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Microfaunal soil food webs in Mediterranean semi-arid agroecosystems. Does organic management improve soil health?

Sara Sánchez-Moreno[a,*], Miriam Cano[a], Antonio López-Pérez[b], José M. Rey Benayas[c]

[a] UPF (DTEVPF) National Institute for Agriculture and Food Research and Technology, Ctra. de la Coruña km 7.5 28040 Madrid, Spain
[b] Centro de Investigación Apícola y Agroambiental (CIAPA, IRIAF) 19180 Marchamalo, Guadalajara, Spain
[c] Forest Ecology and Restoration Group, Departamento de Ciencias de la Vida, Edificio de Ciencias, Universidad de Alcalá, 28805 Alcalá de Henares, Spain

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ABSTRACT

Soil food webs, which are responsible for relevant ecological functions in agroecosystems such as nutrient cycling and pest and disease suppression, represent a crucial aspect of agricultural sustainability. We studied soil properties and microfaunal food web diversity and functioning in six paired organic and conventional fields located in Central Spain to assess the effects of organic farming on soil diversity and functioning in semi-arid conditions. We hypothesized that organic farming may enhance functioning of soil food webs. Our results showed larger differences between crop types, namely olive groves and vineyards, than between farming scheme, i.e. organic and conventional fields, and few benefits of organic farming in terms of soil fertility. Soil properties (total N, C, and P, available P and K, electrical conductivity, NH_4^+, NO_3^-, soil moisture, pH) tended to present higher values in vineyards than in olive groves and in conventional than in organic fields. Some plant-parasitic nematodes were associated to organic fields, especially in vineyards, and all soils fell within a degraded soil food web condition, with low Structure and Enrichment Index values. Nematode metabolic footprints showed relevant seasonal dynamics, with the more intensive herbivore activity in spring. We conclude that the lack of conventional pesticides and mineral fertilizers is probably not enough to improve soil conservation in semi-arid Mediterranean agroecosystems, and thus active soil conservation practices, as reduced tillage or cover cropping, are required to increase agroecosystem sustainability.

1. Introduction

Microfaunal food webs play critical role in soil functioning. Nematodes, the most abundant metazoan organisms in microfaunal food webs, are relevant components of belowground C cycling in spite of their low absolute biomass (Pausch et al., 2016). They occupy multiple positions in the soil food web and present high taxonomic and functional diversity (Ettema, 1998). Among other functions, nematodes participate in nitrogen and carbon mineralization (Bouwman et al., 1994), the regulation of microbial communities (Villenave et al., 2004), pest suppression (Steel and Ferris, 2016), and the redistribution of other organisms in the soil matrix (Knox et al., 2003). Appropriate soil management to enhance soil fauna contribution to soil functioning and derived ecological services should be promoted to increase agricultural sustainability.

Different management systems intended to reduce soil chemical and physical disturbance may improve such agricultural sustainability. In this context, organic farming has been under continuous expansion during the last years in the European Union. The area under organic farming in Europe has notably increased, with the mean annual growth from 6% (EU-27) to 13% (EU-12) from 2002 to 2013 (European Commission, 2013). In 2015, the eight countries with largest areas under organic management hold between 0.46 and 1.9×10^6 ha per country. Among those Spain demonstrates the largest share of and is followed by Italy and France (EUROSTAT, 2016a). Nowadays, public concerns on the effects of pesticides on human health and the environment have increased (Miller, 2013).

Several local studies and meta-analyses have shown the value of organic farming for biodiversity. In their meta-analyses, Bengtsson et al. (2005) and Hole et al. (2005) found that a number of taxonomic groups (including birds, insects, mammals, and plants) usually show increased species richness and abundance in organic as compared to conventional farming systems. Although the effects of organic farming on belowground diversity has been less studied, some reports indicate that organic farming increases arbuscular-mycorrhizal fungi (Verbruggen et al., 2010) and supports higher microbial activity (França et al., 2007). Other studies, however, have found organic farming to be more effective conserving aboveground than belowground diversity (Flohre

* Corresponding author.
E-mail address: sarasm@inia.es (S. Sánchez-Moreno).

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et al., 2011). A comparison of organic and conventional kiwifruit orchards showed that earthworms were negatively affected by conventional practices, while mesofauna (enchytraeids, mites, and collembolans) were stimulated by conventional management (Castro et al., 2015), but reports on the effects of organic farming on soil diversity under semiarid conditions are scarce. Under semiarid conditions, organic farming may increase C and N soil pools (Parras-Alcántara et al., 2015), and conversion from grassland to cultivated organic farming might increase functional microbial diversity (Nautiyal et al., 2010).

Vineyards and olive orchards are typical semi-arid Mediterranean crops and a major feature of the heritage in the Mediterranean basin, where they play an important environmental role fixing soils, maintaining biodiversity, and contributing to producing environmentally rich landscapes (Biasi et al., 2012). There are generally few studies on soil diversity in these woody crops, and the effects of different management systems in such diversity and their associated functions and services have been little addressed.

