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Diversity and abundance of earthworms across an agricultural land-use intensity gradient

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ABSTRACT

Understanding how communities of important soil invertebrates vary with land use may lead to the development of more sustainable land-use strategies. We assessed the abundance and species composition of earthworm communities across six replicated long-term experimental ecosystems that span a gradient in agricultural land-use intensity. The experimental systems include a conventional row-crop agricultural system, two lower-intensity row-crop systems (no-till and tilled organic input), an early successional old-field system, a 40–60 years old coniferous forest plantation, and an old-growth deciduous forest system. Earthworm populations varied among systems; they were lowest in the most intensively managed row-crop system (107 m^{-2}) and coniferous forest (160 m^{-2}); intermediate in the old-field (273 m^{-2}), no-till (328 m^{-2}) and tilled organic (344 m^{-2}) cropping systems; and highest in the old-growth deciduous forest system (701 m^{-2}). Juvenile *Aporrectodea* species were the most common earthworms encountered in intensively managed systems; other species made up a larger proportion of the community in less intensively managed systems. Earthworm community biomass and species richness also varied and were lowest in the conventional row-crop system and greatest in the old-growth forest system. These results suggest that both land-use intensity and land-use type are strong drivers of the abundance and composition of earthworm communities in agricultural ecosystems.

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1. Introduction

Disturbance associated with agricultural intensification may influence the community of belowground invertebrates that inhabit soils and regulate ecosystem function (Fragoso et al., 1997). In particular, the suitability of soil for invertebrate colonization may be substantially affected by tillage, chemical applications, and litter inputs (Edwards et al., 1995; Clapperton, 1999; Callaham et al., 2003). These and other forms of disturbance affect the size and composition of the belowground invertebrate community by differentially affecting ecological groups that exploit different soil niches and can vary with different agricultural practices (Lee, 1985; Edwards et al., 1995; Thomas et al., 2004).

Earthworms are an important component of the invertebrate community in most soils, both in terms of their contribution to overall belowground biomass and in terms of their effects on soil biogeochemical cycles (Lee, 1985; James, 1991; Bohlen et al., 1997). Soil structure, gas dynamics, water flow, and C and N turnover and stabilization may be altered by the presence and community structure of earthworms (VandenBygaart et al., 2000; Pouyat and Carreiro, 2003). Earthworms can be divided into several broad ecological groups based on their physiology and feeding and burrowing behavior (Bouché, 1977, reviewed in Lee, 1985; Hendrix and Bohlen, 2002): epigeic earthworm species inhabit and feed on the surface litter; anecic species produce deep vertical burrows in the mineral soil but browse on the soil surface and are important in the burial of surface litter; and endogeic species burrow horizontally and feed mainly in the rhizosphere and subsoil. These major ecological groups have different effects on

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soils and their variable ecologies suggest that their responses to disturbance may differ greatly and may alter biogeochemical processes (Lee, 1985; Edwards et al., 1995; Bohlen et al., 1997; Hendrix and Bohlen, 2002; Hale et al., 2005). Further, their species-specific life-histories and exploitation of varying soil niches suggest that earthworm responses to soil disturbance may be difficult to predict and depend upon complex interactions between other aspects of agricultural land use and species traits (Hale et al., 2005).

A better understanding of how earthworm communities vary with different types and intensities of agricultural land use may lead to more sustainable soil management strategies. However, there have been few studies of earthworm community response to management intensity that span a wide range of land uses, are not confounded by abiotic factors that can vary at larger spatial scales, such as soil type or climate, and are replicated. Here we report results of a study in which we measured the abundance and species composition of earthworm communities across six replicated long-term experimental ecosystems that ranged in land use and disturbance intensity from high input, intensively managed row-crop agriculture to old-field and old-growth forest ecosystems. The specific objective of the study was to determine how an important group of soil invertebrates vary across a broad range of agricultural land uses typical of the US Midwest.

2. Materials and methods

2.1. Study site

The study was conducted at the Long-Term Ecological Research (LTER) site at Michigan State University's W.K. Kellogg Biological Station in SW Michigan, USA (42°24′N, 85°24′W, elevation 288 m). Soils at the site developed from glacial outwash deposited 12,000 years ago, and are mainly in the Kalamazoo (fine-loamy, mixed, mesic Typic Hapludalfs) and Oshtemo (coarse-loamy, mixed, mesic Typic Hapludalfs) soil series (Robertson et al., 1997). Native vegetation in the area was beech-maple and oak-hickory forests interspersed with open oak savannas (Burbank et al., 1992). Most of the area was cleared for agriculture in the mid-1800s. Annual precipitation is 90 cm, about half of which is snow; mean annual temperature is 9.7 °C. Detailed site and soil descriptions are available at the W. K. Kellogg Biological Station LTER website (http://lter.kbs.msu.edu).

