators of soil disturbances. From an experiment established ten years ago, eight fertilization treatments (including minerals or pig slurries), all combined with minimum tillage (MT) and no-tillage (NT), were studied. Four of these combinations were sampled three times during the winter cereal cropping season. The rest, and a neighbouring oak forest, were only sampled close to the end of the season (May). In total, 34 oribatid species and 4140 individuals were recovered. Oribatid abundance responded positively ($p < 0.05$) to the reduction of tillage intensity (NT) and marginally ($p < 0.1$) to slurry fertilization at sowing (close to maximum legislation allowed rate: $< 210 \text{ kgN ha}^{-1} \text{ yr}^{-1}$). At this slurry rate, Shannon index of diversity varied through the season, and was higher in May in MT than in NT plots. The Berger-Parker index of abundance signals plots without slurries as the most disturbed (compared with the forest). Nitrogen slurry over-fertilization reduced abundance of *Oribatula* (*Zygoribatula*) *connexa connexa*, but the impact on the most relevant species depended on the tillage system: *Epilohmannia cylindrica cylindrica* dominated in MT plots; under NT it was balanced by *Tectocephus velatus sarekensis* and *Passalozetes* (*Passalozetes*) *africanus*. *Scutovertex sculptus* is also very negatively affected by tillage. Oribatida are a good target for the biological indication of soil disturbances associated to agricultural management.

Keywords: Agroecosystem, Biodiversity, Bioindication, Forest, No-tillage, Pig slurry.

1. Introduction

Soil quality is a term that has been historically used to describe the agricultural productivity of soil. In the mid-1990s, in order to include the ecological attributes of soil, a broader term appeared: soil health, although both terms are frequently used synonymously. Soil health is an integrative property that reflects the capacity of soil to respond to agricultural interventions (i.e. tillage, amendments, pesticides), so that it continues to support both agricultural production and the provision of other ecosystem services (Kibblewhite et al., 2008).

In this context, the European Union (2013) has included, within the Common Agricultural Policy, the desire for soil quality (health) preservation. It established a set of minimum management requirements with the aim of preventing soil erosion, maintaining soil organic matter content and soil structure, and avoiding the deterioration of habitats, and to protect and manage water.

However, monitoring soil health, as a wide overall term including physical (i.e., structure), chemical (i.e. available plant nutrients), biological fertility (i.e. soil metabolic activity) and their interactions, is a complex task which can be simplified with the use of different indicators, such as bioindicators. A bioindicator is a living creature that gives information on the environmental conditions by its presence or absence and its behaviour (Van Gestel and Van Brummelen, 1996). This presence/absence/behaviour information is then treated through different approaches. Van Straalen (1998) considers that a multivariate statistical analysis combined with a classification based on ecophysiological types, could provide the required resolution (response to small changes) and specificity (response to a single factor). As stated by the author, the constraint to his approach is the availability of sufficient ecophysiological information. This is the reason why other classification principles (linked to specificity), such as

single indicator species or ratios between species, are also used. In addition, in the resolution domain, the study of species distribution over dominance classes can be also useful.

Soil invertebrates are frequently used as bioindicators (Paoletti, 1988; Ruf et al., 2003; Cenci and Jones, 2009) because of their immediate connection to many soil processes such as carbon transformation, nutrient cycling or the formation of biostructures and pore networks. Among them, soil microarthropods can be used for soil health monitoring because of their indirect effect on the formation of soil structure and soil humus, mainly through fragmentation of organic materials, which result in increasing their availability for microorganisms (Coineau, 1974).

It is well known that abundance of microarthropods increases as the input of crop residues increases due to the annual application of straw or green manure (Kautz et al., 2006) and organic fertilization (Ponce et al., 2011), which also increases diversity. No-tillage when compared with conventional tillage can increase abundance (House and Parmalee, 1985; Dubie et al., 2011) but diversity can also be reduced (Sapkota et al., 2012), or no significant differences may exist when compared with minimum tillage (Franchini and Rockett, 1996). On the other hand, heavy pig slurry rates ($445 \text{ t ha}^{-1} \text{ yr}^{-1}$) in acid soils decrease both abundance and diversity (Bolger and Curry, 1984).

Thus, microarthropods are sensitive to the amount but also to the quality of the organic input. Indeed, Andrés et al. (2011) reported that freshly digested sludge decreased the numbers of oribatid mites (the most sensitive taxa) while increasing the presence of astigmatic mites and symphypleon collembolans.

Some studies focus specifically on oribatid mites (Acari) because among the soil arthropods, mites represent the most diverse and numerous taxon, with oribatids forming the majority of the Acari in forest environments (Mitchell, 1979). To this must

89 be added their traits of low dispersion ability (Lebrun and Van Straalen, 1995) and
90 relatively long period of adult life, which helps with the assessment of long-term
91 disturbances. Besides, the density and distribution of oribatid species are closely related
92 with food quality and disturbance (Maraun and Scheu, 2000); i.e. soil disturbance by
93 tillage (whatever the cultivation system is) reduces the presence of microphytophagous
94 oribatida species (Hülsmann and Wolters, 1998).

95 Iturrondobeitia et al. (2004) recommend classifying at a species level in order to use
96 oribatid mites as bioindicators, as the behaviour of species from the same genus,
97 confronted with different impacts, is known to vary. Shimano (2001) adds that the use
98 of oribatid mites as bioindicators might also be based on the succession of the oribatid
99 fauna, studying the dominance of species or of specimens for different groups.

100 The use of oribatid species for bioindication in agricultural land is a complex issue;
101 firstly, because the number of species is much lower than that of forests (Ruf et al.,
102 2003); secondly, because they must be abundant in the area of study (Çilgi, 1994);
103 thirdly, because it is necessary to incorporate information on life history traits, and
104 habitat and niche profiles (Behan-Pelletier, 1999). Some surveys (Arroyo and
105 Iturrondobeitia, 2006; Luptáček et al., 2012) describe the potential differences in
106 oribatid mites' numbers and diversity according to the intensity of the land use (forest
107 vs agricultural land) in continental climates, while Al-Assiuty et al. (2014) studied the
108 effect of pesticides on the previous mentioned parameters in a hot desert climate.

109 In agricultural systems of arid or semiarid regions without artificial irrigation (dryland
110 agricultural systems), where precipitation is below evapotranspiration demand, the
111 study of oribatid mites may have some additional constraints. It has been noted that
112 periods of drought reduce their abundance in a humid tropical floodplain (Perdue and
113 Crossley, 1989) or species richness in a Mediterranean pine forest (Tsiafouli et al.,

2005), and also the fact that the recovery of the oribatid population from drought periods is relatively slow (Lindberg and Bengtsson, 2005).

In semiarid environments, there is a lack of available information on the Oribatida use as bioindicator with regard to pig slurry (PS) soil disturbances. Environmental aspects of PS use as fertilizer have been largely studied as a source of nitrogen (Hernández et al., 2013), mainly due to European regulations for the use of N in agriculture (European Union, 1991). Ecotoxicological effects on the soil have been studied to a lesser extent, such as in the work by Díez et al. (2001) where toxicity could not be related to the organic compounds provided by the slurry. However, for potential leachates, De la Torre et al. (2000) concluded that both ammonia (NH₃) and Cu (independently) could be associated with slurry toxicity (*Daphnia magna* acute test). Moreover, pig slurry has an influence on soil quality parameters such as aggregate stability or soil organic matter (OM) physical fractions (Yagüe et al., 2012a) although, according to these authors, the effects on soil quality are not very evident when doing classical analysis, such as total oxidizable organic carbon.

As oribatid mites are suitable for indicating soil degradation (Gergócs and Hufnagel, 2009), changes in the community structure caused by management practices such as PS fertilization (especially overfertilization), could be an early warning of soil degradation. However, despite some studies on the impact of pig manure on Oribatida families (Arroyo et al., 2003), the influence of PS on the abundance and diversity of soil Oribatida is unknown under semiarid environments.

In Spain, rainfed agriculture (farming practice that relies on rainfall) is practised on between 75 to 90% of the cultivated surface area (MAGRAMA, 2013). In order to reduce tillage expenses, some farmers have moved from conventional or minimum tillage to no-tillage (glyphosate is used to control weeds). Besides, pig (*Sus scrofa*

domesticus) slurry is considered a good fertilizer option for farmers as it is easily available and minimizes input costs. The NE part of Spain concentrates about 49% of the total Spanish pig herd (MAGRAMA, 2013), which is of around 26 million pigs (Eurostat, 2013). The slurry (PS) produced is mainly applied to cereal crops.

The present study was carried out in a semiarid Mediterranean area of NE Spain where agricultural land coexists with small patches of forests. In this context, the main objective was to evaluate the effects of different agricultural practices introduced some years ago (in a medium term experiment) on oribatid mites, with special emphasis on abundance (individuals per m²), diversity (Shannon index) and dominance (Berger-Parker index), as well as on their variability throughout a winter cereal cropping season. A second objective was to evaluate whether potential changes in these parameters could be used as warning indicators of impacts on soil health. The agricultural practices included the combinations of two tillage systems (minimum tillage and no-tillage) and eight fertilization treatments (mineral fertilizer or PS of different composition); these combinations were compared between themselves and also with the forest areas which surround the experimental field.

We hypothesised that the tillage system combined with different rates and types of fertilizers would result in differences in the population abundance and in the species composition of oribatid mite communities. Furthermore, we expected the effects of these management practices on the oribatid community to vary throughout the winter cereal cropping season.

2. Materials and methods

2.1 Experimental site

The dryland agricultural field plots and the adjacent *Quercus faginea* Mediterranean forest were located in Oliola, NE Spain. The forest lies parallel to the agricultural field. The altitude is 443 m.a.s.l. and coordinates are 41° 52' 29" N, 1° 09' 10" E. The agricultural area is devoted to winter cereals. The rotation was: three years barley (*Hordeum vulgare* L.) and one year wheat (*Triticum aestivum* L.). In the forest area, *Quercus faginea* covers 30-50% of the surface, another 10% is covered by *Acer monspessulanum*, *Buxus sempervirens*, *Rhamnus alaternus*, *Crataegus monogyna* or *Thymus vulgaris*; the rest is covered by different species, mainly grasses.

In the 0-10 cm depth layer, the agricultural land had an average organic matter content of 2%, a C-to-N ratio of 8, and pH_w (1:2.5, soil:water) equalled 8.3. Soil texture was a silty loam, average gravimetric soil water content (Gupta and Wang, 2007) at permanent wilting point (-1500 kPa) and at field capacity (-33 kPa) were 9.2% and 22.2%, respectively. Average dry bulk density of the arable horizon (0-15 cm) just before sowing (and before applying the minimum tillage) was 1650 kg m⁻³. No salinity was present as average electrical conductivity (EC 1:5, soil:water) was below 0.2 dS m⁻¹. In the forest, the organic matter content increased up to 8%, and the C-to-N ratio up to 13. The average gravimetric water content at wilting point (-1500 kPa) and at field capacity (-33 kPa) were 16.0% and 28.5%, respectively. Other characteristics of the forest soil were similar to those of the agricultural land: pH_w (1:2.5, soil:water) equalled 8.0; EC (1:5, soil:water) was 0.18 dS m⁻¹. In both cases, average calcium carbonate content of the fine mineral fraction was around 30%. Soils for the cultivated and forest area were classified (Soil Survey Staff, 2006) as a *Typic Xerofluvent* and a *Typic Haploxerept*, respectively.

The area has an annual average temperature of 12.6°C and high summer temperatures (average of maxima is 30.7°C). Annual precipitation averages 436 mm for the period

2000-2010, with a maximum of 593 mm and a minimum of 292 mm. Rainfall is usually concentrated in two periods: spring and autumn, as can be observed in the 2011-2012 cropping season diagram (Fig. 1).

2.2 Description of the experiment

In the agricultural field, a medium term experiment involving different nitrogen fertilizers (from minerals or from pig slurries) was established in September 2002 and maintained until 2012, with the exception of the 2007/08 winter cereal growing period when the field was left as set-aside (which means ten years of experimentation with nine cereal growing seasons and one fallow year). The agricultural field was divided into three blocks (replicates) of 4350 m² each (87 m wide by 50 m long).

The forest area was also divided into three blocks which were symmetrical with the agricultural ones. Thus, forest blocks had the same arrangement and size as the agricultural ones.

The size of agricultural plots fertilized with pig slurry (from fattening pigs or sows) was 137.5 m² (11 m wide and 12.5 m long) and the size of the control plot and plots receiving mineral fertilization was 87.5 m² (7 m wide and 12.5 m long).

