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Effects of heavy metal pollution of highway origin on soil nematode guilds in North Shenyang, China

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Abstract

Soil samples were collected with distance at 5, 20, 40, 80, 160, and 320 m from the Shen-Ha (Shenyang-Harbin) Highway, Northeast China, to investigate the effect of heavy metals of highway origin on soil nematode guilds. The contents of soil Pb, Cu, Zn, and the nematode community structure were analyzed. The results showed that the contents of total and available Pb, Cu, Zn varied significantly with the different distances from the highway. Pb was the main pollutant in the soils in the vicinity of Shen-Ha Highway. The zone from 20 to 40 m away from the highway was the most polluted area. The highest abundance of soil nematodes was found at 5 m while the lowest at 20 m away from the highway. Thirty six genera of nematodes belonging to 23 families were identified. Nematode guilds having different responses to soil heavy metals were classified into four types. Soil nematode guilds may act as a prominent indicator to heavy metal pollution of highway origin.

Key words: soil pollution of highway origin; heavy metals; soil nematode guilds

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Introduction

In recent years, the construction of highways contributed to the development of industrial and agricultural production. However, the environmental pollution problem, especially heavy metal pollution, appeared during and after the construction of highways. For example, road transportation on the highway and waste materials from construction etc. contaminated the atmosphere, water and soil near the highway via atmospheric fallout. Some studies had proved that heavy metals including Pb, Cu and Zn were the main pollutants from the highway (Nabulo *et al.*, 2006; Preciado *et al.*, 2007). In 1994, approximately 28390 tons of Pb was emitted in the atmosphere, with a contribution of 70% from road transport at the vicinity of highways in the European part of the former Soviet Union (Gromov and Emelina, 1994). These heavy metals were usually dispersed in relatively higher concentrations in the vicinity of a highway with a gradual depletion as distance from the source increases and had a significant impact on the environment (Sezgin *et al.*, 2003).

Heavy metal pollutants influenced the food availability and competitive interactions among species of soil biota and finally affected the biota communities in an indirect way (Korthals *et al.*, 1996a). It has been shown that soil nematodes are good indicators of soil ecological processes (Ekschmitt *et al.*, 2001; Neher, 2001; Liang *et al.*, 2007). Therefore, the studies on soil nematode community level can account for the effects of pollutants on soil ecosystems. Based on the different feeding modes and life-history strategies, soil nematodes were classified according to c-p values ranging from 1 to 5 (Bongers, 1990; Yeates and Bongers, 1999). The nematodes with c-p 1 were colonizers and *r*-strategists with short generation time, and usually tolerant to disturbance. The nematodes with c-p 5 were persisters and *K*-strategists with longest generation time, and usually sensitive to disturbances (Bongers and Bongers, 1998; Ferris *et al.*, 2001).

Soil nematodes have been utilized to evaluate the complex soil pollution condition produced by heavy metals (Yeates *et al.*, 2003; Zhang *et al.*, 2006). Nematodes offered perspectives for the study of pollutant effects at the community level (Korthals *et al.*, 1996b). Analysis of the c-p group composition of the nematode assemblage was a valuable tool to detect heavy metal pollution (Bongers and Ferris, 1999). The relative abundance of the different life-history groups and, to a lesser extent, the different feeding groups of nematodes indicated pollution-induced changes in the soil community (Korthals *et al.*, 1996a).

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The effects of heavy metals on different life-history groups of soil nematodes were different. Georgieva *et al.* (2002) found that Cu and Zn treatments reduced the persisters (*K*-strategists) and stimulated colonizers (*r*-strategists). The nematode community composition and diversity indices were also strongly affected by the contents of soil heavy metals (especially by Pb, Cu, and Zn) (Sánchez-Moreno and Navas, 2007).