2.2. Land-use intensity gradient

Six replicated ecosystem types representing a gradient in land-use intensity were investigated. Three of the ecosystems were annual rotations of corn, soybean and winter wheat that differed in the type and intensity of agronomic management. These rotations were initiated in 1989. Management systems for the annual rotations were, in order of decreasing chemical input and soil disturbance, conventional tillage and inputs of fertilizer and herbicide (CON); no-till with conventional inputs of fertilizer and herbicide (NOT); and an organic system with tillage and leguminous cover crops (ORG). No manure or compost was applied to the ORG system. All three rotations were in winter wheat in 2001. In addition to the annual rotations, a successional old-field system (OLD) that was previously cropped but had been abandoned from agriculture when the LTER study was initiated in 1989 was also included. The least intensively managed systems at the site were two replicated forest systems: 40–60 years old conifer plantations, dominated by *Pinus resinosa*, *P. strobus*, and *Picea resinosa* (CF), and old-growth deciduous forests, dominated by *Acer saccharum*, *Prunus serotina*, and *Carya glabra* (DF). We qualitatively ranked these six systems along a land-use intensity gradient of highest to lowest based on their history of disturbance and management: CON > NOT > ORG > OLD > CF > DF. Systems CON, NOT, ORG, and OLD were replicated six times in 1 ha plots, while the CF and DF systems, which are part of the larger KBS landscape, were replicated three times. All six ecosystems were underlain by the same soil type.

2.3. Earthworm sampling

Earthworms were sampled from all replicate plots from 19 June to 25 June 2001 using excavation and a non-toxic irritant. A template was used to define a 25 cm × 25 cm area in two randomly chosen locations in each replicate and samples were removed from the defined area in two depth increments (0–10 and 10–25 cm) using shovels. In the forested sites, the litter layer was removed prior to soil sampling and any worms found in the organic matter were collected. Soil samples were sorted by hand and earthworms removed and placed in plastic bags containing cool water, out of direct sunlight. Following excavation of the 10–25 cm section, 1 L of mustard solution (1 tablespoon of dry, ground mustard/1 L water) was poured into the hole and worms that emerged were collected for 20 min after mustard addition. The mustard solution served as a non-toxic irritant that drove deep burrowing earthworm species, such as *Lumbricus terrestris*, to the surface (Gunn, 1992; Lawrence and Bowers, 2002). Earthworms were held on ice until they were returned to the laboratory for preservation in 10% formalin solution.

2.4. Identification and determination of biomass and species richness

Earthworms were identified using the external morphology key of Reynolds (1977). Individuals were grouped into two classes, adults and juveniles, based on the presence or absence of the clitellum. Clitellate individuals were identified to species and pre-clitellate individuals were identified to genus only. Specimens that were damaged during the sampling process were identified to genus when head portions were present, and were included in abundance analyses. Specimens without heads were included in analyses of biomass only. Upon identification, each individual was patted dry with a paper towel to remove surface moisture and weighed to the nearest 0.01 g. The number of earthworm species per sample (species richness) was estimated by determining the number of distinct species per sample. Pre-clitellate individuals (identified to genus only) were included in the analysis of species richness only when clitellate individuals of the same genus were absent from the sample. Therefore, our estimates of species richness are somewhat conservative.

2.5. Statistical analysis

Differences in earthworm density, biomass and species richness among ecosystem types and sampling depths were analyzed using a two factor (system, depth) ANOVA for a randomized complete block design, followed by Fisher's Protected LSD test at the $P = 0.05$ confidence level. Earthworm species richness estimates were square root transformed and density and biomass data were expressed on a m^{-2} basis and log transformed prior to analysis to meet the assumptions of ANOVA. Analysis of the age distribution of each sample (proportion juveniles) was conducted following arcsine transformation of the data. Untransformed data are presented in all tables and figures. All analyses were performed with SAS using the GLM procedure (SAS Version 8.02; SAS Institute, Cary, NC, USA).