ARTICLE IN PRESS

Pedobiologia - Journal of Soil Ecology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Pedobiologia - Journal of Soil Ecology

journal homepage: www.elsevier.com/locate/pedobi

Earthworm abundance response to conservation agriculture practices in organic arable farming under Mediterranean climate

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A R T I C L E I N F O

Keywords:
Organic farming
Mediterranean soils
Green manures
Earthworms
Chisel

A B S T R A C T

Earthworms are one of the most important soil macrofaunal groups, and they play a major role in agricultural ecosystems. Agricultural practices, such as reduced tillage, the use of green manures and organic fertilization, can be beneficial for earthworm populations in agricultural systems. However, under a Mediterranean climate, not much is known regarding their response to agricultural management. The aim of this study was to analyse the effects of tillage type, organic fertilization, and green manures on the density and biomass of earthworms in organic arable dryland. The trial was conducted in a four-year crop rotation with a complete factorial design that combined tillage system (mouldboard ploughing vs. chisel), fertilization (composted farmyard manure vs. no fertilizer) and green manures (green manures vs. no green manures). Earthworms were assessed in each plot by the extraction of all individuals in three soil areas of 33 cm × 33 cm that were excavated to a depth of 25 cm. Only five earthworm species were found in this trial, and the earthworm community was dominated by such endogeic ecotypes as *Aporrectodea rosea* and *Allolobophora georgii*, and the anecic ecotype *Aporrectodea trapezoides.* Endogeic species can benefit from soil inversion because of the incorporation of organic matter, but the anecic ones can be negatively affected by it. The results show that plots with farmyard manure had higher density and biomass of earthworms. We observed that the type of tillage significantly affected earthworm populations: plots that had been ploughed with mouldboard ploughing (soil inversion) the year prior to sampling presented more juveniles. The biomass of earthworms was significantly lower in plots with green manures and chiselling. Our results indicated that the combination of chiselling and green manures were not optimal for earthworm populations, but organic fertilization played a considerably more important role and enhanced their abundances.

1. Introduction

Earthworms play a major role in ecosystem functioning because their burrowing and feeding activities modify the soil structure and several soil properties. In particular, earthworms increase soil macroporosity, relocate nutrients along the soil profile and form stable aggregates (Crittenden et al., 2014; Ernst and Emmerling, 2009; Metzke et al., 2007). The significant role of earthworms has been revealed by experiments in which they were eliminated in grass swards causing soil bulk density to increase, while organic matter, soil moisture and infiltration rate greatly decreased (Riley et al., 2008). Conversely, earthworm populations are influenced by soil moisture, organic matter, texture, pH and soil management (Crittenden et al., 2014). Soil tillage can modify the relative abundance of earthworm species and their community structure (Chan, 2001). Some studies concerning the impact of inversion tillage on the abundance of earthworm populations have found that the largest and most fragile earthworms (those with soft epitheliums) are most affected by intensive tillage, and species inhabiting the topsoil are at risk of being negatively affected by ploughing (Pelosi et al., 2014). The variability in burrowing and feeding behaviours can be important in determining the effects that tillage type can have on earthworms (Capowiez et al., 2009). According to Bouché

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http://dx.doi.org/10.1016/j.pedobi.2017.10.002
Received 23 July 2017; Received in revised form 20 October 2017; Accepted 20 October 2017
0031-4056/

(1972), earthworms can be divided into the following ecological groups based on soil habitats and feeding habits: (1) Epigeic species live and feed in the organic layers above the mineral soil surface. (2) Anecic species live in vertical burrows in mineral soil layers, but come to the surface to feed on leaf litter that they drag into their burrows (0–200 cm depth). (3) Endogeic species live in mineral soil layers and feed on soil organic matter. They make horizontal burrows through the soil that they sometimes reuse to feed and move around. Capowiez et al. (2009) and Ernst and Emmerling (2009) showed that soil layer inversion by mouldboard ploughing negatively affected the density of anecic earthworm species, while the density of endogeic species was enhanced.

The influences of other farming practices, such as crop rotation, crop residue management and fertilization, are also important for earthworm populations (Riley et al., 2008). Eriksen-Hamel et al. (2009) reported that the addition of crop residues to tilled soils could alleviate some of the negative impacts of tillage on earthworms, thus improving their growth and maintaining more stable populations. While many studies demonstrate the role of cover crops in decreasing soil erosion and improving weed control and soil fertility (Ward et al., 2012), few investigate the effect of cover crops on earthworms. Farmyard manure is an organic amendment alternative to mineral fertilizers that can be beneficial for earthworm populations in arable fields (Andersen, 1979). Brown et al. (2004) reported that organic manures benefit earthworms both directly and indirectly by providing additional food resources and shelter (through the mulching effect), and stimulating plant growth and litter return.

Diversified crop rotation and green manures are used to manage weeds and pests, and the use of less intensive soil tillage (such as reduced tillage with no soil inversion) can reduce soil erosion, thus ensuring the sustainability of farming systems (Pelosi et al., 2014). Due to the potential beneficial effect of reduced tillage, green manures and organic fertilization on earthworms, a sensible hypothesis could be that the integration of conservation agriculture techniques into organic farming systems should increase their populations and diversity. For instance, some authors have indicated that conservation agriculture and organic farming can increase the abundance of all soil organisms, including earthworm populations (Henneron et al., 2015; Pelosi et al., 2014). Several studies have found higher biodiversity in organically managed systems than in conventional systems, including higher earthworm populations in organically managed fields (Scullion et al., 2002; Padmavathy and Poyyamoli, 2013). Organic farming is fundamentally different from conventional systems due to the exclusion of synthetic pesticides and fertilizers. However, notably few studies provide results confirming that earthworm populations and diversity increase in arable cropping systems with a combination of conservation agriculture techniques and organic farming.

