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Earthworm communities in arable fields and restored field margins, as related to management practices and surrounding landscape diversity

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ABSTRACT

Agricultural intensification has negative impacts on biodiversity at spatial scales from field to landscape. Earthworms are important for soil functioning, so it is crucial to understand the responses of earthworm communities to agricultural management and land use. We aimed to: 1) investigate whether earthworm communities differed between relatively undisturbed field margins, and highly disturbed arable fields; and 2) quantify how earthworm communities of arable fields and field margins are affected by three environmental filters, i.e. soil properties, management practices, and composition of the surrounding landscape. Earthworms were sampled in 26 arable fields and 15 field margins, across a polder area in The Netherlands. While earthworm density, total biomass and species richness did not differ significantly among arable fields and field margins, rarefied earthworm species richness and community composition did. The three environmental filters affected earthworm communities of arable fields and field margins differently. In arable fields, earthworm communities were explained by arable management only (26%). In contrast, all three filters contributed significantly to the variation in earthworm communities of field margins, where management practices explained a larger part of the variation (18%) than the surrounding landscape (11%) and soil properties (10%). Our results suggest that soil properties and surrounding landscape can affect earthworm communities of field margins. However, in the arable fields, where more diverse lumbricid communities are desirable to improve soil functions, such influences are negated by the impact of management at field scale. We demonstrated that field margins enhance earthworm biodiversity in arable landscapes, but surrounding landscape and field margins had limited impact on earthworm communities in arable fields. Decision-making and research should focus on less intensive management options for arable fields to stimulate earthworms and earthworm-mediated soil functions.

1. Introduction

Earthworms play important roles in arable cropping systems, contributing to nutrient cycling, organic matter formation and decomposition, soil structure formation, and water infiltration (Edwards, 2004; Keith and Robinson, 2012). Their presence in agroecosystems can increase crop yields by 25% (van Groenigen et al., 2014). It is well known that earthworms are affected by several environmental filters, which constrain the earthworm species pool found in particular habitats (Decaëns et al., 2008). Examples of environmental filters acting on earthworm communities are soil properties (e.g., soil moisture, organic matter, texture and pH (Curry, 2004)) and agricultural management practices (e.g., tillage (Chan, 2001), pesticide application (Pelosi et al., 2014) and organic matter management (Curry and Schmidt, 2007)).

In general, agricultural intensification negatively affects earthworm communities (Postma-Blaauw et al., 2010). Although agricultural intensification occurs across spatial scales from the field to the landscape (Ettema and Wardle, 2002), landscape effects on earthworm communities have hardly been studied. Landscape-scale agro-intensification refers to the ongoing loss of (semi-) natural area, the increasing surface area for agricultural production, and consequently the homogenization of landscapes. In an attempt to reverse the effects of intensification, agro-environment measures are being implemented in Europe (EU-Commission, 2005). These measures are partly focussed on enhancing biodiversity in agricultural landscapes, and partly on promoting alternative management practices at the field and farm scale, e.g., crop

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diversification and restoration of non-productive landscape elements on farm, such as field margins (EU-Commission, 2005). To better understand the effects of (de)intensification of agriculture, both farm management practices and landscape characteristics need to be considered (e.g., Tscharntke et al., 2005). Most studies that considered landscape effects on earthworm communities in arable fields focussed on the relevance of (semi-)permanent field margins as potential sources for earthworm colonization of arable fields (e.g., Smith et al., 2008; Roarty and Schmidt, 2013; Crittenden et al., 2015, but see Flohre et al., 2011 and Lüscher et al., 2014 for larger scale effects). Semi-permanent field margins are edges of arable fields that have been converted and restored to non-crop area, e.g. strips sown with grass(-herb) mixtures. They are subject to a lower frequency and intensity of soil disturbance. To our knowledge, environmental filters, such as soil properties, management practices and surrounding landscape, affecting earthworm communities of arable fields and field margins have scarcely been studied collectively. Given the fact that fields and margins neighbour each other spatially, but strongly differ in frequency, type and intensity of disturbance, quantifying effects of environmental filters on earthworm communities of these habitats may help to support management and spatial planning at farm and landscape scales to enhance soil biodiversity (Bianchi et al., 2013).