Fertilization treatments were divided into applications at sowing time or at cereal tillering. Then, the treatments associated with fertilization at sowing first, and afterwards the treatments associated with fertilization at tillering, were randomized against the block, for each of the three blocks, and according to a split block design.

In October 2009 all plots were divided according to different soil tillage practices: minimum tillage (MT) by disc-harrowing (~15 cm maximum) and no-tillage. Tillage treatments were randomized, for each block, against the fertilization treatments at sowing. In both tillage systems, straw was removed from the field and just 20 cm of stubble was left. Arable stubble was not burned, in accordance with European standards

for good agricultural and environmental condition of land (European Union, 2013). The surface covered by residues under MT was less than 30% which is considered the minimum threshold for conservation tillage (Bosch-Serra et al., 2009). In NT, at sowing time, weeds were controlled using glyphosate (40%) at a rate of 1.2 L ha⁻¹.

For the present study, 16 agronomic treatments (combining seven fertilization treatments and a control with both types of tillage) were chosen (Table 1). One treatment received 25 t ha⁻¹ yr⁻¹ of slurry from fattening pigs (25FS-0) before sowing (26th October 2011), and the rest were just fertilized at cereal tillering (6th March 2012). At tillering, four treatments received mineral fertilizer as ammonium nitrate or as ammonium calcium nitrate (M; 60 or 120 kg N ha⁻¹), another four received slurry from fattening pigs equivalent to 30 and 55 t ha⁻¹ yr⁻¹ (0-30FS and 0-55FS; respectively) and the last four received slurry from sows (SS), equivalent to 55 and 80 t ha⁻¹ yr⁻¹ (0-55SS and 0-80SS, respectively). The control (0-0) only received phosphorus and potassium fertilization (96 kg P₂O₅ ha⁻¹ yr⁻¹ and 107 kg K₂O ha⁻¹ yr⁻¹) at sowing, but no nitrogen nor organic material were applied. Fertilizer treatments were maintained throughout all the growing seasons. Slurries were spread by splash-plate on the fields, and minerals were spread by hand. At sowing, in minimum tillage plots, slurry was buried as soon as possible (< 24h) after application by disc-harrowing. In no-tillage plots, fertilizer was never buried.

For both types of fertilizers (mineral and slurries), treatments were associated with the shape of a yield-N response curve as a quadratic function (Ortiz et al., 2010), which means that yield increases as a function of N only when N rate is below a threshold; above this threshold, yield decreases.

At cereal tillering, different rates from different pig slurries (fattening or sows) were introduced because their differences in dry matter content (Table 2) facilitate the

grading in N and organic matter (OM) rates (Table 1) to be applied, and also in yields obtained (Table 3). Slurries were always obtained from the same sources at two neighbouring farms. With the exception of the 0-55FS treatment (Table 1), on an annual average basis, fertilization at sowing or at cereal tillering fulfil the official requirements for the area (Generalitat de Catalunya, 2009), which establishes a maximum amount of 210 kg N ha⁻¹ year⁻¹ from slurry to be applied to cereals in nitrate non-vulnerable zones. In vulnerable ones, the amount of 170 kg N ha⁻¹ year⁻¹ is the maximum N threshold from fertilizers of organic origin according to the implementation of the Directive 91/676/CEE (European Union, 1991).

2.3 Sampling, extraction and taxonomic identification of mites

Throughout the 2011-2012 cropping season, sampling dates vary among treatments. The 12 plots associated to the control treatment (0-0) and pig slurry fertilization at sowing time (25FS-0), combined both with different tillage systems (MT or NT), were sampled three times. Sampling dates were the 20th October 2011, the 24th February 2012 and the 23rd May 2012. The rest of the chosen plots receiving slurry at cereal tillering (36) and the three forest blocks were sampled only one time: the 23rd May, just before the driest annual period, characterized by low rainfall and the highest evaporative demand (Fig. 1).

Soil samples were taken at 0-5 cm depth with soil cores (6 cm in diameter with steel bores) as oribatid mites mainly accumulate close to the surface (Marshall, 1974). For each plot of every treatment (fertilization combined with tillage), three soil cores were collected and a composite sample was obtained. As the field trial includes three blocks (three replicates of every treatment), this means that for each fertilization-tillage combination three composite samples (141.37 cm³ each) were obtained. In the forest

area, and for each block, two composite samples were taken with the same soil corers as the ones used in cultivated plots.

Thus, 234 single samples were collected and merged into 72 composite samples, which were statistically analysed.

On each sampling date and for each plot, gravimetrical analysis of soil moisture (drying at 105°C for 24h) was done (Table 4). In May, composite soil samples (0-10 cm) for chemical analysis (Table 5) were also taken from each agricultural plot and the forest (three field replicates).

Oribatids were extracted with a modified Berlese-Tullgren funnel over a period of seven days. The biota obtained were stored in 70% ethanol. Oribatid individuals were counted and identified using different types of microscopes according to the characteristics that must be evaluated. If necessary, in order to better identify taxonomic characters, individuals were immersed in lactic acid. Adult oribatids were identified, if possible, to species level using several taxonomic keys from Lions (1966), Pérez-Íñigo (1968, 1970, 1971, 1972, 1974, 1993, 1997), Subías (1982), Subías and Arillo (2001) and Weigmann (2006). The systematic ordination appearing at Subías (2014) was also followed. Juvenile stages were neither identified nor included in statistical analyses because very often they cannot be determined to species level and also because, when looking at our samples, their proportion was negligible.

For each sampled agricultural plot or for each forest block, three variables were calculated: mean abundance (individuals per m²), the Shannon index of diversity (H' , Krebs, 1999) and the Berger-Parker index of dominance (d , Berger and Parker, 1970; Magurran, 1988; Caruso et al., 2007). The Shannon index of diversity (H') was calculated as:

$$H' = -\sum p_i \ln(p_i)$$

where p_i represents the number of individuals in i^{th} group relative to the total number of individuals found in a given sample.

The Berger-Parker index of dominance (d), was calculated from the simple dominance values was used; in this case, it was calculated as:

$$d = \frac{N_{\max}}{N}$$

where $N_{\max}$ is the number of individuals in the most abundant species and N the total number of individuals found in a given sample.

2.4 Data treatment

Data analysis was done differently for each of the fixed targets. The mean abundance of Oribatida and the Shannon and Berger-Parker indexes required a Box-Cox transformation of data to normalize them. This was done with JMP 9 statistical software (SAS Institute, 2010).

Once data were normalized, the analysis of variance was done with the GLM procedure (Generalized Linear Mixed Model procedure) of the SAS statistical package (SAS Institute, 1999-2001). If the interaction of treatments (fertilization type*tillage management) was significant, pair comparisons were set up by an LS Means test; if not, significant differences among treatments were evaluated using the Duncan's Multiple Range Test (DMRT) procedure at the 0.05 or 0.1 probability level but changing the error term for each treatment according to the experimental design. This second confidence level (0.1) is accepted in soil related studies depending on the data being tested (CIEH and CLAIRE, 2008).

A first GLM statistical analysis assessed the three calculated variables during the 2011-2012 cropping season, for the four agronomic treatments that involved no fertilization at tillering (0-0-MT, 0-0-NT, 25FS-0-MT, 25FS-0-NT).

311 A second GLM statistical analysis (May samplings) included the fourteen agronomic
312 treatments that involved no fertilization at sowing, just at cereal tillering (0, 60M,
313 120M, 30FS, 55FS, 55SS and 80SS) combined with MT and NT.

314 In a third GLM statistical analysis, the forest Oribatid community was simply compared
315 with no-tillage agricultural plots combined with maximum rates of each type of
316 fertilizer (mineral, slurry from fattening pigs, slurry from sows) applied at cereal
317 tillering (120M, 55FS, 80SS) plus the control (0-0). No-tillage plots were chosen as this
318 agricultural practice is the one which leaves stubble at the surface. In addition,
319 maximum rates of M, FS and SS fertilizers, under NT, did not reduce the accumulated
320 straw biomass within each type of fertilizer treatment (Table 3) during the 2002-2011
321 growing period. Furthermore, in this second case, species were ranked by decreasing
322 dominance, and the percentage of the total number of individuals belonging to each
323 species was plotted against species rank in order to represent the community structure.

324 Finally, with May 2012 samples, a detrended correspondence analysis (DCA) was set
325 up to explore whether we should use an ordination method based on a model of linear
326 species response to the underlying treatment gradient, or a weighted-averaging
327 ordination method corresponding to a model of unimodal species response. The steps
328 proposed by Lepš and Šmilauer (2003) using the CANOCO V 4.55 program (Cajo and
329 ter Braak, 1988-2006) were followed. The length of gradient for the first axis was
330 3.297. As it was inside the range between 3 and 4, it means that both types of ordination
331 methods could work reasonably well. Thus, a principal component analysis (PCA) was
332 performed in order to study Oribatida community structure (linear response model).

333 Matrix distances were computed only for species that were represented by more than 4
334 specimens. The rejected species only represented 0.60% of the total number of
335 individuals and 12 species from a total of 34 were excluded from ordination. From the

PCA, the most relevant species were selected. From them, a cluster analysis was set up and Euclidian distances were computed. The JMP 9 statistical software was used for the PCA and the cluster analysis.

3. Results

3.1 Effects of the treatments on the soil's chemical properties

In the agricultural field experiment, no differences were found in chemical properties due to the tillage system; differences were due to fertilization treatments (Table 5). Besides, no interactions were found between both factors (tillage and fertilization). The highest slurry rate (0-55FS) clearly increased mineral nitrogen (as nitrates), phosphorus (P) and potassium (K) content with respect to other slurry treatments, and P and K with respect to mineral treatments. This 55FS rate surpassed the Cu threshold of 12 kg Cu ha⁻¹ (MAPA, 1990) that could be added to agricultural soils (pH>7) over a period of 10 years (Table 2), from a sludge source.

The slurry EC (1:5, slurry:water) was from 2.11 up to 6.31 dS m⁻¹ (Table 2). The slurry pH (Table 2) was close to soil pH (Table 5) and no differences were found associated with treatments.

In the agricultural area, at sampling time, the soil surface was quite dry in October (4-5%, w/w), below the permanent wilting point. Soil water content (SWC) doubled in February and May (8-11%, w/w) but values were still quite low (Table 4). In May, SWC was higher in the forest (26%, w/w).

3.2 Oribatid abundance, Shannon index of diversity (H') and Berger-Parker index of dominance (d)

In total, 34 species of Oribatida (see check-list in Appendix A) were detected (29 species in the forest and 14 species in the cultivated field). A total of 4140 individuals

were recovered, with *Tectocephus velatus sarekensis* (*T. sarekensis*) being the most abundant (1049 individuals collected in all plots), followed by *Passalozetes (Passalozetes) africanus* (*P. africanus.*), *Oribatula (Zygoribatula) connexa connexa* (*O. connexa*), *Epilohmannia cylindrica cylindrica* (*E. cylindrica*) and *Scutovertex sculptus* (*S. sculptus*) with 987, 591, 586 and 335 individuals, respectively. All of them were present in all treatments and in the forest, with the exception of *S. sculptus* which was not present in the forest.

During the winter cereal cropping season oribatid abundance varied depending on the management combination treatment. In February, minimum (2404 individuals m⁻²) and maximum (14815 individuals m⁻²) values were recorded. They were associated, respectively, with 0-0-MT and 25FS-0-NT treatments (Fig. 2A).

In February and May samplings, oribatid abundance was higher (approximately 2.5 times) in NT plots than in MT plots (Fig. 2A, Table 6). Differences associated with tillage were maintained in the rest of the May samplings (Table 7) with no interaction with the wide range of fertilization applied at cereal tillering. In May, a total average of 5162 individuals m⁻² were recorded under NT and 3121 individuals m⁻² under MT. Abundance under NT can be higher at the end of the crop cycle but, depending upon the year, differences can disappear after a summer period (Fig. 2A).