The aim of this study is to analyse the individual and collective effects of tillage type, organic fertilizer and green manures on the density and biomass of earthworms in organic arable cropping systems in the Mediterranean region. Indeed, there is a lack of studies of earthworm populations in Mediterranean agricultural areas. Monitoring earthworms in these areas can be challenging because environmental conditions strongly limit earthworm distribution. Frequently, earthworms are distributed in small patches because many species have narrow ecological requirements that are determined by the high spatial variability of soil and soil water regimes in many Mediterranean landscapes (Gutiérrez-López et al., 2016).

The hypotheses of this study are that (1) the application of farmyard manure as fertilizer will increase earthworm density and biomass; 2) mouldboard ploughing will decrease earthworm populations, specially anecic species; 3) the incorporation of cover crops into the soil as green manures can increase earthworm density and biomass; and 4) the combination of conservation agriculture techniques in organic farming systems could help increase the abundance of earthworms in arable fields under a Mediterranean climate.

To answer these questions, we took advantage of a trial designed to evaluate the effects of tillage, fertilization and green manures on a Mediterranean rainfed crop rotation and measured the abundance of earthworm populations in relation to these factors.

2. Materials and methods

2.1. Experimental site and design

In November of 2011, a midterm field experiment was established in Gallecs, a rural area of Catalonia, Spain. This location is a peri-urban agricultural area of 753 ha situated in the region of Vallès Oriental, 15 km North of Barcelona (41°33′31.9″N 2°11′59.5″E). It has a Mediterranean climate; the mean annual temperature and precipitation are 14.9 °C and 647 mm, respectively. At the beginning of the experiment, soil properties of the field were evaluated. On average, the mineral fraction consisted of 43.3 ± 6.9 % sand, 26.9 ± 4.7 % loam and 29.7 ± 3.7 % clay; the texture was classified as loamy-clay (Soil Survey Staff, 1998); and the soil type was a Haplic Cambisol (IUSS Working Group WRB, 2015). At the beginning of the experiment, the average soil organic matter was 1.5 ± 0.1 % (Walkley-Black) and the pH (H_2O) was 8.1 ± 0.1.

The trial consisted of a four-year crop rotation in a strip strip block design (Federer and King, 2006) comprising three factors: tillage system (mouldboard ploughing (P) vs. chisel (C)), fertilization (composted farmyard (+F) vs. no fertilizer (−F)) and green manures (with green manures (+G) vs. no green manures (−G)). Tillage treatment was laid out in strips, and fertilization in perpendicular strips across tillage strips; the tillage strips were split into subplots for the green manure treatment (nested within each combination of tillage and fertilization). In total 32 plots measuring 13 m × 12 m were established, comprising four replicates of each treatment combination (Fig. 1), although the design implied that the effects of tillage and of fertilization were assessed with less accuracy owing to the blocking structure (see Statistical analysis). The field had been under organic management for five years prior to the trial, with a typical dryland Mediterranean crop rotation that alternated cereals and legumes for human consumption. The crop rotation of this trial consisted of spelt (*Triticum spelta* L., 2011–2012), chickpeas (*Cicer arietinum* L., 2013) winter wheat (*Triticum aestivum* L., 2013–2014) and lentils (*Lens culinaris* Medik, 2015).

Two tillage systems were used: a mouldboard plough (P) (soil inversion at 25 cm depth; EG 85-240-8, Kverneland) plus a rotary harrow (5 cm depth; HR3003D, Kuhn); and a chisel plough (C) (no soil inversion at 25 cm depth; KCCC 1187 – A00, Kverneland) plus a rotary harrow (same as for plough). The fertilization (+F) treatment utilized six-month-long composted cow farmyard manure sourced near the field. The farmyard manure was applied every year before sowing the main crop. The total amount of manure applied differed per the nutritional demands of each crop. The year before sampling, c. 38 Ton ha^{-1} (138.28 kg ha^{-1} N_{tot}) of farmyard manure was applied before winter wheat was sown. The organic fertilizers were mixed in the soil by means of a chisel or mouldboard plough in accordance to the tillage treatment. In September 2012 and 2014, green manure (+G) was sown in the corresponding 16 plots. It consisted of a mixture of oat (*Avena sativa* L.), white mustard (*Sinapis alba* L.), bitter vetch (*Vicia ervilia* (L.) Willd.) and common vetch (*Vicia sativa* L.). At the end of March of the following year, green manure was incorporated into the soil by disc harrowing.

2.2. Earthworm sampling

In February 2015, after three years of crop rotation, earthworms were assessed during green manure or stubble (depending on the type of treatment). Three sampling frames of 33 cm × 33 cm were placed 2 m from the edge of each plot, with two on the mid-line and one on the centre of a randomly chosen side and were manually excavated to a depth of 25 cm. All earthworm and cocoons were hand sorted and