Applied Soil Ecology 83 (2014) 140–148

Contents lists available at ScienceDirect

Applied Soil Ecology

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

Effect of tillage on earthworms over short- and medium-term in conventional and organic farming

S.J. Crittenden*, T. Eswaramurthy, R.G.M de Goede, L. Brussaard, M.M. Pulleman

Department of Soil Quality, Wageningen University, The Netherlands

ARTICLE INFO

Article history:
Received 1 February 2013
Received in revised form 27 February 2014
Accepted 2 March 2014
Available online 28 March 2014

Keywords:
Reduced tillage
Earthworms
Organic farming
Conventional farming
Plowing
Non-inversion tillage

ABSTRACT

Earthworms play an important role in many soil functions and are affected by soil tillage in agricultural soils. However, effects of tillage on earthworms are often studied without considering species and their interactions with soil properties. Furthermore, many field studies are based on one-time samplings that do not allow for characterisation of temporal variation. The current study monitored the short (up to 53 days) and medium term (up to 4 years) effects of soil tillage on earthworms in conventional and organic farming. Earthworm abundances decreased one and three weeks after mouldboard ploughing in both conventional and organic farming, suggesting direct and indirect mechanisms. However, the medium-term study revealed that earthworm populations in mouldboard ploughing systems recovered by spring. The endogeic species *Aporrectodea caliginosa* strongly dominated the earthworm community (76%), whereas anecic species remained <1% of all earthworms in all tillage and farming systems over the entire study. In conventional farming, mean total earthworm abundance was not significantly different in reduced tillage (153 m^{-2}) than mouldboard ploughing (MP; 130 m^{-2}). However, reduced tillage in conventional farming significantly increased the epigeic species *Lumbricus rubellus* from 0.1 m^{-2} in mouldboard ploughing to 9 m^{-2} averaged over 4 years. Contrastingly, in organic farming mean total earthworm abundance was 45% lower in reduced tillage (297 m^{-2}) than MP (430 m^{-2}), across all sampling dates over the medium-term study (significant at 3 of 6 sampling dates). Reduced tillage in organic farming decreased *A. caliginosa* from 304 m^{-2} in mouldboard ploughing to 169 m^{-2} averaged over 4 years (significant at all sampling dates). Multivariate analysis revealed clear separation between farming and tillage systems. Earthworm species abundances, soil moisture, and soil organic matter were positively correlated, whereas earthworm abundances and penetration resistance where negatively correlated. Variability demonstrated between sampling dates highlights the importance of multiple samplings in time to ascertain management effects on earthworms. Findings indicate that a reduction in tillage intensity in conventional farming affects earthworms differently than in organic farming. Differing earthworm species or ecological group response to interactions between soil tillage, crop, and organic matter management in conventional and organic farming has implications for management to maximise soil ecosystem functions.

1. Introduction

Earthworms affect many soil properties in agricultural land including nutrient availability, soil structure, and organic matter dynamics (Edwards, 2004). Earthworms in turn are influenced by soil moisture, organic matter, texture, pH, and soil management (Curry, 2004).

Tillage systems can affect soil biota through changes in habitat (Van Capelle et al., 2012), loss of organic matter (Hendrix et al., 1992), moisture and temperature dynamics (Curry, 2004) and mechanical damage (Lee, 1985). Earthworm population change due to soil tillage depends on tillage intensity (Chan, 2001; Curry, 2004) and may be higher under root than cereal crops (Curry et al., 2002). Moreover, tillage may differentially affect earthworm species, depending on their feeding and burrowing behaviour. Earthworm species classified into ecological groups, defined by Bouché (1977), are epigeic that live on or near the soil surface, endogeic that live and feed in mineral soil, and anecic that are deep burrowing but feed at the soil surface (Sims and Gerard, 1999). Earthworm ecological groups affect soil processes to differing degrees and therefore have varying importance for ecosystem services (Keith and Robinson, 2012).

Conflicting tillage effects on earthworms have been presented in literature (Chan, 2001). On one hand, Van Capelle et al. (2012), in a review of studies conducted in Germany, concluded that reduced tillage intensity increased earthworm abundances and

* Corresponding author. Tel.: +31 0616002428.
E-mail address: Steve.Crittenden@gmail.com (S.J. Crittenden).

http://dx.doi.org/10.1016/j.apsoil.2014.03.001
0929-1393/

species diversity. On the other hand, ploughing can positively influence endogeic species by increasing organic matter availability to them (Ernst and Emmerling, 2009), while it has the opposite affect on anecics (Capowiez et al., 2009). Many studies have focused on earthworms in no-tillage versus conventional ploughing systems in cereal crops, and have often not quantified earthworm species or their functional roles. Therefore, clarification is needed on tillage and arable soil management effects on earthworm species in a wider range of crop rotations.

Intermediate reduced tillage systems that de-compact, yet do not invert soil, are being implemented in arable systems where there is high soil compaction risk (e.g., root crops, high soil moisture). Non-inversion tillage systems, like other reduced tillage systems, are aimed at enhancing soil physical properties (e.g., structural stability, water retention) and soil organic matter (Morris et al., 2010), increasing soil biodiversity (El Titi, 2003), and reducing production costs (Soane et al., 2012). Soil compaction from tillage and field traffic can be detrimental to earthworms when it limits their burrowing activity (Langmaack et al., 1999; Capowiez et al., 2012). In particular, crops such as potatoes and sugar beets require the use of heavy machinery for land preparation and harvesting (Marinissen, 1992) which results in considerable soil disturbance (Buckerfield and Wiseman, 1997), especially under wet soil conditions. There is a lack of research that examines earthworms in reduced tillage systems that include potato or sugar beet, particularly where soils are susceptible to compaction during harvest with heavy machinery.