The effect of providing easily available carbon at sowing (25FS fertilization) on the increment of oribatid population, was just marginally shown ($p < 0.1$) four months later, in February samplings (Table 6). The influence of PS fertilization on oribatid abundance was confirmed in May samplings (after fertilization was applied in early March). Nevertheless, significant differences between treatments were just found at the highest N slurry rate (55FS) which reduced abundance by 66% (2404 individuals m⁻²) when compared with the low rate of mineral fertilizer (60M) which attained 5448 individuals

m⁻² (Table 7). Overall, there was a tendency to reduction in abundance as the N rates
 from pig slurries increased (Table 7) or when N mineral rate was doubled (120M).
 The inverse behaviour of H' and d was clearly shown during the sampling cropping
 season (from October to May) in MT plots (Fig. 2A, Fig. 2B). As the first increased
 (from 0.31 to 0.67), which meant, in our case, that species evenness increases, the
 second diminished (from 0.73 to 0.41). In October, H' was lower under MT, and in
 May, it showed a significant interaction between tillage and fertilization at sowing time
 (Table 6). This fact means that under NT, FS helped to increase H' although the value
 was still lower than that calculated for MT plots (Fig. 2A). However, the species
 richness was low, from eight to ten species (Appendix A). The effects of fertilization at
 sowing on d were only marginally significant ($p < 0.1$) in October samplings (Table 6) as
 was tillage (marginal in October and May). Under NT, species' distribution tended to be
 more biased and this was reflected in the higher values of d (Fig. 2B, Table 6). So, at
 the end of the crop cycle, no-tillage encouraged the reproduction of some species
 (abundance increased), but not diversity in terms of H' (Fig. 2A).
 When fertilization was postponed until the cereal tillering development stage
 (February), in May samplings (grain filling stage) these marginal differences were not
 confirmed. Neither the Shannon or Berger-Parker index were significantly affected by
 tillage at sowing, nor by fertilization received at cereal tillering.
 When plots with maximum soil cover (no-tillage) and maximum rates of each type of
 fertilizer were compared with those of the forest, Oribatida abundance was not affected
 (Table 8). As expected, the forest had the highest H' value (0.91, Table 8) but plots
 receiving slurries showed d values (between 0.35-0.39) statistically similar to those of
 the forest (0.26) which had lower d values than plots with mineral fertilization (0.52) or
 a control fertilization (0.44). The species dominance rank showed a different pattern in

agricultural plots (NT) compared to the forest (Fig. 3), but curves of the rank (vertical axis) were clearly steeper in agricultural plots without slurries (0-0-NT, 0-120M-NT).

3.3. Patterns and connections among Oribatida species according to the agricultural treatments and uses, in May samplings

The PCA analysis showed that 56.1% of data variability was accumulated by the first two constituents, and the 95% by the first seven constituents (Fig. 4, Table 9). The species which presented the highest eigenvector value for each of the axes were: *T. sarekensis* (average size: 323x204 μm), *E. cylindrica* (average size: 462x168 μm), *P. africanus* (average size: 257x125 μm), *Licnoliodes adminensis* (*L. adminensis*), *S. sculptus* (average size: 573x310 μm), *O. connexa* (average size: 532x345 μm), and *Tainsculptoppia subiasi* (*T. subiasi*). The hierarchical clustering analysis of these species (Fig. 5) established two main groups. The first one was composed of species *E. cylindrica*, *P. africanus* and *T. sarekensis*. The second group included two couples of species: *O. connexa* and *S. sculptus* plus *L. adminensis* and *T. subiasi*. *O. connexa* and *S. sculptus* were found in agricultural plots but they showed high sensivity (abundance reduction) to management disturbances. *S. sculptus* presence was sharply reduced by MT or by fertilization at tillering, even at low (acceptable) rates and whatever the tillage system was. *O. connexa* presence was reduced when the amount of N applied surpassed a certain threshold ($>60 \text{ kg N ha}^{-1}$ from minerals or close to 200 kg N ha^{-1} from slurries) whatever the tillage system was. *L. adminensis* and *T. subiasi* were only found in the forest and can be said to characterize this *Quercus faginea* Mediterranean system.

4. Discussion

The soil pH was not modified by fertilization because the excess of calcium carbonate provided such a large buffer capacity that the H^+ ions produced during the oxidation of

the ammonium ion could not alter soil pH (Hagin and Tucker, 1982). The soil P and K levels associated with the 0-55FS treatment are considered excessive for a silty loam soil texture (Rodríguez-Martín et al., 2009; MARM, 2010). Nevertheless, this was not a concern since in calcareous soils plant availability of P is reduced (Barber, 1995), and it is even more reduced under dry conditions because they severely limit P supply by diffusion (Fitter and Hay, 1987). Phosphorus build up is considered a problem when it interacts with other nutrients such as Zn (causing deficiency in plants), or if erosion is present (looking to potential environmental impacts of P losses). Besides, high levels of K are necessary because of the contribution of this nutrient to plant drought tolerance (Gransee et al., 2012). Finally, plant availability of Cu was also limited because it was bound to soil constituents due to the high soil pH (McLaren and Crawford, 1973; Alva et al., 2000; Martínez et al. 2002).

According to the literature, drought conditions during the crop cycle have an overall effect on biological activity: e.g. nitrification cannot proceed at water tensions of 1500 to 2200 kPa (Hagin and Tucker, 1982), and on N dynamics, e.g. ammonia volatilization is reduced from dry soils (Bosch-Serra et al., 2014).

Oribatid abundance figures were in concordance with those typical for these microarthropods: from several hundreds to thousands of individuals per square meter (Jeffery et al., 2010). In our environment (forest and agricultural land), the numbers were lower than those observed in more humid areas (Arroyo and Iturrondobeitia, 2006, Luptáčík et al., 2012; Wissuwa et al., 2013), but much higher than those measured by some other authors in dryland cereal cultivation areas under a similar climate and sampling period (Ponce et al., 2011).

The increment of oribatid mite abundance under NT could not be related to an increment of available plant residue (residue biomass), as straw was removed from the

field in both tillage systems, leaving similar amount of stubble (38% of straw biomass). As NT plots could lead to a better soil moisture maintenance (Perdue and Crossley, 1989; Bescansa et al., 2006), and the fact that from sowing time until cereal tillering rainfall was scarce (Fig. 1), the greater conservation of soil moisture in NT could explain the opposite effects on abundance evolution between NT and MT until February. This hypothesis coincided with the soil-mite build-up in no-tillage. However, in our case, at sampling time, SWC (0-5 cm depth) under NT and MT did not differ (Table 4). The absence of significant differences in SWC could be attributed to the measurement system (gravimetric one) applied just at sampling time. Soil surface cover reduces latent heat flux (by blocking the transport of vapour out of the soil) but soil rewetting dynamics associated with it vary during the day (Novak et al., 2000). As the crop developed and its water demand increased, soil cover in NT lost its importance in abundance maintenance, which decreased, although the studied mite numbers were similar to the ones of the neighbouring forest environment (Table 9), whereas it is generally stated that cultivation significantly decreases numbers of soil arthropods, particularly of the cryptostigmatid mites (Edwards and Lofty, 1975). The dry harsh summer conditions, and the fact that daily maximum temperatures can easily reach 40°C in the shade, could affect Oribatida physiological activity, and the synchronization of life cycle with the environmental factors (Siepel, 1994). Besides, the survival of oribatid mites is highly dependent on temperature (a maximum of 45°C has been recorded). Drought and high temperature could explain the absence of abundance differences between tillage systems at the start of the crop cycle in autumn (Fig. 2A) and the predominance of *P. africanus* (Appendix A) which is considered a Xeric species, a bioindicator of desertification risk (Wallwork, 1988).

With respect to N fertilization, abundance was maintained or even increased (Fig. 2A, Fig. 2B, Table 7) when the optimum N fertilization rate (whatever the fertilizer was) for maximum yields was approached (Table 3). Oribatida abundance in agricultural plots (crop rotation maize-wheat or monoculture) was increased by the addition of P and K, also N (Artemjeva and Tatilova, 1975). The effects were most favourable in the autumn but abundance might be reduced under continuous fallow (Artemjeva and Tatilova, 1975). The abundance increment at the end of February (Fig. 2A) coincided with a sharp increase in temperature (Fig. 1) which is related to the acceleration of OM decomposition. Furthermore, when food is abundant and of high quality, fast development of Oribatida is enhanced (Siepel, 1994). Also, a positive abundance in answer to nutrient enrichment in the form of ammonium has been found in Cryptostigmata (Heneghan and Bolger, 1996). As N rates increased from the optimum, the tendency (smooth slope) was to reduce abundance. This behaviour associated with PS rates was also observed by Domek-Chruścicka and Seniczak (2005).

Nitrogen over-fertilization implied high rates of NH_4^+ -N concentrated in the liquid phase. This form of nitrogen represented from 60% (25FS-0) up to 67-69% (in the rest of the treatments) of total N content (Table 1). Acarids have been positively related with the presence of NH_4^+ -N (Weil and Kroontje, 1979) but the dynamics of the ammonium ion (oxidation and ammonia volatilization) could be also different in both tillage systems, influencing the magnitude of the negative impact on the oribatid community. The N forms have some importance, i.e. ammonia is highly toxic to mites (Moursi, 1962, 1970a,b). Besides, Żyromska-Rudzka (1976) noted a negative reaction of Acarina (abundance reduction) to high doses ($360 \text{ kgN ha}^{-1} \text{ yr}^{-1}$) of mineral N (mainly as granulated ammonia) applied in a meadow (acid soil). She pointed out that it caused short-lasting but heavy concentration of ammonium, reaching even 500 mg kg^{-1} in the

surface layer (2 cm thick) of soil. The real positive or negative relationships (impacts) probably depend upon the rate of NH_4^+ -N application.

Nitrogen over-fertilization also implied high rates of other plant micronutrients such as Cu (Table 2) or Zn, and a higher distribution over the surface of a product with an important salt content (Table 2), which might attain (if not diluted) a EC higher than 30 dS m^{-1} (sodium salts were also present). It is considered that Zn has no significant effect on oribatids, although microphytophagous mites (in which *T. velatus* can be included) can accumulate Zn in higher concentrations than the more typical panphytophagous species (Zaitsev and Van Straalen, 2001). Similar accumulation behaviour according to the trophic group is found for Cu (Skubala and Kafel, 2004) and in acid polluted soils, high concentrations reduce their density and the number of species (Seniczak et al., 1997). However, after a period of 10 years from the establishment of the experiment, the Cu applied cannot explain the absence of differences between tillage systems, mainly the lower abundance under MT (Table 7), where Cu is incorporated in a higher soil volume (dilution effect). Besides, *T. velatus* has been described as a pioneer species on a zinc dump (Skubala and Ciosk, 1999) but is also sensitive at high heavy metals concentrations. Furthermore, inside the Oribatulidae family, *Oribatula tibialis* has been described as tolerant to Cu and other metals (Corral-Hernández and Iturrondobeitia, 2012).

Soil salinity (Table 5) could not explain differences in oribatid abundance as soil EC was not modified by slurry applications (Table 5). The slurry EC was high but within the normal ranges for these residues (Yagüe et al., 2012b), as slurries can reach salinity values close to those of sea water ($>45 \text{ dS m}^{-1}$). Our FS salinity was close to that of the waters classified by Rhoades et al. (1992) as extremely saline ($25\text{-}45 \text{ dS m}^{-1}$), and very saline ($10\text{-}25 \text{ dS m}^{-1}$) for SS. Nevertheless, Díez et al. (2001) signalled that salinization

usually occurs over the first few days following slurry application, but it decreases afterwards because of rainfall (or irrigation). With respect to the ammonium nitrate, its salt index per fertilizer unit is 3.12. It is considered that it has a low salinity effect, although in solution, at 20°C, the EC increases sharply as concentration in water increases (2g L⁻¹ equals a EC of 2.78 dS m⁻¹) and its solubility could be close to 1920 g L⁻¹ (Bosch-Serra et al., 2013). Heungens and Van Daele (1981) described how the increment of salinity in pine litter substrates (up to 0.8-0.9 dS m⁻¹) by applying mineral fertilizers, reduced *T. velatus* numbers. Sengbusch (1984) described *T. velatus* as being inside the euryhaline category. Weigmann (2008) described *T. sarekensis* as a halotolerant species although, in his study, *T. sarekensis* was not found in salt marsh areas of Portugal, just in a dry dam. Fujita and Fujiyama (2001) point out that *T. velatus* (when compared with *T. minor*) prefers rather dry soil conditions. These characteristics could explain why *T. sarekensis* was sharply reduced at high rates of slurry (55FS or 80SS) under MT, despite the fact that higher relative abundances of this species have been described in the MT plot when compared with no-tillage plots (Franchini and Rockett, 1996). The point is that NT provides an irregular layer that renders any direct slurry-soil surface contact or slurry infiltration more difficult, by acting as a mulch and softening the effect of a saline liquid slurry spread over a surface (Appendix A). It must be pointed out that when covered with seawater, the mites become immobile (Schuster, 1979). This behaviour agrees with the work of Bielska (1986) who found that *T. sarekensis* predominated at the edge of a liquid manure flooded area or when this residue was soaked through the soil, but in sites with direct impact of liquid manure (liquid manure flooded area) its presence was sharply reduced.