The highway from Shenyang to Harbin (Shen-Ha Highway) is 532 km, and about 50000 vehicles travel on it every day. Many important agricultural fields are distributed in the vicinity of the highway. Vehicle emission is the one of the most important sources of heavy metals pollution. The heavy metals from vehicle exhaust accumulate in the roadside field soils and cause a threat to ecological environments (Xia *et al*., 2004). Although some research works had been done to evaluate nematode responses to heavy metals from sources such as metallurgical factory (Li *et al*., 2006; Zhang *et al*., 2007) and sewage sludge (Weiss and Larink, 1991), there was a little information on the effect of heavy metal pollution from a highway on soil nematode life-history groups. The objectives of this study were to investigate the distribution of soil nematode guilds along the increasing distance from the Shen-Ha highway, to assess the effect of heavy metal pollution from highway on soil nematode communities, and to provide a nematological basis for environmental monitoring and control near the highway.

1 Materials and methods

Soil samples in the depth of 0–20 cm were taken from a maize field (100 m × 320 m) with increasing distance of 5, 20, 40, 80, 160, and 320 m (Viard *et al*., 2004) from the west side of the Shen-Ha highway on October 5, 2007. The soil is classified as a Hapli-Udic Argosol in Chinese Soil Taxonomy. The samples were collected using a soil corer of 5 cm in diameter with five replications. Each replication was composed of 5 soil cores. Soil samples were placed in individual plastic bag and transported to the laboratory for chemical and nematode analyses.

Soil chemical properties, such as soil pH, total organic carbon (TOC), total nitrogen (TN), total heavy metals (Pb, Cu, Zn), and available metals (Pb, Cu, Zn), were determined according to Li *et al*. (2006).

Nematodes were extracted from 100 g (fresh weight) of soil from each sample using modified Baermann's funnel technique (Tomar *et al*., 2006). After counting the total number of nematodes, 100 specimens per sample were randomly selected and identified to genus level using an inverted compound microscope (Wu *et al*., 2002; Ferris and Matute, 2003; Li *et al*., 2008). Nematode taxonomic and functional diversity was analyzed. To understand the effect of heavy metals from the highway on soil nematode communities accurately, soil nematodes identified were classified to five life-history groups (c-p 1 to 5) and four feeding types (Yeates *et al*., 1993). The colonizer-persister (c-p) values for taxa are adopted from the previous studies (Bongers and Bongers, 1998; Bongers, 1990).

Nematode data were $\ln(x+1)$ transformed before analysis to achieve normality of the data. Then, all data were analyzed by one-way analysis of variance (ANOVA) with treatments as independent variables. Mean separation was conducted based on LSD, and differences with $P < 0.05$ and $P < 0.01$ were considered significant and highly significant respectively. Spearman's correlation test was used to assess the correlation between nematode guilds and soil chemical properties.

2 Results

2.1 Soil chemical properties

The soil chemical properties at different sites with increasing distance from the highway were listed in Table 1. Significant differences were found in soil chemical properties at different sites, except in TOC. The average values of pH ranged from 5.16 to 6.44 and the soil samples between 5 m and 320 m sites were all weakly acidic. The average contents of total N ranged from 0.87 to 1.16 g/kg, the highest value was found at 40 m site and the lowest at 5 m site. The values of C/N were significantly higher at 5 m site than at other sites ($P < 0.05$).

The contents of total Pb, Zn, and Cu varied significantly with the different distance away from the highway. The highest values of total Pb, Zn, and Cu were detected at 40 m, 5 m, and 20 m site, respectively, and the lowest values at 320 m, 320 m and 5 m sites (Table 1). The values of

