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Biosolids applied to agricultural land: Influence on structural and functional endpoints of soil fauna on a short- and long-term scale

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HIGHLIGHTS

- Are there negative impacts of commercial-scale biosolids application on soil fauna?
- Biosolids cause a short-term enhancement effect typical of organic enrichments.
- Earthworm abundance and feeding activity reflect organic enrichment up to 44 months.
- Soil texture and tillage explain differences in earthworm abundance.
- Reason for lack of long-term recovery of structured nematode assemblage not clear.

GRAPHICAL ABSTRACT

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ABSTRACT

Biosolids have well-documented crop and soil benefits similar to other sources of organic amendment, but there is environmental concern due to biosolids-associated pollutants. The present study investigated two field sites that had received biosolids at commercial-scale rates in parallel to associated field sections which were managed similarly but without receiving biosolids (controls). The investigated endpoints were abundance and diversity of soil organisms (nematodes, enchytraeids and earthworms) and soil fauna feeding activity as measured by the bait lamina assay. Repeated sampling of one of the field sites following the only biosolids application demonstrated an enrichment effect typical for organic amendments, which was mostly exhausted after 44 months. After an initial suppression, the proportion of free-living plant-parasitic nematodes tended to increase in the biosolids-amended soil over time. Yet, none of the endpoints at this site indicated significant negative effects resulting from the biosolids until 44 months post application. In contrast to the repeatedly tilled first field site, the second one was left fallow after three biosolids applications, and was sampled 96 months post last application. It was only at this field site that potential evidence for a long-term impact of biosolids was detected with regard to two endpoints: earthworm abundance and structure of the nematode assemblage. Agricultural management and correlation with abiotic soil parameters explained the observed difference in earthworm abundance. Yet,

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the development of a highly structured and mature nematode assemblage at the control but not at the biosolids-amended section of this fallow field could not be explained by such correlations nor by soil metal concentrations. Overall, the present study found only weak evidence for negative long-term impacts of biosolids applied at commercial rates on soil fauna. High-level community parameters such as the nematode structure index (SI) appeared more suitable to detect deleterious effects on soil fauna than simple abundance measurements.

1. Introduction

The treatment of wastewater results in large amounts of municipal biosolids [treated sewage sludge, Cogger et al. (2006)] that need to be managed in a sustainable way. The application of biosolids to agricultural land is one main route of disposal as it recycles nutrients and can improve soil fertility and tilth (Beecher, 2008; Singh and Agrawal, 2008). However, biosolids can contain an array of organic and inorganic constituents of human and environmental health concern. Most jurisdictions typically regulate concentrations of metals and pathogens in biosolids and mandate maximum permissible loading rates into soil as one measure to manage inorganic contaminants. Nevertheless, concerns about land application of biosolids having adverse environmental effects continue, and on this basis further data from realistic field applications is needed (Rogers, 1996; Parker and Laha, 2004; Mantovi et al., 2005; Clarke and Smith, 2011).

On a short time scale, land application of biosolids can enhance microbial activity and biomass, thereby potentially masking negative effects by contaminants such as metals on these endpoints (Speir et al., 2007; Macdonald et al., 2011). On a longer time scale, soil microbial biomass and soil fauna can be impacted as evidenced by field studies with metal-spiked biosolids (Giller et al., 1998, Macdonald et al., 2011). Microorganisms are at the base of the soil food web and effects on microbial communities translate to higher trophic levels represented by soil fauna organisms such as nematodes, collembolans, and oligochaetes. Indeed, the typically short-term enhancing effects of organic enrichments on nematode and earthworm abundance are well documented (Hamilton et al., 1988; Weiss and Larink, 1991, Price and Voroney, 2008), while evidence for adverse long-term effects on soil fauna due to biosolids applied at commercial rates is lacking.