Despite the fact that Aoki (1979) placed members of the Tectocepheidae family within an insensitive group in the face of man-made environmental changes, the reduction of *T.*

sarekensis presence indicates slurry over-fertilization. The genus *Tectocephus* has already been signalled as an appropriate indicator of ecosystem degradation by anthropogenic activities (Gulvik, 2007). Nevertheless, the reduction of its presence is in disagreement with the description of the genus (*Tectocephus*) by Maraun and Scheu (2000), who stated that they recover quickly from disturbances, signalling that it was probably due to their parthenogenetic mode of reproduction. Furthermore, in our experiment, fertilization sidedressing, at the lowest rates for each slurry type (30FS or 55SS) could attenuate the differences associated with tillage management (Appendix A) as numbers of individuals just tended to decrease as NH_4^+ -N rates (for each type of fertilizer) doubled.

Inside the genera *Epilohmannia*, *Passalozetes* and *Zygoribatula* some thalassophile species have been found (Travé, 1981). *E. cylindrica* had a similar reaction to the NT treatment as *T. sarekensis* but under temporary salinization by slurry fertilization (55FS or 80SS) or under a high mineral N rate (120M), the trend in abundance was inverted, and *E. cylindrica* predominated. The reason could be the more marked euedaphic character of this species, rather than thinking of potentially advantageous osmoregulation mechanism. It can be added that its morphological size traits (mainly the narrow body) favour adaptation to our soil physical conditions: high soil bulk density and the fact that only 20-27% of the soil porosity is associated with pores larger (in diameter) than 400 μm in the first 5 cm depth (data not shown). The size of pores could be a barrier for larger species, which must remain at the soil surface, thus being easily immersed in the saline slurry after its application, while *E. cylindrica* remains more protected inside the soil. The tolerance of *E. cylindrica* to this temporary but highly anthropogenic disturbance, also reinforces the wide ecological value of this species, which has also been observed in southern forests of Spain (Kahwash, 1988) or

in more northerly Spanish barley fields where different pesticides were applied (Arroyo et al., 2005).

The results also indicate that *P. africanus* was tolerant but also sensitive to tillage and fertilization management and it was more affected than *E. cylindrica* by the potential negative effects of high rates of fertilizers when soil was not covered by stubble. The reason could be that in very dry environments (such as ours), as it can resist high temperatures (Pérez-Iñigo, 1993), it is found close to the surface. Thus, it is very vulnerable to slurry spreading by a splash-plate.

The *S. sculptus* and *O. connexa* are xerophytes (Pérez-Iñigo, 1993), bigger in size than the mites of the first group (*E. cylindrica*, *P. africanus*, *T. sarekensis*). They live in the most superficial soil layer. *S. sculptus* has been found in non-cultivated areas (Iturrondobeitia et al., 2004), in abandoned crop lands (Arroyo et al., 2005) or in a grassland (Corral-Hernández and Iturrondobeitia, 2012) receiving low N input ($\sim 19 \text{ kg N ha}^{-1} \text{ month}^{-1}$). Its morphological characteristics and behaviour, explain its sensitivity to tillage (its presence was sharply reduced under MT) independently of fertilization inputs, but also why *S. sculptus* numbers were very negatively affected by fertilization at tillering, even at acceptable N rates. Thus, *S. sculptus* is considered too sensitive to agricultural management practices to be used as a bioindicator of soil degradation by agricultural practices.

Some *Zygoribatula* sp. mites have been described as dominant in alfalfa fields (foliage and litter) from Greece (Badieritakis et al., 2014) and *O. connexa* has been found in grasslands with high N input of cattle slurry but fractioned over the year ($\sim 48 \text{ kg N ha}^{-1} \text{ month}^{-1}$; Corral-Hernández and Iturrondobeitia, 2012), but no oribatulids were found under conventional tillage when compared to no-tillage (Franchini and Rockett, 1996). In our study, *O. connexa* was present in both tillage systems and numbers just decreased

after N fertilization when applied rate surpassed 60 kg N ha⁻¹ from minerals or it was close to 200 kg N ha⁻¹ from slurries. Data suggest that the reduction of individuals of this species could be also related to nitrogen over-fertilization. The effect will not just be related to the total N amount applied when comparing with Corral-Hernández and Iturrondobeitia (2012), but to the fact that this amount has been applied once, not split during the crop cycle, and in the driest soil conditions. This behaviour is a key point about using *O. connexa* as a bioindicator.

Furthermore, in soils covered by oak leaves, the abundance of *L. adminensis* must be mentioned. The species disappeared in the agricultural land as previously stated by Mínguez-Martínez (1981). In relation to the presence of *T. subiasi*, the genus *Oxyoppia* (inside which it was initially included) has been described as present in Spanish xerophytic environments (Subías and Arillo, 2001), such as ours.

The range of H' values in agricultural plots (Fig. 2A, Tables 7 and 8) were similar to those recorded in grassland fields fertilized with PS (Domek-Chruścicka and Seniczak, 2005) but could not attain the forest values (Table 8).

The Berger-Parker index is independent of species richness. As soil physical disturbance increases due to agricultural management, d increases (Caruso et al., 2007). According to d figures, the highest and most significant soil disturbance under no-tillage, when compared with the forest, was found in plots which were not fertilized with pig slurries (Table 8). In fact, the control and the 0-120M fertilizer treatment (under NT) showed the concentration of community dominance to a few species (Fig. 3). At sowing, disturbance was higher under MT vs NT although, in both cases, it was reduced by the annually addition of slurry (Fig. 2B). As crop developed, the recovery under MT was dynamic, attaining levels below the NT management before harvest. The

organic matter incorporation in slurry treatments associated with different remnants of straw might attenuate imbalances between species on the abundance distribution.

The lack of influence of fertilization at tillering in H' and d figures (Table 7), could be attributed to the low number of species in agricultural plots (Appendix A) and the short period between fertilization and sampling (three months). Differences in H' were found under NT in samples taken six months (May 2012) after sowing fertilization (Fig. 2A, Table 6). Differences in d were found under MT in samples taken 12 months after (October 2011) the last fertilization at sowing time (October 2010). In both cases, fertilization at sowing, at agronomic rates ($<210 \text{ kg N ha}^{-1} \text{ yr}^{-1}$), increased diversity or reduced disturbance, respectively. This fact reinforces the statement (Usher et al., 1982) that the composition of oribatid communities after perturbation needs to be studied by repeated post-treatment sampling, apart from comparison between treated and untreated areas

5. Conclusions

In the context of important drought periods during the winter cereal cropping season, no-tillage management can maintain Oribatida abundance figures in agricultural plots similar those of the forest, and higher than under minimum tillage.

Whatever the tillage system, abundance can be marginally increased ($p < 0.1$) by slurry application at sowing at agronomic rates ($<210 \text{ kg N ha}^{-1} \text{ yr}^{-1}$), but as a temporary effect, not lasting more than six months. By contrast, nitrogen over-fertilization at cereal tillering will lead to greater reduction of abundance, whatever the nature of the fertilizer (M, FS, SS).

Also, under NT and according to the Berger-Parker index values obtained, the addition of slurries can reduce disturbances to a similar level to that of undisturbed soils (forest).

Under MT, the agricultural system is able to recover from these agricultural management disturbances throughout the winter cereal cropping season and before crop harvest. This fact means that under MT, d is significantly reduced below the values obtained under NT, while diversity (Shannon index) is significantly increased.

There is a time lag (around six-seven months) between the introduction of the management practice and the impact on Oribatida species' composition. The dynamics described in Oribatida behaviour are important when projecting sampling events in agricultural soils.

In this dryland agricultural system, despite the reduction of disturbances by combining management practices, they are not able to maintain diversity (H') at similar values to those of the forest.

Seven oribatid mite species were identified as indicators of land use and management agricultural treatments. Nitrogen over-fertilization negatively affected the presence of *P. africanus* and *T. sarekensis*; the reduction was more accentuated under MT. By contrast, *E. cylindrica*, when facing N over-fertilization, increased its presence under MT.

Oribatula connexa connexa and *S. sculptus* were also present in agricultural plots and they were also negatively affected by N over-fertilization whatever the tillage system was. The potential use of *S. sculptus* as bioindicator is more limited, mainly because of its high sensitivity to tillage and N inputs.

The natural biotope (Mediterranean forest) was dominated by the mites *L. adminensis* and *T. subiasi*.

Further research, at small field scale, is needed before generalising the use Oribatida species as bioindicators of the impacts of unsustainable agricultural practices, such as N over-fertilization, in Mediterranean environments. Furthermore, experimental studies

should integrate physical and chemical parameters. Specific research could be developed to assess the responses of oribatid species to specific levels of N rates and formulations (organic and mineral fertilizers) throughout the year. Also, it would be advisable to go more deeply into the implications of the dominance of some species (associated with disturbances by over-fertilization) in relation to organic matter decomposition and nutrient cycling. These studies could provide a correct interpretation of soil oribatida patterns in the context of their use as early indicators of soil health degradation.

Acknowledgements

This study was supported by the National Institute for Agricultural and Food Scientific Research and Technology of Spain-INIA (projects RTA2010-126 and RTA2013-57) and by FEDER (European Fund for Regional Development) and FEADER (European Agricultural Fund for Rural Development) funds. The support on field maintenance from the Department of Agriculture, Livestock, Fisheries, Food and Natural Environment, Generalitat de Catalunya (Spain), is fully acknowledged. We are also grateful to R.A. Norton for providing us with some references, to J.M. Llop Masip for field assistance, to M. Béjar Maceiras and especially to J.L. Ruiz Bellet for their help during the revision process. Finally, the authors are very grateful to Dr Julio Arroyo (University College Dublin, Ireland) for his constructive comments which improved the manuscript, to the anonymous reviewer and to the editor-in-chief who also contributed to it.

References

708 Al-Assiuty, A.I.M., Khalil, M.A., Ismail, A.A., Van Straalen, N.M., Ageba, M.F., 2014.
 709 Effects of fungicides and biofungicides on population density and community structure
 710 of soil oribatid mites. *Sci. Total Environ.* 466-467, 412-420.
 711 Alva, A.K., Huang, B., Paramasivam, S., 2000. Soil pH affects copper fractionation and
 712 phytotoxicity. *Soil Sci. Soc. Am. J.* 64, 955-962.
 713 Andrés, P., Mateos, E., Tarrasón, D., Cabrera, C., Figuerola, B., 2011. Effects of
 714 digested, composted, and thermally dried sewage sludge on soil microbiota and
 715 mesofauna. *Appl. Soil Ecol.* 48, 236-242.
 716 Aoki, J., 1979. Differences in sensitivities of oribatid families to environmental change
 717 by human impacts. *Rev. Écol. Biol. Sol.* 16, 415-422.
 718 Arroyo, J., Iturrondobeitia, J.C., Caballero, A.I., González-Carcedo, S., 2003. Una
 719 aproximación al uso de taxones de artrópodos como bioindicadores de condiciones
 720 edáficas en agrosistemas. *Bol. S.E.A.* 32, 73-79.
 721 Arroyo, J., Iturrondobeitia, J.C., Rad, C., González-Carcedo, S., 2005. Oribatid mite
 722 (Acari) community structure in steppic habitats of Burgos Province, central northern
 723 Spain. *J. Nat. His.* 39, 3453-3470.
 724 Arroyo, J., Iturrondobeitia, J.C., 2006. Differences in the diversity of oribatid mite
 725 communities in forests and agrosystems lands. *Eur. J. Soil Biol.* 42, 259-269.
 726 Artemjeva, T.I., Gatilova, F.G., 1975. Soil microfauna changes under the influence of
 727 various fertilizers, in: Vanek J (Ed.) *Progress in Soil Zoology*, Czechoslovak Academy
 728 of Sciences, Prague, p. 463-467.
 729 Badieritakis, E.G., Fantinou, A.A., Emmanouel, N.G., 2014. A qualitative and
 730 quantitative study of mites in similar alfalfa fields in Greece. *Exp. Appl. Acarol.* 62,
 731 195-214.

732 Barber, S.A., 1995. Soil Nutrient Bioavailability. A mechanistic approach. John Wiley
733 and Sons, Inc., NY, USA.

734 Behan-Pelletier, V.M., 1999. Oribatid mite biodiversity in agroecosystems: role for
735 bioindication. *Agric. Ecosyst. Environ.* 74, 411-423.

736 Berger, W.H., Parker, F.L., 1970. Diversity of planktonic foraminifera in deep-sea
737 sediments. *Science* 168, 1345-1347.

738 Bescansa, P., Imaz, M.J., Virto, I., Enrique, A., Hoogmoed, W.B., 2006. Soil water
739 retention as affected by tillage and residue management in semiarid Spain. *Soil Till.*
740 *Res.* 87, 19-27.