Table 1 Soil chemical properties at different sites

Parameter	Distance from sample site to Shen-Ha Highway					
	5 m	20 m	40 m	80 m	160 m	320 m
pH	6.44 ± 0.15 a	5.69 ± 0.48 b	5.35 ± 0.27 bc	5.61 ± 0.21 b	5.16 ± 0.16 c	6.43 ± 0.32 a
TOC (g/kg)	14.62 ± 1.82 a	13.17 ± 0.37 a	12.68 ± 0.67 a	12.16 ± 0.37 a	12.42 ± 0.99 a	10.46 ± 1.32 a
TN (g/kg)	0.87 ± 0.14 c	1.13 ± 0.05 a	1.16 ± 0.17 a	1.07 ± 0.09 ab	1.09 ± 0.10 a	0.93 ± 0.09 bc
C/N	16.96 ± 5.94 a	11.68 ± 0.60 b	11.01 ± 1.20 b	11.41 ± 1.15 b	11.45 ± 1.38 b	11.26 ± 0.88 b
T-Pb (mg/kg)	61.36 ± 5.26 b	65.96 ± 15.02 b	82.12 ± 6.25 a	56.23 ± 17.35 bc	44.89 ± 11.95 c	44.73 ± 8.9 c
T-Zn (mg/kg)	150.18 ± 7.72 a	116.42 ± 7.49 b	130.20 ± 14.59 b	120.24 ± 12.55 b	123.41 ± 18.96 b	92.27 ± 2.35 c
T-Cu (mg/kg)	20.42 ± 3.76 b	27.41 ± 1.99 a	23.26 ± 2.92 b	21.03 ± 1.55 b	22.20 ± 3.66 b	21.86 ± 3.40 b
A-Pb (mg/kg)	4.60 ± 1.24 e	5.25 ± 0.68 de	8.05 ± 1.00 ab	6.08 ± 0.94 cd	7.06 ± 1.68 bc	8.80 ± 0.58 a
A-Zn (mg/kg)	6.31 ± 1.35 a	3.00 ± 0.45 c	2.49 ± 0.22 c	2.93 ± 0.55 c	4.69 ± 1.74 b	2.18 ± 0.57 c
A-Cu (mg/kg)	3.86 ± 0.35 c	4.64 ± 0.30 b	5.96 ± 0.68 a	5.74 ± 0.50 a	5.70 ± 0.28 a	3.70 ± 0.33 c

Mean values in a row with different letters are significantly different from each other at $P < 0.05$; values are expressed as mean ± SD ($n = 5$).
TOC: total organic carbon; TN: total nitrogen; T-Pb: total Pb; T-Zn: total Zn; T-Cu: total Cu.
A-Pb: available Pb; A-Zn: available Zn; A-Cu: available Cu.

total Pb and Cu showed a similar trend, which increased at first and then decreased. In addition, the total Zn showed a decreasing trend along the increasing distance from the highway, with the average values ranging from 92.27 to 150.18 mg/kg.

Significant differences in the contents of available Pb, Zn, and Cu were also observed with the different distance from the highway ($P < 0.01$). The contents of available Pb, Zn, and Cu showed similar trends with those of total Pb, Zn and Cu. The highest values of available Pb, Zn and Cu appeared at 320 m, 5 m, and 40 m site, respectively. The lowest values of available Cu and Zn were both detected at 320 m site, but that of available Pb was the lowest at 5 m site.

2.2 Total nematode number

The average value of total nematode number ranged from 293 to 720 individuals per 100 g dry soil, decreased from the highest at 5 m site to the lowest at 20 m site and subsequently increased from 20 m to 40 m site (Fig. 1). Significant differences in the total nematode number were found between the 5 m site and other sites ($P < 0.05$).

2.3 Taxonomic composition of soil nematodes

Thirty six genera of soil nematodes belonging to 23 families were identified (Table 2). The highest number of genera was 27, which was found at 5 m and 160 m

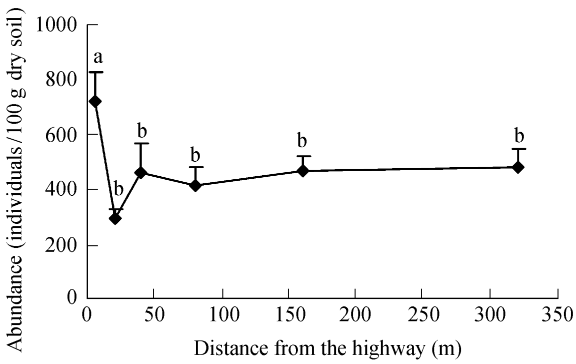

Fig. 1 Abundance of total nematodes at different sites. Error bars represent the standard error of the mean, $n = 5$, bars with different letters are significantly different, $P < 0.05$.