Additionally, farming system can have a large influence on earthworms. Organic farming, where synthetic pesticides and fertilisers are prohibited, makes greater use of animal and green manures, diverse crop rotations, and mechanical weeding (Gomiero et al., 2011). Hole et al. (2005) reviews studies where earthworms are both positively and negatively affected by organic farming. Most studies of earthworms in organic arable farming have been limited to short duration experiments that compared fields without proper experimental design to account for spatial variability in soil properties (Irmler, 2010).

Recent studies have investigated arable soil tillage effects on earthworms (Capowiez et al., 2009; Ernst and Emmerling, 2009; Peigné et al., 2009; De Oliveira et al., 2012). However, an extensive literature search revealed few studies that have assessed the effects of tillage systems on earthworms over short- and medium-timescales simultaneously in both conventional and organic farming systems.

The objective of this study was to quantify the effects of tillage systems on earthworm populations in conventional and organic farming. It was hypothesised that mouldboard ploughing reduces earthworm populations immediately following ploughing (epigeic and anecic species in particular) in both conventional and organic farming and that this decrease would continue for several weeks relative to the reduced tillage treatment. Over the medium term (4 years), it was hypothesised that reduced tillage intensity systems increase earthworm populations relative to mouldboard ploughing in both conventional and organic farming (epigeic and anecic species in particular). Furthermore, earthworm species abundances were expected to be positively correlated with soil organic matter content and soil moisture but negatively correlated to soil compaction.

2. Materials and methods

2.1. Site characteristics

The study was conducted at the PPO Lelystad experimental farm of Applied Plant Research Wageningen UR, in the Netherlands, in a polder reclaimed in 1957 (52° 31′N, 5° 29′E). The daily mean temperature ranged from 2 °C in winter to 17 °C in summer months, and mean rainfall was 794 mm per year during the study (Royal Netherlands Meteorological Institute, 2013). The soil type is a calcareous marine clay loam with 23% clay, 12% silt, and 66% sand. Soil pH is 7.9, and soil organic matter is 3.2% averaged across fields at the experimental farm.

2.2. Experimental design

Soil tillage treatments were sampled in two parallel field experiments (conventional and organic farming) in this study (Fig. 1). Conventional and organic farming systems had unique crop rotations with individual fields at a different phase of their rotation (Table 1). Rotations contained mainly root and cereal crops, although grass and cabbage were also included in organic farming. Cover crops were grown during fallow periods when feasible. Conventional fields received yearly synthetic fertiliser applications and were treated bi-weekly with herbicides during the growing season. Organic fields received yearly cow manure (solid or slurry) applications of 20–40 t ha^{-1} yr^{-1}. Organic field A in autumn 2010 did not receive manure because of the reduced nitrogen required by the following leguminous crop (wheat/faba). Tillage treatments received the same amounts of fertilisers and herbicides in conventional fields, or manure in organic fields. Organic fields received certification in 2004 and no synthetic fertilisers or pesticides have been used since 2002.

Sampling was conducted in two fields under conventional and two fields under organic farming. Each field contained 12 plots (3 tillage systems by 4 blocks) of 85 m by 12.6 m each, arranged in randomised complete blocks (Fig. 1). Each plot contained 4 beds of 3.15 m along controlled traffic lanes where all field operations, except harvest, were done. All plots were mouldboard ploughed annually previous to tillage system initiation in autumn 2008. Tillage systems were: (i) minimum tillage (MT) with optional sub-soiling to 20 cm in autumn if soil compaction was high (based on visual assessment of soil pit and/or penetrometer readings) with cultivation to 8 cm for seedbed preparation, (ii) non-inversion tillage (NIT) with yearly sub-soiling to 20 cm in autumn and cultivation to 8 cm for seedbed preparation, (iii) mouldboard ploughing (MP) to 25 cm in autumn and cultivation to 8 cm for seedbed preparation. Sub-soiling in MT (done only in 2009 and 2010) and NIT plots was done using a Kongskilde Paragrubber Eco 3000.

A short-term study was conducted in conventional field B (Conv B) and organic field B (Org B), and medium-term earthworm monitoring was done in conventional field A (Conv A) and organic field A (Org A) (Fig. 1 and Table 1). Separate fields were used for the short- and medium-term studies to reduce disturbance due to sampling.

2.3. Data collection and analyses

2.3.1. Short-term study

A sampling campaign was conducted during autumn 2011 to investigate the short-term effects of mouldboard ploughing on earthworm populations. Earthworms were sampled 15 days (d) before ploughing in MP and NIT plots of Conv B, then 5 d, 16 d, and 35 d after ploughing to assess effects over time. MP and NIT plots of Org B were sampled 3 d before ploughing then 2 d, 20 d, and 53 d, and 191 d (after seeding of spring wheat) after ploughing. NIT plots were sampled, as a reference, on the same dates as MP plots, to account for changes in earthworm populations resulting from changing environmental conditions with time. Conv B was non-inversion tilled on 28-Oct-2011, before initiation of the short-term study. Org B was not non-inversion tilled during autumn 2011. Three 20 cm × 20 cm × 20 cm monoliths were handsorted for earthworms from each plot according to Van Vliet and De Goede (2006). To extract anecic earthworms from below 20 cm, 500 ml of 0.185%