741 Bielska, I. 1986. Communities of moss mites (Acari, Oribatei) of chosen grasslands
742 periodically flooded with liquid manure. *Pol. Ecol. Stud.* 12, 163-178.

743 Bolger, T., Curry, J.P., 1984. Influences of pig slurry on soil microarthropods in
744 grassland. *Rev. Écol. Biol. Sol* 21, 269-281.

745 Bosch-Serra, A.D., Porta-Montserrat P., Torres-Fabregat, J. 2009. Treballar el Sòl. Un
746 art per descobrir. Edicions i Publicacions of Lleida University, Lleida, Spain.

747 Bosch-Serra, A.D., Estudillos, G., Güeche, J., 2013. Fertigation program (software,
748 English version), in: Bosch-Serra, A.D. (Ed.). *Fertilitat, Fertilització i Fertirrigació* (CD
749 format). Edicions i Publicacions of Lleida University, Lleida, Spain.

750 Bosch-Serra, A.D., Yagüe, M.R., Teira-Esmatges, M.R. 2014. Ammonia emissions
751 from different fertilizing strategies in Mediterranean rainfed winter cereals. *Atmos.*
752 *Environ.* 84, 204-212.

753 Cajo J.F., ter Braak J.F., 1988-2006. Program CANOCO Version 4.55 October 2006.
754 Plant Research International, Wageningen University and Research Centre,
755 Wageningen, The Netherlands.

756 Caruso, T., Pigino, G., Bernini, F., Bargagli, R., Migliorini, M., 2007. The Berger-
 757 Parker index as an effective tool for monitoring the biodiversity of disturbed soils: a
 758 case study on Mediterranean oribatid (Acari: Oribatida) assemblages. *Biodivers.*
 759 *Conserv.* 16, 3277-3285.

760 Cenci, R.M., Jones, R.J.A. (Eds.), 2009. Holistic approach to biodiversity and
 761 bioindication in soil. Report EUR23940 EN. Office for the Official Publications of the
 762 European Communities, Luxembourg. Available at:
 763 http://eusoils.jrc.ec.europa.eu/esdb_archive/eusoils_docs/other/EUR23940.pdf (verified
 764 2014.06.08).

765 CIEH (Chartered Institute of Environmental Health) and CLAIRE (Contaminated Land:
 766 Applications in Real Environments), 2008. Guidance on comparing soil contamination
 767 data with a critical concentration. Available at:
 768 [http://www.cieh.org/library/Knowledge/Environmental_protection/Contaminated_land/
 769 Statistics_guidance_contaminated_2008.pdf](http://www.cieh.org/library/Knowledge/Environmental_protection/Contaminated_land/Statistics_guidance_contaminated_2008.pdf) (verified 2014.06.08).

770 Çilgi, T., 1994. Sarthropod “indicator species” for environmental impact assessment of
 771 pesticides in field studies. *Aspect Appl. Biol.* 37, 131-140.

772 Coineau, Y., 1974. Introduction a l’étude des microarthropodes du sol et de ses annexes.
 773 Doin, Paris.

774 Corral-Hernández, E., Iturrondobeitia, J.C., 2012. Effects of cattle and industries on
 775 oribatid mite communities of grassland soil in the Basque Country (Spain). *Int. J.*
 776 *Acarol.* 38, 217-229.

777 De la Torre, A.I., Jiménez, J.A., Carballo, M., Fernandez, C., Roset, J., Muñoz, M.J.,
 778 2000. Ecotoxicological evaluation of pig slurry. *Chemosphere* 41, 1629-1635.

779 Díez, J.A., De la Torre, A.I., Cartagena, M.C., Carballo, M., Vallejo, A., Muñoz, M.J.,
 780 2001. Evaluation of the application of pig slurry to an experimental crop using
 781 agronomic and ecotoxicological approaches. *J. Environ. Qual.* 30, 2165-2171.
 782 Domek-Chruścicka, K., Seniczak, S., 2005. The effect of pig liquid manure fertilization
 783 on the crop of alternating grassland and some groups of soil mesofauna. *Folia Biol.*
 784 (Kraków) 53(suppl.), 139-143.
 785 Dubie, T.R., Greenwood, C.M., Godsey, C., Payton, M.E., 2011. Effects of tillage on
 786 soil microarthropods in winter wheat. *Southwestern Entomol.* 36, 11-20.
 787 Edwards, C.A., Lofty, J.R., 1975. The influence of cultivations on soil animal
 788 populations, in: Vaněk, J. (Ed.). *Progress in Soil Zoology*, Dr W.Junk, The Hague -
 789 Academia, Prague, 399-407.
 790 European Union, 1991. Council Directive 91/676/EEC, of 12 December 1991,
 791 concerning the protection of waters against pollution caused by nitrates from
 792 agricultural sources. *Off. J. Eur. Communities L* 375.
 793 European Union, 2013. Regulation (EU) No. 1306/2013 of the European Parliament and
 794 of the council of 17 December 2013 on the financing, management and monitoring of
 795 the common agricultural policy and repealing Council Regulations (EEC) No 352/78,
 796 (EC) No 165/94, (EC) No 2799/98, (EC) No 814/2000, (EC) No 1290/2005 and (EC)
 797 No 485/2008. *Off. J. Eur. Communities L* 347, 549-607.
 798 Eurostat (Statistical Office of the European Communities), 2013. Pig farming statistics.
 799 Available at:
 800 http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Pig_farming_statistics
 801 (verified 2014.01.27).
 802 Fitter, A.H., Hay, R.K.M., 1987 (2nd ed.). *Environmental Physiology of Plants*.
 803 Academic Press, London, UK.

804 Franchini, P., Rockett, C.L., 1996. Oribatid mites as “indicator” species for estimating
805 the environmental impact of conventional and conservation tillage practices.
806 *Pedobiologia* 40, 217-225.

807 Fujita, M., Fujiyama, S., 2001. How can the minor species, *Tectocepheus minor*
808 (Oribatida), dominate *T. velatus* in a no-tillage crop field?. *Pedobiologia* 45, 36-45.

809 Generalitat de Catalunya, 2009. Decret 136/2009, d’1 de setembre, d’aprovació del
810 programa d’actuació aplicable a les zones vulnerables en relació amb la contaminació
811 de nitrats que procedeixen de fonts agràries i de gestió de les dejeccions ramaderes.
812 DOGC 5457, 65858-65902. Available at:
813 [http://www20.gencat.cat/docs/arc/Home/Consultes%20i%20tramits/Normativa/Normati](http://www20.gencat.cat/docs/arc/Home/Consultes%20i%20tramits/Normativa/Normativa%20catalana%20en%20materia%20de%20residus/decret_136_2009.pdf)
814 [va%20catalana%20en%20materia%20de%20residus/decret_136_2009.pdf](http://www20.gencat.cat/docs/arc/Home/Consultes%20i%20tramits/Normativa/Normativa%20catalana%20en%20materia%20de%20residus/decret_136_2009.pdf) (verified
815 2014.06.08).

816 Gergócs, V., Hufnagel, L., 2009. Application of oribatid mites as indicators (review).
817 *Appl. Ecol. Env. Res.* 7, 79-98.

818 Gransee, A., König, H.P., Führs, H., McHoul, J., 2012. Recent advances in
819 understanding the role of potassium and magnesium in mitigating abiotic stress in crops.
820 *Proceedings of the International Fertilizer Society* 711, Leek, UK.

821 Gulvik, M.E., 2007. Mites (Acari) as indicators of soil biodiversity and land use
822 monitoring: a review. *Pol. J. Ecol.* 55, 415-440.

823 Gupta, S.C., Wang, D., 2007. Water retention in soil. 1864-1869. In: Lal, R. (Ed.),
824 *Encyclopedia of Soil Science*, 2nd edition. Taylor and Francis, New York.

825 Hagin, J., Tucker, B., 1982. Fertilization of dryland and irrigated soils. *Advanced Series*
826 *in Agriculture Science* 12. Springer-Verlag, Berlin, Germany

827 Heneghan, L., Bolger, T., 1996. Effects of acid rain components on soil
828 microarthropods: a field manipulation. *Pedobiologia* 40, 413-438.

829 Hernández, D., Polo, A., Plaza, C., 2013. Long-term effects of pig slurry on barley yield
 830 and N use efficiency under semiarid Mediterranean conditions. *Eur. J. Agron.* 44, 78-
 831 86.

832 Heungens, A., Van Daele, E., 1981. The influence of salt concentration on the mite
 833 population in pine litter. *Pedobiologia* 22, 39-51.

834 House, G.J., Parmelee, R.W., 1985. Comparison of soil arthropods and earthworms
 835 from conventional and no-tillage agroecosystems. *Soil Till. Res.* 5, 351-360.

836 Hülsmann, A., Wolters, V., 1998. The effects of different tillage practices on soil mites,
 837 with particular reference to Oribatida. *Appl. Soil Ecol.* 9, 327-332.

838 Iturrondobeitia, J.C., Caballero, A., Arroyo, L. 2004. Avances en la utilización de los
 839 ácaros oribátidos como indicadores de las condiciones edáficas. *Munibe* 21, 71-91.
 840 Available at: [http://www.aranzadi-](http://www.aranzadi-zientziak.org/fileadmin/docs/Munibe/2005071091.pdf)
 841 [zientziak.org/fileadmin/docs/Munibe/2005071091.pdf](http://www.aranzadi-zientziak.org/fileadmin/docs/Munibe/2005071091.pdf) (verified 2014.06.08).

842 Jeffery, S., Gardi, C., Jones, A., Montanarella, L., Marmo, L., Miko, L., Ritz, K., Peres,
 843 G., Römbke, J., Van der Putten, W.H. (Eds.), 2010. *European Atlas of Soil Biodiversity*.
 844 European Commission, Publications Office of the European Union, Luxembourg.
 845 Available at: http://eusoils.jrc.ec.europa.eu/library/maps/biodiversity_atlas/ (verified
 846 2014.06.08).

847 Kahwash, M.A.M., 1988. *Ácaros oribáticos del sur de España*, Tesis Doctoral.
 848 Universidad Complutense de Madrid, Madrid.

849 Kautz, T., López-Fando, C., Ellmer, F., 2006. Abundance and biodiversity of soil
 850 microarthropods as influenced by different types of organic manure in a long-term field
 851 experiment in Central Spain. *Appl. Soil Ecol.* 33, 278-285.

852 Kibblewhite, M.G., Ritz, K., Swift, M., 2008. Soil health in agricultural systems. *Trans.*
 853 *R. Soc. B. Biol. Sci.* 363, 685-701.

854 Krebs, C.J., 1999. Ecological Methodology, 2nd ed., Addison Wesley. Longman, Menlo
 855 Park.

856 Lepš, J., Šmilauer, P., 2003. Multivariate analysis of ecological data using CANOCO.
 857 Cambridge University Press, UK.

858 Lebrun, Ph., Van Straalen, N.M., 1995. Oribatid mites: prospects for their use in
 859 ecotoxicology. Exp. Appl. Acarol. 19, 361-379.

860 Lindberg, N., Bengtsson, J., 2005. Population responses of oribatid mites and
 861 collembolans after drought. Appl. Soil Ecol. 28, 163-174.

862 Lions, J.C., 1966. Contribution à l'étude du genre *Rhysotritia* (Acarien, Oribate):
 863 *Rhysotritia clavata sextiana* n. subsp. Vie et Milieu 17C, 779-794.

864 Luptáčík, P., Miklišová, D., Kovác, L., 2012. Diversity and community structure of soil
 865 Oribatida (Acari) in an arable field with alluvial soils. Eur. J. Soil Biol. 50, 97-105.

866 MAGRAMA (Ministerio de Agricultura, Alimentación y Medio Ambiente), 2013.
 867 Anuario de estadística. Available at:
 868 <http://www.magrama.gob.es/es/estadistica/temas/default.aspx> (verified 2014.06.08).

869 Magurran, A.E., 1988. Ecological Diversity and its Measurement. Croom Helm,
 870 London.

871 Maynard, D.G., Kalka, Y.P., 1993. Nitrate and exchange ammonium nitrogen, in: Carter
 872 M.R. (Ed.). Sampling and methods of analysis. Canadian Society of Soil Science. Lewis
 873 Publishers. CRC Press, Boca Raton, FL, pp. 25-38.

874 MAPA (Ministerio de Agricultura, Pesca y Alimentación), 1990. Real Decreto
 875 1310/1990 de 29 de octubre, por el que se regula la utilización de los lodos de
 876 depuración en el sector agrario. BOE 262, 32339 - 32340.

