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Original article

Earthworm assemblages as affected by field margin strips and tillage intensity: An on-farm approach

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ABSTRACT

Earthworm species contribute to soil ecosystem functions in varying ways. Important soil functions like structural maintenance and nutrient cycling are affected by earthworms, thus it is essential to understand how arable farm management influences earthworm species. One aim of arable field margin strips and non-inversion tillage is to enhance agrobiodiversity, however their influence on earthworm species assemblages remains unclear. In particular, on-farm studies conducted over multiple years that capture variability across the landscape are rare. The current study monitored earthworm species assemblages on 4 farms in Hoeksche Waard, The Netherlands, from 2010 to 2012. It was hypothesised that arable field margin strips (FM) and non-inversion tillage (NIT; a reduced tillage system that loosens subsoil at 30–35 cm depth) would have higher earthworm species abundances (epigeics and anecics in particular), soil organic matter, and soil moisture than adjacent mouldboard ploughing (MP) fields, and that earthworm numbers would decrease with distance away from FM into arable fields (MP only). FM contained a mean total earthworm abundance of 284 m^{-2} and biomass of 84 g m^{-2} whereas adjacent MP arable fields had only 164 earthworms m^{-2} and 31 g m^{-2}. *Aporrectodea rosea*, *Lumbricus rubellus*, *Lumbricus terrestris*, and *Lumbricus castaneus* were significantly more abundant in FM than adjacent arable soil under MP. However, no decreasing trend with distance from FM was observed in earthworm species abundances. A tillage experiment initiated on the farms with FM showed that relative to MP, NIT significantly increased mean total earthworm abundance by 34% to 275 m^{-2} and mean total earthworm biomass by 15% to 51 g m^{-2} overall sampling dates and farms. *L. rubellus*, *A. rosea*, and *L. terrestris* were significantly more abundant overall in NIT than MP. FM and NIT positively affected earthworm species richness and abundances and it is noteworthy that these effects could be observed despite variation in environmental conditions and soil properties between samplings, farms, and crops. Higher top-soil organic matter and less physical disturbance in FM and NIT likely contributed to higher earthworm species richness and abundances. The anecic species *L. terrestris* (linked to water infiltration and organic matter incorporation) was more abundant in FM, but densities remained very low in arable soil, irrespective of tillage system.

1. Introduction

Functional agrobiodiversity (FAB) programs are being implemented to reverse negative impacts of agricultural land-use intensification. Practises such as non-crop areas (i.e., field margin strips), reduced tillage, and crop diversification aim to promote above and/or below-ground biodiversity and function [1]. Earthworms play important roles in soil nutrient and organic matter dynamics, and soil structure formation [2] and are strongly affected by soil pH, organic matter, and soil moisture [3]. Arable cropping and soil tillage affect earthworms through mechanical damage, reduction and vertical redistribution of organic matter, changes in soil water regime, and habitat disruption [3–6]. Ecological groups of earthworms [7] play important roles in determining certain soil functions [8]. Epigeic earthworms live and feed at the soil surface and contribute to organic matter incorporation and decomposition, anecic earthworms also feed at the soil surface but create deep vertical burrows and are considered most important for continuous soil pore formation and water infiltration [8,9]. Endogeic

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earthworms affect soil porosity and aggregate stability by feeding in the upper mineral soil layers [8,9]. However, farm management effects on total earthworm numbers have often been studied without acknowledgement of changes in species composition [10].

Field margin strips are border areas of arable fields that can contain grass/herb mixtures with flowering species to encourage above-ground biodiversity and natural enemies of crop pests [11,12] and may be implemented as part of FAB programs [1] and agri-environmental schemes [13]. Field margin strips have also been created as buffer strips to reduce surface water contamination and enhance landscape aesthetics [1]. It has been proposed that grassy field margin strips along arable fields can contribute to higher soil macrofaunal diversity and provide source populations for species, including earthworms, that can colonise arable fields [14,15]. Studies have shown higher earthworm numbers and diversity in grassy field margin strips compared to adjacent arable soil [15,16], however field margin strips have also been shown to contain lower earthworm numbers than adjacent arable fields [14]. Therefore, effects of grassy field margins on earthworm species assemblages require clarification.

Reduced tillage systems that improve soil structure (e.g., aggregate stability, friability and shear strength) [17,18] and reduce farming costs [19] continue to gain attention in The Netherlands and other parts of Europe. Contrasting results have been reported for effects of tillage systems on earthworms, probably due to large variation in reduced tillage practises and implements, and due to lack of attention for differing responses among earthworm species [20]. In particular, non-inversion tillage, a reduced tillage system without soil inversion by ploughing but still a relatively intense cultivation, may benefit earthworms, especially epigeics and anecics, by decreasing the intensity of soil disturbance while leaving an increased proportion of crop residues at the soil surface [3,19–21]. On the other hand, ploughing may give advantage to endogeic species (e.g., *Aporrectodea caliginosa*) because of increased access to food after incorporation of crop residues [6,20].

