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Impacts of earthworms on soil nutrients and plant growth in soybean and maize agroecosystems

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Abstract

The objective of this experiment was to determine the effects of earthworms on soil N pools and plant growth in soybean and maize agroecosystems. The species and number of individuals in earthworm communities were manipulated in plot-scale field enclosures (2.4 m × 1.2 m) by first reducing earthworm populations within enclosures with carbaryl pesticide, and then adding earthworm treatments to the enclosures. Soybean was grown in the enclosures in the first year and stover maize in the second year.

The success of earthworm manipulations in field enclosures was affected by climate conditions and available food resources. The endogeic earthworm species *Aporrectodea caliginosa* was dominant in all enclosures, while introduced anecic *Lumbricus terrestris* earthworms had poor survival. In the first season, when climate conditions were favourable for earthworm survival and growth, there was a significant ($P < 0.05$) linear increase in soil mineral-N and microbial biomass N concentrations in the 0–15 cm depth of enclosures with more earthworms. Similarly, soybean grain and grain-N yield was significantly ($P < 0.05$) greater in enclosures with the largest earthworm populations than the control which had no earthworms added. In the second season, when climate conditions were less favourable, there was no effect of earthworms on soil N pools or maize plants, probably due to poor survival of introduced earthworms.

Keywords: Earthworms; Population manipulation; Field enclosures; Soil nutrient dynamics

1. Introduction

Earthworms are commonly referred to as ecosystem engineers for their ability to modify soils and plant communities (Lavelle et al., 1997; Hale et al., 2005). Through the incorporation of surface litter, casting, burrowing and other activities, earthworms can significantly alter soil physical properties (Edwards and Shipitalo, 1998), soil nutrients (Edwards and Bohlen, 1996), soil biological communities (Doube and Brown, 1998), and above-ground plant communities (Piearce et al., 1994; Wurst et al., 2005).

The functional relationships between earthworms, soils and plants have been extensively studied in microcosm and laboratory experiments. However, extrapolating these results to the ecosystem-level is difficult. Earthworm activities may be overstated in small-scale experiments due to the control of environmental variables like temperature, soil moisture and food availability or because an unrealistic number of earthworms are added to small containers or mesocosms. The challenge is to quantify the influence of realistic earthworm communities at the field-level (Bohlen et al., 2004), which is often done by manipulating earthworm populations and communities in large-scale field enclosures (see Bohlen et al., 1995; Baker et al., 1996; Subler et al., 1997). However, there is considerable variation in the success of earthworm manipulations in field enclosures, depending on the methods used, climate and soil conditions (Bohlen et al., 1995; Baker et al., 1996; Zaller and Arnone, 1999; Emmerling and Pausch, 2001).

Therefore, the objectives of this experiment were (1) to determine the effects of an earthworm community, dominated by *A. caliginosa* and *L. terrestris*, on soil nutrient dynamics and plant growth in soybean and maize agroecosystems, and

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(2) determine the success of manipulating earthworm communities by reducing the population with pesticide and adding earthworms belonging to different functional groups.

2. Materials and methods

The study was conducted from May to September in 2004 and 2005 on the Research Farm of Macdonald Campus of McGill University, Quebec, Canada (45°25′N, 73°56′W). The field was used for soybean and maize production in the 2 years prior to this experiment and before that was a turfgrass sports field. The soil was a mixed, frigid Typic Endoquent, classified as a Chicot series sandy loam. It had a pH (H_2O) of 5.9, an organic C content of 24.5 g C kg^{-1}, and contained 580 g kg^{-1} sand, 300 g kg^{-1} silt, and 120 g kg^{-1} clay. A field survey in May, 2003 found an earthworm community with an average of 50 individuals m^{-2} of *A. caliginosa* and 15 individuals m^{-2} of *L. terrestris*, and age class ratios of juveniles to adults of 4:1 and 3:1, respectively.

Field enclosures were installed in April, 2004. These rectangular sheet metal enclosures measured 2.4 m × 1.2 m (2.9 m^2) and were buried to a depth of 0.30–0.40 m. The corners and top edges of the enclosures were bent at right angles to ensure a tight fit between pieces and minimize earthworms escaping from the enclosures. The enclosures remained in place for the 2004 and 2005 seasons.