The objectives of this study were two-fold. First, earthworm communities were compared between arable fields (hereafter named "fields") and semi-permanent field margins (hereafter named "margins") with different spatial configurations (fields had margins present or not). Second, the relative contribution of the environmental filters, soil properties (hereafter named "soil"), management practices (hereafter named "management") and composition of the surrounding landscape up to 500 m radius (hereafter named "landscape"), on earthworm communities of fields and margins was quantified. We hypothesized that earthworm density, species richness, and biomass would be lower in fields than margins, but not between fields with and without a margin. Furthermore, we hypothesized that earthworm communities would differ between margins and fields, but not between fields with and without a margin. We did not expect differences between fields with and without margins, because previous studies only showed limited spill-over effects of earthworms from margins to fields (e.g. Smith et al., 2008; Roarty and Schmidt, 2013; Crittenden et al., 2015). Our third hypothesis was that a higher proportion of nearby non-arable surface area would contribute to more diverse earthworm communities in margins, and not in fields. It was thus hypothesized that for fields, landscape effects would be overshadowed by management practices, because of an expected large effect of management-associated periodic disturbance (physical, chemical and biological) on earthworms.

2. Materials and methods

2.1. Study area

Our study was carried out in the Hoeksche Waard, in the southwestern part of The Netherlands. The region, with a surface area of about 324 km^2 comprises a set of polders, progressively reclaimed from the sea since the 15th century, and is dominated by prime agricultural soils for arable cropping, mostly potato, sugar beet and wheat (Crittenden et al., 2015). Soils are hydromorphic calcareous sandy loam to clay formed in marine sediments (de Bakker and Schelling, 1966). Daily average temperature is 10.8 °C and annual precipitation is 883 mm (Royal Netherlands Meteorological Institute, 2016). The region is also characterized by a large network of margins (> 400 km) including annual flower strips and semi-permanent grass or grass-herb mixtures.

2.2. Sampling design and methods

Farm selection was aimed at an even geographic representation over the Hoeksche Waard, and was dependent on farmers' willingness to participate in the project. Twenty-six fields and 15 margins were sampled across a total of 15 farms. All fields had been under crop production for at least 25 years, and had been cultivated to winter wheat in the year of sampling. Thirteen of the 26 fields had margins, in which sampling was conducted. In addition, there were two margins sampled where the associated field was not sampled because they did not have winter wheat at the time. Sampling was done in September and October 2012, after harvest and before tillage in the arable fields. At the time of sampling, fields were covered with either wheat stubble and residue, or with a green manure of *Lolium* grasses or radish (*Raphanus sativus* subsp. *oleiferus*). Sampled margins had been sown with perennial grasses or mixtures of herbs and grasses between 2000 and 2010 and did not undergo soil disturbance since then. Grass(-herb) margins established later than 2010 were excluded from this study, as the time between the last ploughing event and our sampling campaign was considered too short; additionally, margins sown with annual flowers were also excluded from this study because they are ploughed and resown every year.

In each field, six earthworm samples were taken within a 10 m radius. The center of the circle was at about 40 m from the edge of the field or the margin, when present. In the margins, four earthworm samples were taken along the margin, 20 m apart. The center of the sampling areas was georeferenced to allow for further spatial analyses.

Earthworm sampling was done using the methodology described by van Vliet and de Goede (2006): a soil monolith of 20 × 20 × 20 cm was dug out and hand-sorted for earthworms, followed by the application of 0.5 l of 0.2% formaldehyde solution onto the bottom of the pit, to expel burrowing anecic earthworms. Each sample of earthworms was weighed the same day upon extraction, and subsequently stored in 70% alcohol until identification. Biomass was measured taking into account not only whole individuals, but also pieces, heads and tails. However, only intact individuals or heads were considered for identification, and consequent quantifications of species richness, density and composition. Adult and juvenile individuals were identified using Sims and Gerard (1999) and Stöp-Bowitz (1969), respectively; 0.2% of the intact individuals could not be identified and were therefore excluded from data analysis.

Around each earthworm sampling pit, five soil cores were taken to a depth of 20 cm and pooled into one composite soil sample per sampling location. Samples were analysed for pH-H_2O with a volume ratio soil:water of 1:5, and texture using laser diffraction (Buurman et al., 2001). Total nitrogen and carbon were analysed by the Stable Isotope Facility of UC Davis with a PDZ Europa ANCA-GLS elemental analyser (Sercon Ltd, Crewe, Cheshire, UK) after removal of inorganic C using the acid fumigation method (Harris et al., 2001). Soil moisture content at the time of sampling was measured gravimetrically after 24 h at 105° C. For details regarding soil properties, see Tables A1 (with detailed explanations), A2 and A3 (with summary statistics of the explanatory variables of fields and margins, respectively) of Appendix A in Supplementary material.

2.3. Management

Farmers were interviewed using standardized questionnaires about the management of the sampled fields and margins, with focus on the last rotation cycle from 2009 to 2012. Farmers were asked about the main and cover crops that were cultivated, tillage operations, crop residue management, pesticide types and number of applications, as well as types and amounts of mineral fertilizers and manure applications. A detailed description of the management-related variables of arable fields is provided in Table A1 of Appendix A in Supplementary material, and summary statistics in Table A2 of Appendix A in Supplementary