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Nematodes as indicators of soil recovery in tailings of a lead/zinc mine

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ABSTRACT

Trophic groups and functional guilds of soil nematodes were measured under four mine tailing subsystems in the Baoshan lead/zinc mine, Hunan Province, southern China to test the indicator value of nematodes for heavy metal pollution. No obvious correlation was found between heavy metal concentration and the total number of nematodes. However, the densities of c–p3, c–p4 and c–p5 nematodes were negatively correlated with Pb and Zn concentrations, suggesting that the abundance of nematode groups of high c–p values is useful indicators of heavy metal contamination. The “weighted faunal analysis” provided a better assessment of soil health condition than Maturity Index (MI) in situations where there were extremely low numbers of soil nematodes. Results showed that the effect of heavy metal contamination on soil nematodes might be strongly influenced by plants. Although the abundance of plant-feeding nematodes did not reflect the heavy metal conditions in the soil, it might be used as an index for assessing the soil remediation potential of pioneering plants. *Patrinia villosa* seems superior to *Viola baoshanensis* as a pioneer plant species for soil remediation based on analysis of rhizosphere nematode community.

1. Introduction

Nematodes are an important component of the soil ecosystem with profound effects on organic matter decomposition, nutrient transformation and energy transfer (Anderson et al., 1981; Freckman, 1988; Yeates and Bongers, 1999; Neher, 2001; Coleman et al., 2004). Many reports suggest that nematodes are useful bioindicators in soil and aquatic ecosystems. Their indicator value in relation to soil functioning or soil properties has been well illustrated (Goralczyk, 1998; Bongers and Ferris, 1999; Ekschmitt et al., 2001). Omnivore–predator nematodes are most sensitive to environmental disturbance (Bongers and Bongers, 1998; Georgieva et al., 2002), while bacterivorous and fungivorous nematodes respond at different rates to residue application under conventional tillage and no-till agroecosystems (Fu et al., 2000). Graphic representation of the relative biomass of bacterivorous, fungivorous and herbivorous nematodes has been used to explain structure of the soil food web in relation to resource inputs (Ferris and Bongers, 2006).

Soil nematodes are ubiquitous; they are well adapted to a wide range of environmental conditions; and they respond rapidly to disturbance. In addition, nematodes are transparent, their diagnostic internal features can be seen without dissection, and their life course is short. These features enhance their bioindicator potential for assessment of environmental health (Bongers and Ferris, 1999; Urzelai et al., 2000; Diemont et al., 2006; Ferris and Bongers, 2006). In recent years, the relationship between heavy metal contamination and soil nematodes has attracted increasing attention (Bardgett et al., 1994; Nagy, 1999; Korthals et al., 2000; Li et al., 2006).

Bongers (1990) developed the Maturity Index (MI) based on the weighted mean frequency of nematodes in five colonizer–persister (c–p) classes. The c–p scaling is based on functional responses of soil nematodes to resource and environmental change (Ettema and Bongers, 1993; Freckman and Ettema, 1993; Bongers, 1999; Bongers and Ferris, 1999). Ferris et al. (2001) developed a graphic faunal analysis system, which integrates the information of c–p scaling and trophic groups of nematodes and allows diagnosis of food web structure and soil health condition.

In this study, trophic groups and c–p scaling of soil nematodes were investigated under different vegetation types and in slag and sludge mine tailings. The objectives were: (1) to determine how soil nematodes respond to heavy metal contamination and (2) to test

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how the diagnostic tools (i.e. Maturity Index, weighted faunal analysis) perform in assessing soil recovery from lead and zinc contamination in mine tailings.

2. Material and methods

2.1. Site description

The sampling was conducted in tailings of the Baoshan lead/zinc mine which is located in Guiyang County (E112°35′, N25°42′), Hunan Province, China, at an elevation of 400–650 m. High yielding Pb and Zn deposits have been extracted since the Tang dynasty (A.D. 618–907) but mining ceased in 1996 because of low production (Liu et al., 2004). Based on vegetation coverage and soil substrate, the mine tailing area can be roughly categorized into the following four subsystems: I: soil covered with *Viola baoshanensis* (≈30%) and *Patrinia villosa* (≈60%) plants by 10 years after mining ceased; II: soil covered (≈60%) with Polygonaceae plants within 5 years after mining ceased; III: mine tailing slag without vegetation; IV: mine tailing sludge without vegetation. For this study, we randomly selected three replicate sampling plots for each subsystem. The area of each sampling plot was approximately 400–600 m^2 (Fig. 1).

2.2. Soil analyses

Soil pH was determined in 1:2.5 (w/v) soil solutions, and soil moisture was measured by oven drying for 72 h at 105 °C. Soil organic C was determined by combustion of dry soil in a muffle furnace at 490 °C for 8 h. Total nitrogen was measured colorimetrically using the indophenol blue method (Keeney and Nelson, 1982). Total soil Pb and Zn concentrations were determined by inductively coupled plasma atomic emission spectrometry (ICP-AES) after acid digestion (McGrath and Cunliffe, 1985). Microbial Biomass C (C_{mic}) was determined with the fumigation extraction procedure (Vance et al., 1987).