At the beginning of each season, carbaryl pesticide (Sevin®) was applied to reduce earthworm populations in the enclosures. Beginning on April 28th, 2004, carbaryl was applied five times during a 25-day period, giving a total load of about 0.02 kg a.i. m^{-2}. The next year, we began on April 16th, 2005, and applied carbaryl four times during a 35-day period for a total load of about 0.04 kg a.i. m^{-2}. In both years, the last application of carbaryl was made 10 days before adding earthworms to the enclosures.

On May 28th, 2004, a single row of 100 soybeans (*Glycine max* (L.) cv. Merril) was sown by hand lengthwise, in the centre of each enclosure (equivalent to a planting density of 350,000 plants ha^{-1}). Germination and seedling establishment was even across all treatments, except in one enclosure. Here we planted 30 additional seeds and thinned to a similar density as the other enclosures within 3 weeks of the original sowing date. On June 1st, 2005, a single row of 15 silage maize (*Zea mays* (L.) cv. Mycogene 2K350) seeds were sown by hand lengthwise, in the centre of each enclosure (equivalent to a planting density of 52,000 plants ha^{-1}). Germination and seedling establishment was uneven and additional seeds were planted 7 days later. After 2 weeks, we thinned to 12 plants per enclosure. No fertiliser or pesticide was added to either crop. Weeds were removed by hand as required throughout the season.

2.1. Experimental design

The experiment was a randomised complete block design with seven earthworm population treatments and four blocks. The seven earthworm population treatments were three combinations of earthworms as *A. caliginosa* only (A), *L. terrestris* only (L), and a combined *A. caliginosa* and *L. terrestris* treatment (AL), at either a background population level (1×) or double the background population level (2×), and a control treatment with a reduced earthworm population. In the 1–4 weeks before the experiment began, earthworms were collected from around the field site and nearby arable fields by hand-sorting and formalin extraction (Raw, 1959). The earthworms were sorted by species and age-class and kept in laboratory cultures (38 l plastic bins) containing soil from the field site, regularly watered and fed with composted cattle manure. The mean fresh weight biomass of earthworms added to enclosures was similar in both years. In 2004 the fresh weight biomass of adult and juvenile *A. caliginosa* was 0.48 ± 0.19 g and 0.31 ± 0.11 g, respectively, and 4.79 ± 1.07 g and 1.53 ± 0.87 g for adult and juvenile *L. terrestris*, respectively. In 2005 the fresh weight biomass of adult and juvenile *A. caliginosa* was 0.59 ± 0.27 g and 0.24 ± 0.13 g, respectively, and 4.72 ± 0.86 g and 1.87 ± 0.99 g for adult and juvenile *L. terrestris*, respectively. The ratio of juvenile to adult earthworms added to enclosures in both years was 1.5 for *A. caliginosa* and 3.9 for *L. terrestris*. In both years, we attempted to add earthworms to the enclosures on a cloudy overcast day; June 1st in 2004, and June 6th in 2005. Earthworms were transported to the field in 1 l pots, each containing 10–30 earthworms in about 100 g of moist field soil. The earthworms in each pot were spread evenly in two trenches (5–10 cm deep), dug lengthwise in the enclosures. The earthworms were then lightly covered with soil and about 7 l of water was poured evenly along the trenches. Straw was lightly placed above the trenches to provide additional protection from direct sunlight and predators. The straw was removed 3 days later. The number and biomass of earthworms added to each treatment in June and collected in

Table 1
Earthworm populations and biomass added in June 2004 and collected in October 2004 from enclosures under soybean production[†]

Earthworm treatment	Population (individuals m^{-2} ± S.E.)		Biomass (g fresh weight m^{-2} ± S.E.)	
	June	October	June	October
Control	0	77 ± 12 b	0	25 ± 7.5 b
A1x	50	190 ± 56 ab	21	56 ± 15 ab
A2x	100	330 ± 87 a	42	86 ± 22 ab
L1x	15	170 ± 24 ab	34	55 ± 9.2 ab
L2x	30	220 ± 46 ab	67	77 ± 12 ab
AL1x	65	180 ± 62 ab	55	86 ± 25 ab
AL2x	130	380 ± 47 a	109	92 ± 8.7 a
Background[††]		123 ± 30		59 ± 4.5
ANOVA treatment effects				
Treatment		$P = 0.01$		$P = 0.03$

[†] Values in each column for each treatment followed by similar letters are not significantly different by Tukey's HSD test ($P = 0.05$).
[††] Background samples were the average of two pits and therefore were not included in the statistical analysis.