Among soil organisms, nematodes possess several attributes that make them good indicators. Nematodes are abundant, ubiquitous and diverse, participate in several soil food web links and are sensitive to agricultural disturbance (Yeates, 2003). Due to such attributes, multiple nematode-based indicators have been developed. Besides classical diversity indices, maturity indices have been used to infer the position of the nematode community along the ecological succession (Bongers, 1990; Korthals et al., 1996), and soil food web indices are used to infer food web complexity and main channels of organic matter decomposition (Ferris et al., 2004). Nematode functional guilds have been shown to reflect soil food web functions in response to, for example, global change (Cesarz et al., 2015). Nematode metabolic footprints (NMF), proposed by Ferris (2010), assess the magnitude of nematode contribution to soil functioning by partitioning the amount of C used by nematodes in production (biomass growth, egg laying) and lost in respiration. The inference of soil nematode biomass and the partitioning of nematode C use into such components allow inferring nematode trophic group activity (herbivores, bacterivores, fungivores, and omnivore/carnivore nematodes) and functional groups (enrichment, basal, and structure nematode indicators). NMF has been found to be sensitive to tillage (Zhang et al., 2012), cover cropping (Ferris et al., 2012b), fertilization (Zhang et al., 2016a), and microclimate variations (Bhusal et al., 2015). The inclusion of inferred nematode biomass in calculation of nematode-based diversity indices (Ferris and Tuomisto, 2015) open new perspectives in the analyses of the functionality of soil organisms.

Spain holds the largest vineyard and olive-growing areas in Europe, with 0.8 and 2.2×10^6 ha, respectively (EUROSTAT, 2016b). Within the country, Castilla-La Mancha, in the South-Central part of Spain, possesses the largest area of vineyards and the second largest area of olive trees (MAPAMA, 2017a). Here we studied soil properties and nematode food webs in organic and conventional olive groves and vineyards in South-Central Spain to evaluate 1) nematode diversity in woody crops under semiarid conditions, and 2) the effects of organic and conventional practices on soil functioning in such systems. We hypothesized that organic agroecosystems harbour a greater nematode diversity, soil food web complexity, and soil functioning that conventional agroecosystems.

2. Material and methods

2.1. Study site

The study was carried out in Ciudad Real province (near Valdepeñas, 38° 45′ N - 3° 23′ W, Castilla-La Mancha region, South-Central Spain). The area has a typical Mediterranean climate with a mean annual temperature of 15.6 °C and precipitation of 418 mm (MAPAMA, 2017b). Soils included in the study were classified as calcil cambisols and presented a loam texture with an average of 20.8% clay, 31.7% silt and 47.5% sand.

Table 1
Location, type of management, field size, and type of irrigation of the studied farms. No. of trees per hectare (in olive groves) and training system (in vineyards) is indicated.

Olive	Location	Management	ha	No. trees/ha	Irrigation
Site 1	38º 49' 19" N	ORG	2.8	50	rainfed
	3º 16' 41" W	CONV	1.4	50	rainfed
Site 2	38º 49' 19" N	ORG	1.6	70	rainfed
	3º 16' 34" W	CONV	1.6	80	rainfed
Site 3	38º 48' 48"	ORG	2.7	100	rainfed
	3º 12' 42"	CONV	3.0	100	rainfed

Vineyard	Location	Management	ha	Training	Irrigation
Site 1	38º 49' 16"	ORG	2.9	None	rainfed
	3º 16' 44"	CONV	3.4	None	rainfed
Site 2	38º 47' 42" N	ORG	1.9	Metal posts	irrigated
	3º 9' 19" W	CONV	2.1	None	rainfed
Site 3	38º 47' 29" N	ORG	4.6	Metal posts	irrigated
	3º 9' 16"	CONV	5.7	None	rainfed

Three olive growing and three vine growing sites were chosen in the study area. At each site, two adjacent fields, one conventional and one organic, were selected as representatives of typical management in the region. If no adjacent fields were available, the organic and conventional fields at each pair were as nearby as possible (four out of the six pairs were adjacent or a few meters apart, for the other two maximum distance between paired fields was 500 m). In total, 12 fields (3 organic and 3 conventional vineyards and 3 organic and 3 conventional olive groves) were included in this study. Each pair of fields was selected to be as similar as possible to make straightforward comparisons. Location, type of management, field area, tree density (in the case of olive groves), type of training (in vineyards), and irrigation systems in the fields are indicated in Table 1.

Field management was quite similar among conventional or organic fields. All conventional fields were fertilized in spring with mineral fertilizers (NPK 15:15:15), at a rate of 450 kg/ha in vineyards and 2 kg/tree in olive groves. Chemical weeding with glyphosate at standard recommended field doses occurred once a year (January–February) in olive groves and twice a year (July and August) in vineyards. In conventional vineyards, paclobutrazol was applied annually as plant growth regulator. Tebuconazole and copper oxychloride were used a maximum of once a year in vineyards and olive groves, respectively.

Organic fields were all certified and did not use any mineral fertilizer or chemical pesticide. Sulphur 98.5% was typically used every spring as main fungicide in organic vineyards. In organic olive groves *Bacillus thuringiensis* was used to control insect pests when necessary. One organic olive grove grew and incorporated a chickpea green manure every three years.

Sheep manure was used as soil amendment in all conventional and organic fields every two years at rates around 5000 kg/ha in vineyards, and every 2–3 years at 3500 kg/ha in olive groves. All conventional and organic fields were tilled 4–6 times a year at 20–30 cm depth to control weeds, and the soil was continuously bare in all systems.

2.2. Soil sampling

In each olive grove, five individual trees were chosen in the central area of each field. Three subsamples of about 300 g of soil were collected around each tree at 1.5 m from the tree trunk and composed into one soil sample. Thus, five composite soil samples were collected from each field. In the vineyards, five vines were chosen in the central zone of each field and one composed sample was taken around each plant by collecting three subsamples at 0.5 m from the vine rootstock. When vines were growing in metal espaliers, the subsamples were taken right below the irrigation line between rootstocks.

The individual subsamples were taken with a shovel at 0–15 cm