877 Maraun M., Scheu S., 2000. The structure of oribatid mite communities (Acari,
878 Oribatida): patterns, mechanisms and implications for future research. *Ecography* 23,
879 374-383.

880 MARM (Ministerio de Medio Ambiente y Medio Rural y Marino), 2010. Guía práctica
881 de la fertilización de los cultivos en España. Centro de Publicaciones de la Secretaría
882 General Técnica del MARM, Madrid.

883 Marshall, V.G., 1974. Seasonal and vertical distribution of soil fauna in a thinned and
884 urea-fertilized douglas fir forest. *Can. J. Soil Sci.* 54, 491-500.

885 Martínez, C.E., McBride, M.B., Kandianis, M.T., Duxbury, J.M., Yoon, S.J., Blead,
886 W.F., 2002. Zinc-sulfur and cadmium association in metalliferous pleats evidence from
887 spectroscopy, distribution coefficients, and phytoavailability. *Environ. Sci. Technol.* 36,
888 3683-3689.

889 McLaren, R.G., Crawford, D.V., 1973. Studies on soil copper. II. The specific
890 adsorption of copper by soils. *J. Soil Sci.* 24, 443-452.

891 Mínguez-Martínez, M.E., 1981. Estudio taxocenótico de los oribátidos (Acarida,
892 Oribatida) de *El Pardo*, Tesis Doctoral. Universidad Complutense de Madrid, Madrid.

893 Mitchell, M.J., 1979. Effects of physical parameters and food resources on oribatid
894 mites in forest soils, in: Rodríguez, J.G. (Ed.). *Recent Advances in Acarology*, Vol. 1,
895 Academic Press, New York, 585-592.

896 Moursi, A.A., 1962. The lethal doses of CO₂, N₂, NH₃ and H₂S for soil arthropoda.
897 *Pedobiologia* 2, 9-14.

898 Moursi, A.A., 1970a. Behaviour of soil arthropods towards gases (Acarina, Collembola,
899 and centipedes). *Bulletin of the Entomological Society of Egypt, Economics Series* 4,
900 237-239.

901 Moursi, A.A., 1970b. Toxicity of ammonia on soil arthropods. Bulletin of the
 902 Entomological Society of Egypt, Economics Series 4, 241-244.

903 Novak, M.D., Chen, W., Orchansky, A.L., Ketler, R., 2000. Turbulent exchange
 904 processes within and above a straw mulch. Part II: Thermal and moisture regimes.
 905 Agric. For. Meteorol. 102, 155-171.

906 Ortiz C., Bosch A.D., Boixadera J., 2010. Efectos de la fertilización nitrogenada con
 907 purín porcino en cereal de secano en el valle del Ebro (Cataluña, NE España), in: Usón
 908 Murillo A., Boixadera Llobet J, Bosch-Serra A.D. y Enrique Martín A. (Eds.)
 909 Tecnología de suelos: estudio de casos. Edicions i Publicacions of Lleida University,
 910 Lleida, Spain, pp. 277-291.

911 Paoletti, M.G., 1988. Soil invertebrates in cultivated and uncultivated soils in
 912 northeastern Italy. Redia 71, 501-563.

913 Perdue, J.C., Crossley, D.A. jr., 1989. Seasonal abundance of soil mites (Acari) in
 914 experimental agroecosystems: effects of drought in no-tillage and conventional tillage.
 915 Soil Till. Res. 15, 117-124.

916 Pérez-Íñigo, C., 1968. Ácaros oribátidos de suelos de España peninsular e islas Baleares
 917 (1ª parte). (Acari, Oribatei). Graellsia 24, 143-238.

918 Pérez-Íñigo, C., 1970. Ácaros oribátidos de suelos de España peninsular e islas Baleares
 919 (Parte II). (Acari, Oribatei). Eos 45, 241-317.

920 Pérez-Íñigo, C., 1971. Ácaros oribátidos de suelos de España peninsular e islas Baleares
 921 (Parte III). (Acari, Oribatei). Eos 46, 263-350.

922 Pérez-Íñigo, C., 1972. Ácaros oribátidos de suelos de España peninsular e islas Baleares
 923 (Parte IV). (Acari, Oribatei). Eos 47 [1971], 247-333.

924 Pérez-Íñigo, C., 1974. Ácaros oribátidos de suelos de España peninsular e islas Baleares
 925 (Parte V). (Acari, Oribatei). Eos 48 [1972], 367-475.

926 Pérez-Íñigo, C., 1993. Acari, Oribatei, Poronota, in: Ramos, M.A. (Ed.), Fauna Ibérica,
 927 vol.9. Museo Nacional de Ciencias Naturales, CSIC, Madrid.

928 Pérez-Íñigo, C., 1997. Acari, Oribatei, Gymnonota I, in: Ramos, M.A. (Ed.), Fauna
 929 Ibérica, vol.3. Museo Nacional de Ciencias Naturales, CSIC, Madrid.

930 Ponce, C., Bravo, C., García de León, D., Magaña, M., Alonso-López, J.C., 2011.
 931 Effects of organic farming on plant and arthropod communities: A case study in
 932 Mediterranean dryland cereal. *Agr. Ecosyst. Environ.* 141, 193-201.

933 Rhoades, J.D., Kandiah, A., Mashali, A.M., 1992. The use of saline waters for crop
 934 production. Irrigation and drainage paper 48, FAO, Rome.

935 Rodríguez Martín, J.A.; López Arias, M., Grau Corbí, J.M., 2009. Metales pesados,
 936 materia orgánica y otros parámetros de los suelos agrícolas y de pastos de España. INIA
 937 (Instituto Nacional de Investigaciones Agrarias) - MARM (Ministerio de Medio
 938 Ambiente Rural y Marino), Madrid.

939 Ruf, A., Beck, L., Dreher, P., Hund-Rinke, K., Römcke, J., Spelda, J., 2003. A
 940 biological classification concept for the assessment of soil quality: “biological soil
 941 classification scheme” (BBSK). *Agr. Ecosyst. Environ.* 98, 263-271.

942 Sapkota, T.B., Mazzonini, M., Bàrberi, P., Antichi, D., Silvestri, N., 2012. Fifteen years
 943 of no till increase soil organic matter, microbial biomass and arthropod diversity in
 944 cover crop-based arable cropping systems. *Agron. Sustain. Dev.* 32, 853-863.

945 SAS Institute, 1999-2001. SAS/TAT. Software V 8.2. SAS Institute Inc, Cary.

946 SAS Institute, 2010. JMP 9 Statistical Software. SAS Institute Inc, Cary.

947 Schuster, R., 1979. Soil mites in the marine environment, in: Rodriguez, J.G. (Ed.),
 948 Recent Advances in Acarology, Volume I, Academic Press, London, 593-602.

949 Sengbusch, H.G., 1984. A study of the possible effect of increasing salt concentration
 950 on the distribution of oribatid mites in Northwest Germany (Acariformes:Oribatida), in:
 951 Griffiths, D.A., Bowman, C.E. (Eds.). *Acarology* 6, Vol. 2, 910-916.

952 Seniczak, S., Klimek, A., Gackowski, G., Kaczmarek, S., Zalewski, W., 1997. Effect of
 953 copper smelting air pollution on the mites (Acari) associated with young Scots pine
 954 forests polluted by a copper smelting works at Głogów, Poland. II. Soil mites. *Water*
 955 *Air Soil Poll.* 97, 287-302.

956 Shimano S., 2011. Aoki's oribatid-based bioindicator systems. *Zoosymposia* 6, 200-
 957 209.

958 Siepel, H., 1994. Life-history tactics of soil microarthropods. *Biol. Fertil. Soils* 18, 263-
 959 278.

960 Skubala, P., Ciosk, M., 1999. Oribatid mites (Acari, Oribatida) colonizing the zinc
 961 metallurgic dump. *Fragm. Faun.* 42, 41-55.

962 Skubala P., Kafel, A., 2004. Oribatid mite communities and metal bioaccumulation in
 963 oribatid species (Acari, Oribatida) along the heavy metal gradient in forest ecosystems.
 964 *Environ. Pollut.* 132, 51-60.

965 Soil Survey Staff, 2006. *Soil Taxonomy: A basic system of soil classification for*
 966 *making and interpreting soil surveys.* United States Department of Agriculture,
 967 Washington. Natural Resources Conservation Service. *Agriculture Handbook.* US
 968 Government Printing Office, Washington DC.

969 Subías L.S., 1982. Oribátidos de Murcia I (Oribátidos inferiores. Parte I). (Acarida,
 970 Oribátida). *Anales de la Universidad de Murcia* 38, 133-151.

971 Subías L.S., 2014. Listado sistemático, sinonímico y biogeográfico de los ácaros
 972 oribátidos (*Acariformes: Oribatida*) del mundo (excepto fósiles). *Graellsia* 60, 3–305
 973 (2004). Actualizado en junio de 2006, en abril de 2007, en mayo de 2008, en abril de

2009, en julio de 2010, en febrero de 2011, en abril de 2012, en mayo de 2013 y en
 febrero de 2014. Available at:
http://escalera.bio.ucm.es/usuarios/bba/cont/docs/RO_1.pdf (verified 08.06.2014).
 Subías L.S., Arillo, A., 2001. Acari, Oribatei, Gymnonota II, in: Ramos, M.A. (Ed.),
 Fauna Ibérica, vol.15. Museo Nacional de Ciencias Naturales, CSIC, Madrid.
 Travé, J. 1981. Les biocénoses halophiles d'acariens de l'archipel de Kerguelen.
 C.N.F.R.A. 48, 149-158.
 Tsiafouli, M.A., Kallimanis, A.S., Katana, E., Stamou, G.P., Sgardelis, S.P., 2005.
 Responses of soil microarthropods to experimental short-term manipulations of soil
 moisture. *Appl. Soil Ecol.* 29, 17-26.
 Usher, M.B., Booth, R.G., Sparkes, K.E., 1982. A review of progress in understanding
 the organization of communities of soil arthropods. *Pedobiologia* 23, 126-144.
 Van Gestel C.A.M., Van Brummelen T.C., 1996. Incorporation of the biomarker
 concept in ecotoxicology calls for a redefinition of terms. *Ecotoxicology* 5, 217-225.
 Van Straalen N.M., 1998. Evaluation of bioindicator systems derived from soil
 arthropod communities. *Appl. Soil Ecol.* 9, 429-437.
 Wallwork, J.A., 1988. The soil fauna as bioindicators, in: *Biología Ambiental. Actas del*
Congreso de Biología Ambiental. II. Congreso Mundial Vasco. Servicio Editorial,
Universidad del País Vasco, San Sebastián, Spain.
 Weigmann, G., 2006. *Hornmilben (Oribatida)*. Verlag Goecke and Evers, Keltern.
 Weigmann, G., 2008. Oribatid mite communities in Atlantic salt marshes: an ecological
 and biogeographical comparison between German and Portuguese sea shores, in:
 Bertrand, M., Kreiter, S., McCoy, K.D., Migeon, A., Navajas, M., Tixier, M.S., Vial, L.
 (Eds.), *Integrative acarology. Proceedings of the 6th European Congress. Montpellier,*
21-25 July. European Association of Acarologists, 275-283.

999 Weil, R.R., Kroontje, W., 1979. Effects of manuring on the arthropod community in an
1000 arable soil. *Soil Biol. Biochem.* 11, 669-679.

1001 Wissuwa, J., Salamon, J.A., Frank, T., 2013. Oribatida (Acari) in grassy arable fallows
1002 are more affected by soil properties than habitat age and plant species. *Eur. J. Soil Biol.*
1003 59, 8-14.

1004 Yagüe, M.R., Bosch-Serra, A.D., Antúnez, M., Boixadera, J., 2012a. Pig slurry and
1005 mineral fertilization strategies' effects on soil quality: macroaggregate stability and
1006 organic matter fractions. *Sci. Total Environ.* 438, 218–224.

1007 Yagüe, M.R., Bosch-Serra, A.D., Boixadera, J., 2012b. Measurement and estimation of
1008 the fertiliser value of pig slurry by physicochemical models: Usefulness and constraints.
1009 *Biosyst. Eng.* 111, 206-216.

1010 Zaitsev, A.S., Van Straalen, N.M., 2001. Species diversity and metal accumulation in
1011 oribatid mites (Acari, Oribatida) of forest affected by a metallurgical plant.
1012 *Pedobiologia* 45, 467-479.

1013 Żyromska-Rudzka, H., 1976. The effect of mineral fertilization of a meadow on the
1014 oribatid mites and other soil mesofauna. *Pol. Ecol. Stud.* 2, 157-182.

