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Tillage and slurry over-fertilization affect oribatid mite communities in a semiarid Mediterranean environment

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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: $<210\,\mathrm{kg\,N\,ha^{-1}\,yr^{-1}}$). 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 *Tectocepheus 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.

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

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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 Parmelee, 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 $t\,ha^{-1}\,yr^{-1}$) 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 symphypleona 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 be added their traits of low dispersion ability (Lebrun and Van Straalen, 1995) and relatively long period of adult life, which helps with the assessment of long-term disturbances. Besides, the density and distribution of oribatid species are closely related with food quality and disturbance (Maraun and Scheu, 2000); i.e. soil disturbance by tillage (whatever the cultivation system is) reduces the presence of microphytophagous oribatida species (Hülsmann and Wolters, 1998).

Iturrondobeitia et al. (2004) recommend classifying at a species level in order to use oribatid mites as bioindicators, as the behaviour of species from the same genus, confronted with different impacts, is known to vary. Shimano (2011) adds that the use of oribatid mites as bioindicators might also be based on the succession of the oribatid fauna, studying the dominance of species or of specimens for different groups.

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

In agricultural systems of arid or semiarid regions without artificial irrigation (dryland agricultural systems), where precipitation is below evapotranspiration demand, the study of oribatid mites may have some additional constraints. It has been noted that periods of drought reduce their abundance in a humid tropical floodplain (Perdue and 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 (NH_3) 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 over-fertilization), 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 m^{-2}), 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