The present study made use of two experimental field sites in Canada at which the fate and transport of biosolids-associated contaminants had been studied after commercial rate applications (Akhand et al., 2006; Gottschall et al., 2012, 2013). Structural and functional endpoints of soil fauna were assessed that are rarely studied in this combination: abundance and diversity of nematodes, enchytraeids and earthworms as well as feeding activity of soil fauna measured by the bait lamina test. The present study focusses on three aspects: Firstly, to evaluate short-term effects of organic enrichment induced by biosolids and as reflected in selected endpoints (nematodes, enchytraeids and feeding activity). This was assessed repeatedly in six-month intervals at one field site within the first two years after application. Secondly, to evaluate evidence for potential long-term effects of biosolids at both field sites. This analysis was based on earthworms and nematodes, including a nematode-based food web analysis following Ferris et al. (2001), as these were the only endpoints that showed potentially biosolids-related impacts. Thirdly, to evaluate whether intrinsic site conditions such as abiotic soil properties and the history of the field site management could explain the observed patterns.

2. Material and methods

2.1. Study sites

The two field sites used in the present study are located in Ontario, Canada on an Agriculture and Agri-Food Canada experimental farm and on the research farm of the University of Western Ontario. They are named “Ottawa” and “London”, respectively, in the following. Both sites are tile-drained and had not received biosolids prior to the present study. Both sites received biosolids that are widely used for commercial application and that meet the regulatory requirements of the Province of Ontario. The study sites were originally established to monitor the transport and fate of biosolids-associated organic and inorganic contaminants in tile drainage and shallow groundwater (Gottschall et al., 2012; Gottschall et al., 2013; Akhand et al., 2006). Although the field site set-ups were designed for monitoring transport (requiring large non-intermittent pieces of tiled land), and therefore not optimal for faunal studies (no randomized block design), these sites provided a unique opportunity to investigate potential long-term effects of biosolids after years of standard agricultural management under controlled conditions. There is no previous study of soil fauna at these field sites.

2.1.1. Ottawa site

The geographic coordinates of the field site in Ottawa are 45°18′52.52″N, 75°46′45.4″W. The field had been under corn-soybean-wheat rotation since 2003, and left fallow during the summer 2008 following light pre-planting chisel plowing in late spring 2008 to prepare the soil for seeding. Anaerobically digested and dewatered biosolids from a sewage treatment plant of Ottawa, Ontario were applied at a rate of 22 tons d.w./ha in fall 2008. Biosolids were applied to one section of the field while the other section, separated from the biosolids-treated section by about 120 m, received no biosolids (control). The biosolid and control sections were roughly 3.9 and 2.8 ha, respectively. Within 24 h post application, biosolids were folded over in the soil via mouldboard plough such that they formed a distinct layer at a soil depth of about 20 cm. As all other management activities, plowing was performed similarly on both sections of the field. A wheat-soybean rotation followed the biosolids application, as did light tillage in spring and fall using a mulch finisher and disk ripper to a maximum 10 cm depth throughout the whole study duration. Glyphosate and fenoxaprop-p-ethyl were used for weed control. In an attempt to balance fertility in both field sections and follow standard agricultural practice, the control section received inorganic nitrogen fertilization (95.3 kg N/ha) in the late spring of 2009, in contrast to nutrients added with biosolids (682 kg N/ha, 902 kg P/ha, and 5170 kg organic C/ha). Further details on the characteristics of the field site, the applied biosolids and the field site management are provided in Gottschall et al. (2012, 2013).

Eight permanent plots (plot dimensions of 10 m × 10 m) were established randomly across the whole range of each of the biosolids-treated and the control section of the field. In the present study, these 16 plots were sampled for nematodes and enchytraeids in April 2009 (6 months post application, 6 MPA), in October 2009 (12 MPA), April 2010 (18 MPA), October 2010 (24 MPA), and in May 2011 (31 MPA). In June 2012 (44 MPA) they were sampled for nematodes and earthworms. Bait lamina tests were conducted around the five last sampling dates (12 MPA to 44 MPA). The tests and all samplings were conducted just before harvest in the fall and just before planting in the spring, respectively. Additionally, eight plots (spatially equally distributed over control and biosolids section, but not a subset of the permanent plots) were sampled for nematodes and enchytraeids in September 2008, one week prior to biosolids application, to establish pre-application characteristics.