Legends to Figures

Figure 1. Monthly rainfall, reference crop evapotranspiration (ET_0 , FAO Penman-Monteith equation) and mean air temperature averages from an automatic meteorological station located in the experimental field during the cropping year (July 2011 - June 2012).

Figure 2. Shannon index of diversity, Oribatida abundance (A), and Berger-Parker index of abundance (B) from October 2011 to February and May 2012 samplings, and according to different soil management treatments: minimum and no tillage combined with ($25 \text{ t ha}^{-1} \text{ year}^{-1}$) or without (0) slurry fertilization from fattening pigs (FS), applied at sowing. Between tillage systems or fertilization treatments, comparisons were set up separately for each sampling month. Means followed by a different letter (“x” or “y” for comparisons between tillage systems; “a” or “b” for comparisons between fertilization treatments) are significantly different (5% level). For Oribatida abundance in February (linked to fertilization treatment) and Berger-Parker index, the 0.1 level of significance was used.

Figure 3. Dominance curves (decreasing rank) of Oribatida species in May samplings, in the forest and in no-tillage plots (NT). No-tillage was combined with maximum annual rates of 120 kg N ha^{-1} , 55 t ha^{-1} and 80 t ha^{-1} of mineral fertiliser (M), slurry from fattening pigs (FS) and slurry from sows (SS), respectively. Fertilizers were just applied at cereal tillering (February), not at sowing time (0).

Figure 4. Ordination diagram from a principal component analysis of the 22 identified oribatid mite species represented by more than 4 specimens. The most relevant species from agricultural plots are labelled: *E. cylindrica*: *Epilohmannia cylindrica cylindrica* (Berlese, 1904); *O. connexa*: *Oribatula (Zygoribatula) connexa connexa* (Berlese, 1904); *P. africanus*: *Passalozetes (Passalozetes) africanus* (Grandjean, 1932); *S.*

1040 *sculptus*: *Scutovertex sculptus* (Michael, 1879); *T. sarekensis*: *Tectocephus velatus*
1041 *sarekensis* (Trägårdh, 1910).

1042 Figure 5. Hierarchical clustering analysis of the seven oribatid mite species associated
1043 to the 95.3% cumulative percentage of variance in the principal component analysis.
1044 Dendrograms were calculated using flexible treatment grouping where the proximity
1045 measure is Euclidean distance.

1046 **Appendix A.**
1047 List of Oribatida species following the systematic ordination from Subías (2014). The absolute abundance, for each fertilization
1048 treatment combined with minimum tillage (MT) or no-tillage (NT), and for the forest[†] are included. Data are divided according to
1049 sampling period.

Oribatid families and species	October				February				May																
	0-0-MT	0-0-NT	25FS-0-MT	25FS-0-NT	0-0-MT	0-0-NT	25FS-0-MT	25FS-0-NT	0-0-MT	0-0-NT	25FS-0-MT	25FS-0-NT	0-60M-MT	0-60M-NT	0-120M-MT	0-120M-NT	0-30FS-MT	0-30FS-NT	0-55FS-MT	0-55FS-NT	0-55SS-MT	0-55SS-NT	0-80SS-MT	0-80SS-NT	FOREST
Cosmochthoniidae Grandjean, 1947																									
<i>Cosmochthonius (Cosmochtonius) foliatus</i> Subías, 1982	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
<i>Sphaerochthonius splendidus</i> (Berlese, 1904)	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	23
Lohmanniidae Berlese, 1916																									
<i>Papillacarus aciculatus</i> (Berlese, 1905)	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Epilohmanniidae Oudemans, 1923																									
<i>Epilohmannia cylindrica cylindrica</i> (Berlese, 1904)	6	30	25	33	4	5	5	25	4	21	9	41	18	42	40	25	36	6	30	21	12	23	54	19	3
Euphthiracaridae Jacot, 1930																									
<i>Acrotritia curticephala</i> (Jacot, 1938)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
Phthiracaridae Perty, 1841																									
<i>Phthiracarus</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12
Trhypochthoniidae Willmann, 1931																									
<i>Trhypochthonius tectorum tectorum</i> (Berlese, 1896)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12
Neoliodidae Sellnick, 1928																									
<i>Neoliodes theleproctus</i> (Hermann, 1804)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
<i>Poroliodes farinosus</i> (Koch, 1839)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Licnodamaeidae Grandjean, 1954																									
<i>Licnoliodes adminensis</i> Grandjean, 1933	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	63
Licnobelbidae Grandjean, 1965																									
<i>Licnobelba latiflabellata</i> (Paoli, 1908)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Ceratoppiidae Kunst, 1971																									

<i>Ceratoppia bipilis bipilis</i> (Hermann, 1804)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Gustaviidae Oudemans, 1900																									
<i>Gustavia longicornis</i> (Berlese, 1904)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Liacaridae Sellnick, 1928																									
<i>Liacarus (Doryceranosus) curtipilis</i> Willmann, 1935	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Zetorchestidae Michael, 1898																									
<i>Belorcheses gebennicus</i> Grandjean, 1957	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19
Ctenobelbidae Grandjean, 1965																									
<i>Ctenobelba (Ctenobelba) pectinigera</i> (Berlese, 1908)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15
Oppiidae Sellnick, 1937																									
<i>Oppia denticulada</i> (G. and R. Canestrini, 1882)	-	-	-	-	2	3	5	10	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	6
<i>Ramusella (Ramusella) sengbuschi sengbuschi</i> Hammer, 1968	-	1	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Tainsculptoppia subiasi</i> (Pérez-Íñigo jr., 1990)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26
<i>Microppia minus minus</i> (Paoli, 1908)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
<i>Rhinoppia (Rhinoppia) minidentata</i> (Subías and Rodríguez, 1988)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
<i>Neotrichoppia (Confinoppia) confinis tenuiseta</i> Subías and Rodríguez, 1986	1	-	-	2	-	-	-	-	3	3	17	9	2	1	5	6	4	6	-	6	1	4	3	3	30
Suctobelbidae Jacot, 1938																									
<i>Suctobelbella (Suctobelbella) sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Carabodidae Koch, 1837																									
<i>Carabodes (Klapperiches) translamellatus</i> Pérez-Íñigo jr., 1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Tectocephidae Grandjean, 1954																									
<i>Tectocephus velatus sarekensis</i> Trägårdh, 1910	26	31	53	38	2	23	27	41	5	69	6	50	17	75	11	30	34	29	2	23	30	32	6	21	17
Scutoverticidae Grandjean, 1954																									
<i>Scutovertex sculptus</i> Michael, 1879	2	4	-	2	2	42	5	42	5	23	5	30	1	5	1	1	10	14	5	1	4	42	2	6	-
Passalozetidae Grandjean, 1954																									
<i>Passalozetes (Passalozetes) africanus</i> Grandjean, 1932	111	42	97	16	36	89	105	119	25	34	5	45	15	7	12	57	24	28	7	15	11	10	9	19	-
Chamobatidae Thor, 1937																									
<i>Chamobates (Chamobates) pusillus</i> (Berlese, 1895)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Oribatulidae Thor, 1929																									
<i>Lucoppia burrowsi</i> (Michael, 1890)	-	-	-	-	-	-	5	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	1

<i>Oribatula (Zygoribatula) connexa connexa</i> Berlese, 1904	28	11	71	13	11	48	24	59	8	5	24	11	39	26	5	7	3	3	2	7	15	29	5	3	5
Scheloribatidae Grandjean, 1933																									
<i>Scheloribates (Scheloribates) minifimbriatus</i> Mínguez, Subias and Ruiz, 1986	-	-	-	-	-	-	-	-	7	4	14	4	5	-	2	3	4	2	-	1	-	3	1	-	19
Protoribatidae J. and P. Balogh, 1984																									
<i>Protoribates (Protoribates) capucinus capucinus</i> Berlese, 1908	-	2	2	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Transoribates latus</i> (Mihelčič, 1965)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Galumnidae Jacot, 1925																									
<i>Galumna (Galumna) tarsipennata</i> Oudemans, 1914	5	1	-	3	5	2	5	86	2	1	-	3	4	21	-	4	3	7	1	3	2	2	1	12	5

1050 † Acronyms of fertilization treatments are described in Table 1.

1051 **Table 1.** Fertilization treatments including averages of the total nitrogen (organic plus mineral) applied (TN)[†], ammonium N (NH₄⁺-N) and
1052 organic matter (OM) applied annually to the experimental fields and also for the sampling year. Fertilizers (mineral or from different slurry
1053 sources) were applied at sowing or at cereal tillering. Sampling dates for the oribatid mite study are included.
1054

Fertilization treatment	Annual slurry fertilizer application		Averages from October 2002 (sowing) to June 2011 (harvest)			Fertilization on 26 October 2011 (sowing)			Fertilization on 6 March 2012 (tillering)			Oribatida sampling date [‡]
	Sowing	Tillering	TN	NH ₄ ⁺ -N	OM	TN	NH ₄ ⁺ -N	OM	TN	NH ₄ ⁺ -N	OM	
			----- kg ha ⁻¹ yr ⁻¹ (± SD) § -----			----- kg ha ⁻¹ -----						
0-0	0	0	0	0	0	0	0	0	0	0	0	1, 2, 3
0-60M	0	0	60	0	0	0	0	0	60	0	0	3
0-120M [¶]	0	0	120	0	0	0	0	0	120	0	0	3
0-30FS [#]	0	30FS	210 (± 48)	139 (± 31)	1533 (± 858)	0	0	0	216	146	2111	3
0-55FS	0	55FS	389 (± 84)	259 (± 61)	2834 (± 810)	0	0	0	371	248	3834	3
0-55SS ^{††}	0	55SS	92 (± 49)	59 (± 28)	663 (± 1542)	0	0	0	135	93	1425	3
0-80SS	0	80SS	179 (± 95)	108 (± 54)	1952 (± 1470)	0	0	0	202	140	2134	3
25FS-0	25FS	0	194 (± 47)	132 (± 37)	1710 (± 240)	176	105	1943	0	0	0	1, 2, 3

1055
1056 [†] The difference between the total nitrogen applied and the nitrogen in NH₄⁺-N form equals to the organic N applied.
1057 [‡] Numbers 1, 2 and 3 indicate date of sampling: in October (2011.10.20), in February (2012.02.24) and in May (2012.05.23), respectively.
1058 [§] SD: standard deviation.
1059 [¶] M: mineral N fertilizer applied as ammonium nitrate or as ammonium calcium nitrate, as sidedressing. Numbers indicate the applied rate: 60 kg
1060 N ha⁻¹ yr⁻¹ or 120 kg N ha⁻¹ yr⁻¹.
1061 [#] FS: slurry from fattening pigs. Numbers indicate the average theoretical applied rates in the 2011-2012 campaign: 25 t ha⁻¹ yr⁻¹, 30 t ha⁻¹ yr⁻¹ or
1062 55 t ha⁻¹ yr⁻¹, which are associated to a real average rates of 25, 30 and 54 t ha⁻¹ yr⁻¹, respectively.
1063 ^{††} SS: slurry from sows. Numbers indicate the theoretical applied rates in the 2011-2012 campaign: 55 t ha⁻¹ yr⁻¹ or 80 t ha⁻¹ yr⁻¹, which are
1064 associated to a real average rates of 56 and 83 t ha⁻¹ yr⁻¹, respectively.
1065
1066

1067 **Table 2.** Pig slurry characteristics, for the 2011-2012 crop season not included in the general description of treatments: pH, electrical
1068 conductivity (EC), and dry matter (DM), plus phosphorus (P), potassium (K) and copper (Cu) content[†] obtained by acid extraction. The total
1069 amount of Cu applied for each treatment is also included.

Fertilization treatment (at sowing –at tillering)	pH (1:5 [‡])	EC (1:5 [‡]) dS m ⁻¹	DM %	P ---	K % ---	Cu mg kg ⁻¹	Cu kg ha ⁻¹
0-30FS [§]	8.7	6.31	9.7	2.2	4.4	309	0.9
0-55FS							1.6
0-55SS [#]	8.7	2.11	3.5	2.4	2.5	352	0.7
0-80SS							1.0
25FS-0	8.7	6.25	11.4	2.0	5.3	333	0.9

1070 [†] On a dry matter basis.

1071 [‡] Ratio slurry: distilled water.

1072 [§] FS: slurry from fattening pigs. Numbers indicate the average theoretical applied rates in the 2011-2012 campaign: 25 t ha⁻¹ yr⁻¹, 30 t ha⁻¹ yr⁻¹ or
1073 55 t ha⁻¹ yr⁻¹, which are associated to a real average rates of 25, 30 and 54 t ha⁻¹ yr⁻¹, respectively.