Table 2 Relative abundance (%) of nematode genera at different sites

Genus	Guild*	Distance from sample site to Shen-Ha Highway						P value
		5 m	20 m	40 m	80 m	160 m	320 m	
Mesorhabdtis	Ba1	0.4	3.4	0.5	1.1	2.7	3.7	ns
Monhystera	Ba1	1.0	1.8	0.0	1.7	0.2	0.8	< 0.05
Panagrolaimus	Ba1	0.3	0.0	0.0	0.0	0.0	0.0	ns
Rhabditis	Ba1	0.4	0.0	0.0	0.2	0.0	0.0	ns
Acrobeles	Ba2	1.4	0.4	0.0	0.2	0.0	1.2	ns
Acrobeloides	Ba2	0.9	0.4	3.4	0.0	1.5	0.3	ns
Cephalobus	Ba2	6.2	7.5	3.9	4.0	0.6	4.0	ns
Chiloplacus	Ba2	8.6	2.3	4.8	0.0	2.2	0.0	< 0.05
Eucephalobus	Ba2	1.4	2.3	2.6	4.7	1.7	2.0	ns
Wilsonema	Ba2	0.2	0.4	0.0	0.8	0.5	0.0	ns
Prismatolaimus	Ba3	0.0	0.0	0.0	0.9	0.2	2.1	< 0.01
Teratocephalus	Ba3	0.0	0.0	0.6	0.0	0.0	0.0	ns
Aphelenchus	Fu2	6.5	5.0	3.5	2.4	1.7	3.0	ns
Aphelenchoides	Fu2	0.0	0.8	0.2	0.3	0.2	2.4	ns
Diphtherophora	Fu3	1.0	0.0	0.0	0.0	0.0	0.0	< 0.01
Dorylaimoides	Fu4	2.7	1.5	0.1	3.4	1.3	0.9	ns
Tylencholaimus	Fu4	0.0	0.0	0.1	0.5	0.0	0.0	ns
Epidorylaimus	Op4	0.0	0.2	0.0	0.0	0.2	0.0	ns
Eudorylaimus	Op4	1.9	1.3	0.8	0.9	0.4	1.9	ns
Iotonchus	Op4	0.0	0.0	0.0	0.0	0.2	0.0	ns
Mylonchulus	Op4	0.0	0.0	0.0	0.2	0.2	0.0	ns
Thornenema	Op4	1.0	1.0	0.0	0.0	0.4	0.0	ns
Aporcelaimellus	Op5	1.1	0.0	0.2	0.2	0.6	0.0	ns
Axonchium	Op5	4.4	1.2	1.8	0.6	1.2	0.0	< 0.01
Discolaimus	Op5	0.3	0.0	0.0	0.0	0.0	0.0	ns
Aglenchus	H2	1.4	0.0	0.0	0.0	0.0	0.0	ns
Boleodorus	H2	1.4	3.8	1.8	6.6	0.0	5.0	< 0.05
Filenchus	H2	3.5	4.1	3.2	1.3	1.2	2.4	ns
Tylenchus	H2	1.0	2.5	3.0	0.5	4.2	3.7	ns
Criconemoides	H3	0.2	0.0	0.0	0.0	0.6	0.0	ns
Helicotylenchus	H3	37.9	38.2	51.5	58.2	61.6	57.3	ns
Heterodera	H3	0.0	0.0	8.8	0.4	1.1	0.0	< 0.05
Hirschmaniella	H3	0.0	0.0	1.0	1.3	2.1	2.6	ns
Pratylenchus	H3	12.2	18.4	5.9	7.9	7.1	6.5	ns
Trophurus	H3	2.3	3.4	0.8	1.6	6.0	0.0	ns
Dorylaimellus	H5	0.4	0.0	1.5	0.0	0.4	0.3	ns
Number of taxa		27	21	22	24	27	18	ns

* Guild designation is the composite of feeding habit and c-p value.
Ba: bacterivores; Fu: fungivores; Op: omnivore-predators; H: herbivores; numbers following the letters in Guild indicate the c-p value of each taxon (Bongers and Bongers, 1998; Bongers, 1990; Ferris and Matute, 2003; Li *et al*., 2008).
ns: non-significant.

site. *Helicotylenchus* was the dominant genus at all the sampling sites with the highest dominance (61.6%) at 160 m site. *Pratylenchus* was dominant only at 5 and 20 m sites. *Panagrolaimus*, *Diphtherophora*, *Aglenchus*, *Discolaimus* were only present at 5 m site.