Influences of field margin strips and non-inversion tillage on earthworm assemblages in field studies should be conducted at multiple on-farm locations to capture spatial heterogeneity across the landscape and to verify patterns observed at single field research stations (e.g., [21–23]). Moreover, it is important that earthworm samplings take place over multiple seasons and years to encompass temporal variability [24,25]. The objective of the current study was to quantify the effects of field margin strips and reduced tillage on earthworms species assemblages for multiple farms and cropping seasons. Arable field margin strips were expected to contain higher earthworm numbers than adjacent arable land (i.e., total abundance and total biomass, epigeic and anecic species abundances, and adult/juvenile ratio). These earthworm parameters were expected to decrease with distance from field margin strips. In addition, non-inversion tillage would result in higher earthworm parameters compared to mouldboard ploughing. Lastly, higher earthworm species abundances (epigeic and anecic species in particular) in FM and NIT were expected to coincide with increased topsoil soil organic matter and soil moisture at the time of sampling compared to MP (due to crop residues left at the soil surface to a greater extent, longer cover crop presence, and less soil disturbance compared to MP).

2. Materials and methods

2.1. Study area

The study was conducted in Hoeksche Waard, The Netherlands. The region is a 325 km^{-2} island consisting of polders that were gradually reclaimed from the sea starting in the 15th century. Currently, Hoeksche Waard is mainly under arable land use with crop rotations that include potato, sugar beet, and winter wheat among other cereal and horticultural crops [26,27]. A functional agrobiodiversity (FAB) program began in 2004 on farms where field margin strips were created to promote natural crop pest enemies [1,26]. Daily mean temperature is 10 °C and annual precipitation is 900 mm [28]. Soils are hydromorphic calcareous sandy loam to clay [29], formed in marine deposits that, in general, overlay more sandy layers (below 45–60 cm) [30]. Mean high groundwater depths are 45–60 cm and mean low depths are 140–170 cm [30].

2.2. Experimental design

Earthworms were sampled on 3 private farms in the eastern part of Hoeksche Waard and at PPO Westmaas research farm of Wageningen University and Research Centre, all within a 10 km radius of each other. Sampling was done during spring 2010, autumn 2010, autumn 2011, and spring 2012.

Transects ($n = 4$) were set up within fields neighbouring field margin strips (FM) to test the effects of distance from FM on earthworm species abundances. Sampling along the transects consisted of 4 sample locations in grassy field margin strips, and 4 at 0.5 m, 30 m, and 60 m from field margin edges in each mouldboard ploughed field. Earthworm samples at each distance were spaced 8 m apart laterally (Fig. 1).

An additional aspect of land management was investigated at each farm by using a Tillage Experiment set up in 2008 that consisted of non-inversion tillage (NIT) plots within pre-existing conventional mouldboard ploughing fields ($n = 4$). Sampling locations in NIT plots were paired with adjacent locations in MP fields. At least a 2 m buffer was maintained between the outermost sampling locations and plot edges. In each tillage pair ($n = 4$) a total of 8 earthworm samples were taken per plot per sampling date. The sampling scheme consisted of 4 sample locations spaced 8 m apart at 30 m and 4 sample locations at 60 m from field edges (Fig. 1). Only 3 of 4 farms had complete tillage system pairs at the autumn 2011 and spring 2012 samplings.

Simultaneous sampling of earthworms and soil properties in the FM and Tillage Experiments allowed for data to be combined and inferences to be drawn on the influences of land management on soil properties and correlations with earthworm species abundances.

2.3. Farm management

In the FM Experiment permanent FM were established between 2001 and 2005. Strips (3–4 m wide) located between ditches and arable fields were seeded with grass or grass/herb mixtures. FM were mown 1–2 times per year. Cuttings from FM were left in the strips on two farms, and were removed on the other two. FM were driven upon incidentally during ditch cleaning and other occasions. Neither fertilisers nor agrochemicals were applied to the strips.

In the Tillage Experiment both tillage systems contained a set of distinct practises which were uniform across farms. The principle difference between tillage systems is the primary tillage instrument (mouldboard ploughing (MP) or non-inversion tillage (NIT)). MP was done every autumn to 25–30 cm depth (in the FM and Tillage experiment). NIT was characterised by use of the Kongskilde Paragrubber Eco 3000 (or chisel plough in some cases) to 30–35 cm to replace the mouldboard plough as primary tillage instrument so that soil was loosened at depth (about 50% of subsoil volume directly affected by tines) and not inverted during tillage. Cover crops and crop residues were managed differently in NIT and MP due to the difference in primary tillage. Cover crops and crop residues are left at the soil surface and not incorporated into the soil in