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Within-field spatial distribution of earthworm populations related to species interactions and soil apparent electrical conductivity

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ABSTRACT

Within-field spatial distribution of ecosystem engineers such as earthworms determine the spatial patterns of important ecosystem processes at the field scale. But the driving factors that shape the within-field spatial variability of earthworm populations remain largely unclear. The aim of this study was to describe the earthworm distribution patterns in a tilled arable field and to explain earthworm spatial variability as a function of biotic interactions within populations and of abiotic soil heterogeneity measured as the soil apparent electrical conductivity (EC_a).

Earthworms were sampled at 100 locations within an area of (105×75) m^2 in a harvested wheat field on a loess soil in central Belgium. The soil EC_a was measured using a mobile electromagnetic induction (EMI) sensor as a proxy for soil textural composition. Maps of earthworm density and soil EC_a were produced by variogram modeling and ordinary kriging. Two approaches were followed in the data analysis: (i) a pixel-by-pixel comparison of the spatial patterns based on categorical maps derived from a fuzzy *k*-means clustering, and (ii) causal modeling based on point-by-point Mantel tests.

The endogeic species *Aporrectodea caliginosa* and *A. rosea* inhabited similarly sized and overlapping patches, which were neither related to the spatial occurrence of the deep-burrowing species *Lumbricus terrestris* and *A. longa*, nor to the measured soil EC_a variability. Endogeic adults and juveniles lived closely associated in the same spatial clusters. The segregated field distributions of both deep-burrowing species were largely determined by the subsoil textural properties (as measured by EC_a) and not by competition. *A. longa* individuals lived in field areas with high ECav values (related to relatively higher clay content) while *L. terrestris* juveniles occupied regions with low ECav values. Anecic juveniles were found in larger and spatially differing clusters than adults, suggesting the dispersal of juveniles from parental clusters into neighbouring areas. *L. terrestris* adults were spatially organized in distinct patches of ~15 m diameter and it is hypothesized that the particular mating behaviour of this species requires such intimate distributions.

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The rapid, easy and non-invasive geo-referenced soil characterization by means of EMI-based measurements proved to be a useful tool for determining and understanding the within-field spatial distributions of earthworms but requires further testing in a variety of (agro-)ecosystems.

1. Introduction

Ecosystem engineers such as earthworms play a major role in the regulation of ecosystem processes and, ultimately, in the services delivered by the ecosystem (Lavelle et al., 2006). The spatial variability of earthworms will likewise influence spatial patterns of important ecosystem processes such as litter decomposition and nutrient cycling (Ettema and Wardle, 2002). The patchy spatial distribution of earthworms at the field scale in a variety of ecosystems is now well accepted (e.g. Poier and Richter, 1992; Rossi et al., 1997; Cannavacciuolo et al., 1998; Nuutinen et al., 1998; Hernández et al., 2007), however the factors that determine this variability are not yet sufficiently understood. Understanding these driving factors may provide vital information about colonization rates and target earthworm densities for optimized soil ecosystem management, and for the design of adequate sampling schemes for earthworm population monitoring.

The spatial variability of earthworms at the field scale can be attributed to two types of factors: biotic and abiotic (Whalen, 2004; Aubert et al., 2005). Biotic interactions of competition, facilitation, or co-existence occur both at intra- and interspecific level, and may be responsible for the spatial structuring within and between earthworm populations. For example, it can be expected that individuals/species exhibiting similar ecological strategies may try to minimize resource competition by occurring in spatially differing locations (e.g. Jiménez et al., 2006). Abiotic conditions at the field scale are the result of the interaction between local topography, soil texture and related soil hydrology and nutrient availability. But management practices, especially tillage, also alter the spatial variability of these abiotic factors (Govers et al., 1994). Given pre-existing spatial variability in soil properties at the field scale, earthworms are expected to occur in higher densities where the soil is intrinsically more favourable. This may be either because individuals move to the best soil patches and/or reproduction is faster in favourable patches (Barot et al., 2007). Relationships between earthworm spatial distribution and soil properties have been studied before (e.g. organic carbon content and soil hydrology in Poier and Richter, 1992; Cannavacciuolo et al., 1998), but rarely were these factors able to satisfactorily explain the observed spatial variability. Earthworm activities in turn can affect soil structure and soil chemical properties, hence the importance of investigating the effect of stable soil variables such as texture on the spatial variability of earthworm populations.

Characterizing the within-field soil textural variability is time, labour and cost intensive, since it relies on extensive soil sampling and subsequent soil analyses. Recently, the use of mobile, sensor-based measurements of soil apparent electrical conductivity (EC_a) has proved to be a quick, easy and reliable method for establishing within-field spatial variability in soil texture (Cockx et al., 2005). Soil EC_a is an integrating function of soil properties such as salinity, water content, texture and cation exchange capacity and under non-saline conditions it can be used as a proxy for the soil texture (Vitharana et al., 2006).

In this study, a geostatistical analysis of the density of the most abundant anecic and endogeic earthworm species and of the soil EC_a was performed for a temperate, arable loess soil. The aims were (i) to describe the observed within-field spatial variability of earthworms and soil EC_a, and (ii) to interpret the (dis)similarities and causal relationships between these spatial patterns in terms of community (within and between ecological categories), population (juvenile vs. adult) and abiotic (EC_a) interactions.

2. Materials and methods

2.1. Study site

The study was conducted in a tilled arable field with an area of 4 ha in the loess belt of central Belgium (50°61′32″N, 4°57′14″E). The study area is characterized by a marine temperate climate. The soil is a Luvisol formed in aeolian loess that was deposited during the last glaciation. The topography is rolling with elevations between 135 and 145 m above sea level. The studied field was converted from pasture to arable land in 1966 and a rotation scheme with sugar beet and winter wheat was implemented ever since. Every year, the field is conventionally ploughed in spring to a depth of 20 cm. Every second year, before sugar beet planting, 60 t of farm yard manure per hectare is applied. In 2002, as an exception to the regular rotation scheme, chicory (*Cichorium intybus* cv. ‘sativum’) was grown instead of sugar beet. In November 2003, when the field sampling for this study was carried out, the wheat crop had been harvested while its stubble was still left on the field. Field sampling for this study was conducted in a representative subarea measuring 105 m × 75 m (Fig. 1). The sampled area was buffered against edge effects to the north, east and west by a strip of the same arable field of at least 100 m in width. The southern side was buffered by a narrower strip of at least 20 m. Beyond this buffer a pasture was located.

2.2. Data collection

2.2.1. Earthworm sampling

Earthworms were sampled at 100 locations within the study area between late October and mid November 2003. Temperature and moisture conditions were favourable for earthworm sampling throughout the period (RMI, 2004). 48 sampling locations were laid out on a regular grid (15 m × 15 m) while the remaining 52 sampling plots were randomly distributed over the area (Fig. 1). Earthworms were sampled by mustard