2.4 Nematode guilds

The soil nematode feeding types (bacterivores (Ba), fungivores (Fu), herbivores (H) and omnivores-predators (O_p)) and life-history groups (c-p 1 to 5) are listed in Table 3. The numbers of bacterivores with c-p 2 decreased with the increasing distance from the highway and the bacterivores with c-p 3 showed an opposite trend. Among all groups, the abundance of nematodes were low with high c-p values (c-p 4 and 5) than that with low c-p values (c-p 1, 2 and 3). Significant differences in the number of omnivores-predators with c-p 5 were found among different sites ($P < 0.01$). The herbivores with c-p 3 were the dominant group, but no significant difference was found in their dominance values.

2.5 Correlations of nematode guilds with soil chemical properties

The correlations between soil nematode guilds and soil chemical properties are listed in Table 4. Significant positive correlations were observed between the content of total organic carbon and the numbers of bacterivores with c-p 2 and fungivores with c-p 3 ($P < 0.01$), and between C/N and the numbers of bacterivores with c-p 2, omnivore-predators with c-p 5 and fungivores with c-p 2–3 ($P < 0.01$). Significant negative correlation was found between the content of total nitrogen and the numbers of fungivores with c-p 2 ($P < 0.01$), herbivores with c-p 2 ($P < 0.01$) and omnivore-predators with c-p 4–5 ($P < 0.05$).

The numbers of bacterivores with c-p 1 negatively correlated with the contents of total Pb ($P < 0.01$), while those of fungivores with c-p 4 and omnivore-predators with c-p 5 negatively correlated with the contents of available Pb and total Cu ($P < 0.05$). Significant positive correlations were observed between the total and available Zn and bacterivores with c-p 2 ($P < 0.05$), fungivores with c-p 3 ($P < 0.01$) and omnivore-predators with c-p 5 ($P < 0.01$), and between the available Zn and fungivores with c-p 2 and herbivores with c-p 3 ($P < 0.05$), while significant negative correlation was found between the total Zn and bacterivores with c-p 3 ($P < 0.05$). Fungivores with c-p 2, herbivores with c-p 2 and omnivore-predators with c-p 4 negatively correlated with the content of available Cu and positively correlated with pH.

3 Discussion

Viard *et al*. (2004) testified that Pb was the main heavy metal in evaluating pollution from highway traffic. In current study, it was found that the soil in the vicinity of the highway had been contaminated by Pb, but not by Cu and Zn according to the Chinese National Standard (GB15618-1995). Du *et al*. (2007) found that Pb pollution affected a roadside soil mainly within 50 m away from the highway. Our results also showed that the contents of both total and available Pb were high at 40 m from the highway. The dispersion of contaminants is influenced by meteorological

Table 3 Absolute abundance (individuals per 100 g dry soil) of nematode guilds at different sites