2.3. Nematode sampling and analyses

Five composite soil samples were taken in each sampling plot at each subsystem site. The composite samples were comprised of three soil cores taken from the upper 0–5 cm soil. Because *V. baoshanensis* and *P. villosa* were the two dominant plant species in subsystem I, rhizosphere soils of the two plants were sampled separately in order to compare the soil nematode community structure between rhizosphere and non-rhizosphere soil. The rhizosphere soils of *V. baoshanensis* and *P. villosa* were designated as Ir1 and Ir2, respectively. Sampling was conducted on January 5, 2006. The mean annual temperature in this region is 17.2 °C, the mean rainfall is 1525 mm, and the mean evaporation is 701.2 mm.

For each composite soil sample, nematodes were extracted from 50 g of moist soil using the Baermann funnel method (Barker, 1985). After fixation in 4% formalin solution, nematodes were counted under an inverted microscope and the first 100 individuals encountered were identified into trophic groups and functional guilds. All nematodes were identified when the nematode were fewer than 100 individuals in a sample.

The Maturity Index (MI) was calculated as the weighted mean of the c–p values of the free-living nematodes (Bongers, 1990; Bongers and Bongers, 1998). MI is used to evaluate the functional responses of soil nematodes to resource and environmental change.

Nematode faunal analysis, based on a weighted matrix classification of life traits and feeding habits, provides qualitative measures of the soil food web. The structure index (SI) is based on the relative weighted abundance of disruption-sensitive guilds representing structure; the enrichment index (EI) is based on opportunistic bacterial- and fungal-feeding nematodes representing enrichment. At the base of both indices are taxa tolerant of adverse conditions and basal to all nematode assemblages. When EI is plotted against SI for a sample of nematodes, the resulting graph can be divided into four quadrats which are descriptive of food web characteristics (Ferris et al., 2001; Ferris and Matute, 2003).

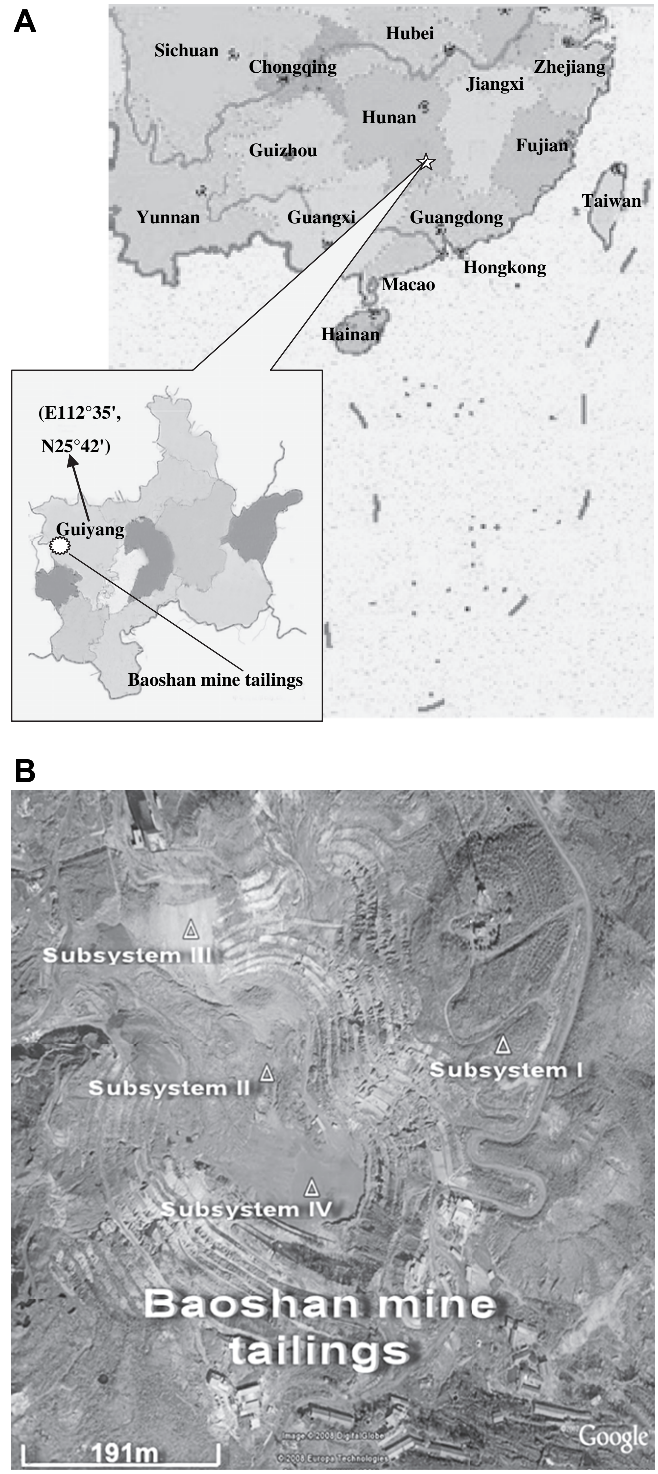

Fig. 1. Map of sampling site. (A): location of Baoshan mine tailings; (B): different subsystems in Baoshan mine tailings (modified from Google Earth).

2.4. Statistical analysis

All data were analyzed by ANOVA using SPSS 15.0 statistical software (SPSS Inc., Chicago, IL). LSD was applied to test the