1074 [#] SS: slurry from sows. Numbers indicate the theoretical applied rates in the 2011-2012 campaign: 55 t ha⁻¹ yr⁻¹ or 80 t ha⁻¹ yr⁻¹, which are
1075 associated to a real average rates of 56 and 83 t ha⁻¹ yr⁻¹, respectively.

1076 **Table 3.** Accumulated grain yield (0% humidity) and straw biomass throughout 8 winter cereal growing seasons, for plots under different
1077 fertilization treatments (from 2002 to 2011 harvests), and combined with minimum tillage (MT) or no-tillage (NT) from 2009 sowing onwards.
1078

Fertilization treatments during the cereal growing season (at sowing –at tillering)	Grain yield		Straw biomass [†]	
	MT	NT	MT	NT
	----- kg ha ⁻¹ -----			
0-0	21116	22618	25605	28322
0-60M [‡]	26610	27021	35974	37115
0-120M	25737	25453	37361	37453
0-30FS [§]	31387	31987	41821	44435
0-55FS	25430	26011	43755	45935
0-55SS [¶]	29244	29548	38026	37482
0-80SS	29317	29801	41443	41603
25FS-0	26594	23731	37602	31489

1079

1080 [†] Stubble accounts for 38% of straw biomass.

1081 [‡] M: mineral nitrogen fertilizer applied at cereal tillering. Numbers indicate the applied rate: 60 kg N ha⁻¹ yr⁻¹ or 120 kg N ha⁻¹ yr⁻¹.

1082 [§] FS: slurry from fattening pigs. Numbers indicate the average theoretical applied rates in the 2011-2012 campaign: 25 t ha⁻¹ yr⁻¹, 30 t ha⁻¹ yr⁻¹ or
1083 55 t ha⁻¹ yr⁻¹.

1084 [¶] SS: slurry from sows. Numbers indicate the theoretical applied rates in the 2011-2012 campaign: 55 t ha⁻¹ yr⁻¹ or 80 t ha⁻¹ yr⁻¹.

1085

1086 **Table 4.** Soil average water content (% w/w) at sampling depth (0-5cm) from agronomic treatments[†]: 0-0MT, 0-0NT, 25FS-0MT, 25FS-0NT,
 1087 and for the forest area[‡]. Sampling was done during the 2011-2012 winter cereal cropping season.
 1088

Month/ year	Minimum tillage (MT)	No-tillage (NT)	Forest
	-----% (± SD) [§] -----		
October/ 2011	4.11 (± 0.85)	4.74 (± 0.92)	-
February/ 2012	8.46 (± 1.36)	9.29 (± 1.26)	-
May/ 2012	9.87 (± 1.58)	10.62 (± 1.44)	25.78 (± 4.13)

1089
 1090 [†] Numbers are fertilizer applied rates (at sowing-at tillering); 0: no N applied; 25FS: 25 t of pig slurry from fattening pigs ha⁻¹ yr⁻¹.
 1091 [‡] Average gravimetric soil water content at wilting point (-1500 kPa) and at field capacity (-33 kPa) was 9.2% and 22.2% for agricultural plots
 1092 and 16.0% and 28.5% for the forest; respectively.
 1093 [§] SD: standard deviation.

1094 **Table 5.** Average soil characteristics (0-10 cm) in May 2012 samplings, for different fertilization treatments in the agricultural soil (n=6) and in
1095 the forest soil (n=3): pH (potentiometry), electrical conductivity (EC), organic matter (OM, Walkley–Black), total nitrogen (N, Kjeldahl), carbon
1096 to nitrogen ratio (C/N) and nitrate mineral nitrogen (NO₃⁻-N , cadmium column technique, Maynard and Kalka 1993), phosphorus (P, Olsen) and
1097 potassium (K, NH₄AcO 1N) content. The standard deviation of values (± SD) is included for the forest.

Fertilization treatments in agricultural plots and the forest	pH (1:2.5 [†])	EC (1:5 [†] , 25°C) dS m ⁻¹	OM ----- % -----	N ----- % -----	C/N	NO ₃ ⁻ -N ----- mg kg ⁻¹ -----	P	K
0-0	8.3	0.15 b	1.6 b	0.12 b	7.5	0.97 b	31 de	279 c
0-60M [‡]	8.3	0.19 a	1.7 ab	0.10 b	8.3	- na -	40 c	294 c
0-120M	8.3	0.15 b	1.6 b	0.12 b	7.9	5.11 a	24 e	188 d
0-30FS [§]	8.3	0.16 ab	1.8 ab	0.13 ab	7.9	2.13 b	53 b	408 b
0-55FS	8.3	0.17 ab	1.9 a	0.14 a	7.7	5.05 a	78 a	528 a
0-55SS [#]	8.4	0.14 b	1.6 b	0.12 b	7.3	1.71 b	35 cd	280 c
0-80SS	8.3	0.15 b	1.8 ab	0.13 ab	7.8	2.19 b	52 b	258 cd
25FS-0	8.3	0.14 b	1.8 ab	0.13 ab	8.1	1.57 b	36 cd	268 c
Significance	ns	**	***	**	ns	***	***	***
Forest	8.0 (±0.1)	0.18 (±0.02)	8.0 (±1.0)	0.36 (±0.14)	13.0 (±1.1)	- na -	11 (±2)	196 (±13)

1098 ns: not significant; ** Significant at the 0.01 probability level;*** Significant at the 0.001 probability level.

1099 Within columns of agricultural plots, means followed by the same letter are not significantly different according to DMRT at the 5% level.

1100 na: not available.

1101 [†]Ratio soil: distilled water.

1102 [‡]M: mineral nitrogen fertilizer applied at cereal tillering. Numbers indicate the applied rate: 60 kg N ha⁻¹ yr⁻¹ or 120 kg N ha⁻¹ yr⁻¹.

1103 [§]FS: slurry from fattening pigs. Numbers indicate the average theoretical rates applied in the 2011-2012 campaign: 25 t ha⁻¹ yr⁻¹, 30 t ha⁻¹ yr⁻¹ or
1104 55 t ha⁻¹ yr⁻¹, which are associated to a real average rates of 25, 30 and 54 t ha⁻¹ yr⁻¹, respectively.

1105 [#]SS: slurry from sows. Numbers indicate the theoretical rates applied in the 2011-2012 campaign: 55 t ha⁻¹ yr⁻¹ or 80 t ha⁻¹ yr⁻¹, which are
1106 associated to a real average rates of 56 and 83 t ha⁻¹ yr⁻¹, respectively.

1107

1108 **Table 6.** Summary of the analysis of variance (GLM procedure) of the response to the fattening slurry application (or not) at sowing (Fsowing)
1109 and to the tillage system (Tillage: minimum or no-tillage), in Oribatida abundance, Shannon diversity index and Berger-Parker dominance index,
1110 during a winter cereal cropping season.
1111

Sampling date	Abundance			Shannon diversity index			Berger-Parker dominance index		
	Fsowing	Tillage	Fsowing x Tillage	Fsowing	Tillage	Fsowing x Tillage	Fsowing	Tillage	Fsowing x Tillage
October 2011	ns	ns	ns	ns	*	ns	†	†	ns
February 2012	†	*	ns	ns	ns	ns	ns	ns	ns
May 2012	ns	**	ns	**	**	**	ns	†	ns

1112
1113 †, *, **. Significant at the 0.10, 0.05 and 0.01 probability level, respectively. ns: not significant.
1114 No significant differences were associated to blocks or their interactions with the main treatments.

1115 **Table 7.** Average values[†] of Oribatida abundance (individuals m⁻²), Shannon diversity index (*H'*) and Berger-Parker dominance index (*d*) for
1116 May samplings in agricultural plots, and according to soil management treatment: minimum tillage (MT) or no-tillage (NT), and fertilization at
1117 cereal tillering [‡].
1118

Variable	Tillage system		Fertilization at cereal tillering, without N fertilization at sowing [§]						
	MT	NT	0	60M	120M	30FS	55FS	55SS	80SS
Abundance	3121 (18990) y	5162 (16854) x	4304 (18103) ab	5448 (19690) a	4052 (18108) ab	4149 (18400) ab	2404 (15814) b	4285 (18191) ab	3199 (17147) ab
<i>H'</i>	0.57 (-0.50)	0.62 (-0.45)	0.62 (-0.45)	0.62 (-0.45)	0.52 (-0.53)	0.66 (-0.40)	0.53 (-0.53)	0.62 (-0.45)	0.55 (-0.51)
<i>d</i>	0.47 (-0.35)	0.44 (-0.38)	0.43 (-0.38)	0.43 (-0.38)	0.53 (-0.31)	0.37 (-0.45)	0.48 (-0.36)	0.45 (-0.37)	0.50 (-0.34)

1119
1120 [†] Numbers in brackets are Box-Cox transformed data.
1121 [‡] No interaction in the analysis of variance (GLM procedure) was found between type of tillage at sowing and fertilization at cereal tillering.
1122 Within a row, means followed by the same letter are not significantly different according to Duncan Multiple Range Test at the 5% level of
1123 significance.
1124 [§] M: mineral nitrogen fertilizer. Numbers indicate the applied rate: 60 kg N ha⁻¹ yr⁻¹ or 120 kg N ha⁻¹ yr⁻¹;
1125 FS: slurry from fattening pigs. Numbers indicate the average theoretical applied rate: 30 t ha⁻¹ yr⁻¹ or 55 t ha⁻¹ yr⁻¹;
1126 SS: slurry from sows. Numbers indicate the average theoretical applied rate: 55 t ha⁻¹ yr⁻¹ or 80 t ha⁻¹ yr⁻¹.
1127

1128 **Table 8.** Average values[†] of abundance (individuals m⁻²), Shannon diversity index and Berger-Parker dominance index for the forest and no-
1129 tillage plots (NT), in May samplings. No-tillage plots are combined with maximum rates of different fertilizers applied at cereal tillering.
1130

Soil use strategy [‡]	Forest	0-0-NT	0-120M-NT	0-55FS-NT	0-80SS-NT
Abundance	5681 (19741)	6205 (20995)	5158 (19316)	2986 (16893)	3219 (17464)
Shannon diversity index	0.91 (-0.11) a	0.56 (-0.51) b	0.59(-0.48) b	0.62 (-0.45) b	0.66 (-0.40) b
Berger-Parker dominance index	0.26 (-0.60) b	0.44 (-0.36) a	0.52 (-0.29) a	0.39 (-0.43) ab	0.35 (-0.47) ab

1131
1132 [†] Numbers in brackets are Box-Cox transformed values. Within rows, means followed by the same letter are not significantly different according
1133 to DMRT at 5% level.
1134 [‡] Fertilization applied at sowing (0: no nitrogen)-fertilization at cereal tillering (0: no nitrogen; 120M: 120 kg N ha⁻¹ yr⁻¹ of mineral fertilizer;
1135 55FS: 56 t ha⁻¹ yr⁻¹ of slurry from fattening pigs; 80SS: 83 t ha⁻¹ yr⁻¹ of slurry from sows)-tillage management.
1136

1137 **Table 9.** Ordination of oribatid mite species[†] according to the principal component analysis[‡].
 1138

Axes	1	2	3	4	5	6	7
Eigenvalue	110.5	80.0	46.2	31.2	25.8	18.6	10.8
Accumulated percentage of fitted variance	32.5	56.1	69.6	79.0	86.6	92.1	95.3
Species	<i>T. sarekensis</i>	<i>E. cylindrica</i>	<i>P. africanus</i>	<i>L. adminensis</i>	<i>S. sculptus</i>	<i>O. connexa</i>	<i>T. subiasi</i>
Eigenvector	0.88	0.96	-0.81	0.66	-0.85	0.69	0.83

1139
 1140 [†] *E. cylindrica*: *Epilohmannia cylindrica cylindrica* (Berlese, 1904); *O. connexa*: *Oribatula (Zygoribatula) connexa connexa* (Berlese, 1904); *P.*
 1141 *africanus*: *Passalozetes (Passalozetes) africanus* (Grandjean, 1932); *S. sculptus*: *Scutovertex sculptus* (Michael, 1879); *T. sarekensis*:
 1142 *Tectocephus velatus sarekensis* (Trägårdh, 1910); *L. adminensis*: *Licnoliodes adminensis* (Grandjean, 1933); *T. subiasi*: *Tainsculptoppia subiasi*
 1143 (Pérez-Iñigo jr., 1990).
 1144 [‡] Eigenvectors from the covariance matrix are ordered by eigenvalues (highest to lowest), which means that components are in order of
 1145 significance.

1146 **Fig. 1**

1147

1148

1149

1151 **Fig. 3**

1152

1153

Fig. 4.