Guild	Distance from sample site to Shen-Ha Highway					
	5 m	20 m	40 m	80 m	160 m	320 m
Ba1	15 ± 5 a	11 ± 6 a	1 ± 1 a	12 ± 5 a	13 ± 8 a	21 ± 3 a
Ba2	128 ± 32 a	40 ± 8 b	55 ± 12 b	39 ± 8 b	31 ± 14 b	36 ± 8 b
Ba3	0 ± 0 b	0 ± 0 b	2 ± 2 b	5 ± 3 ab	1 ± 1 b	9 ± 3 a
Fu2	47 ± 13 a	15 ± 3 a	21 ± 12 a	11 ± 5 a	11 ± 9 a	24 ± 6 a
Fu3	7 ± 3 a	0 ± 0 b	0 ± 0 b	0 ± 0 b	0 ± 0 b	0 ± 0 b
Fu4	18 ± 11 a	5 ± 3 a	1 ± 1 a	16 ± 9 a	5 ± 3 a	4 ± 2 a
Op4	16 ± 9 a	8 ± 4 a	3 ± 3 a	4 ± 3 a	5 ± 2 a	8 ± 3 a
Op5	36 ± 9 a	3 ± 2 b	11 ± 5 b	3 ± 1 b	7 ± 4 b	0 ± 0 b
H2	53 ± 16 a	30 ± 9 a	36 ± 12 a	34 ± 12 a	23 ± 4 a	53 ± 12 a
H3	396 ± 102 a	181 ± 33 a	328 ± 89 a	292 ± 57 a	369 ± 49 a	324 ± 63 a
H5	4 ± 2 a	0 ± 0 a	5 ± 3 a	0 ± 0 a	1 ± 1 a	1 ± 1 a

Mean values in a line with different letters are significantly different from each other at $P < 0.05$; values are expressed as mean ± standard error ($n = 5$).

Table 4 Correlation between nematode guilds and soil chemical properties

Guild	pH	TOC	TN	C/N	T-Pb	T-Cu	T-Zn	A-Pb	A-Cu	A-Zn
Ba1	0.304	0.242	–0.150	0.292	–0.606**	–0.238	–0.026	0.034	–0.217	0.164
Ba2	0.294	0.609**	–0.311	0.802**	0.140	–0.164	0.624**	–0.217	–0.229	0.430*
Ba3	0.263	–0.320	–0.136	–0.215	–0.138	–0.06	–0.419*	0.304	–0.208	–0.325
Fu2	0.478**	0.312	–0.506**	0.634**	0.221	–0.145	0.233	–0.236	–0.401*	0.429*
Fu3	0.357	0.563**	–0.306	0.615**	0.107	–0.100	0.554**	–0.319	–0.331	0.635**
Fu4	0.215	–0.008	–0.272	0.103	–0.026	–0.374*	0.276	–0.369*	–0.107	0.107
Op4	0.391*	–0.047	–0.412*	0.310	–0.146	–0.094	0.076	–0.094	–0.365*	0.173
Op5	0.337	0.264	–0.429*	0.550**	0.063	–0.406*	0.559**	–0.443*	–0.177	0.497**
H2	0.525**	–0.002	–0.470**	0.307	0.190	0.058	–0.048	–0.056	–0.477**	0.170
H3	–0.019	0.007	–0.268	0.133	0.049	–0.140	0.168	0.005	0.022	0.361*
H5	–0.042	0.188	–0.038	0.182	0.237	0.113	0.338	0.142	–0.003	0.173

* $P < 0.05$; ** $P < 0.01$.

conditions, like wind, rainfall, profiles or traffic intensity (Viard *et al*., 2004). Therefore, the heavy metals from the highway influenced by factors like wind would spread to a certain distance and then deposit and accumulate in soil. This was the reason why we did not find a high content of Pb at 5 m from the highway. But the content of available Pb at 320 m from the highway was high. It could be concluded that the Pb mainly from the traffic emission had little effect on the soils far away from the highway and the background value of soil and other factors were main factors to affect the concentration of soil Pb in this condition.

The total nematode numbers showed a similar trend to the content of soil Zn and the opposite trend with soil Pb and Cu. The responses of nematode genera in the different or the same guilds to heavy metal pollution were varied. There were also different responses in different life-history groups and feeding types of soil nematodes to heavy metal pollution from the highway. The soil nematodes communities were classified to several types according to the responses to the highway pollution. The first response type of the life-history groups was the group with negative responses to the heavy metal, which included bacterivores with c-p 1 and 3, and fungivores and omnivores-predators with c-p 4. According to Shukurov *et al*. (2006), a negatively bioindicative response to heavy-metal pollution was most evident among the omnivore-predators and fungivores. Several publications also indicated that contamination of a field with heavy metals decreased nematode abundance and generic richness (Korthals *et al*., 1996b; Georgieva *et al*., 2002; Nagy *et al*., 2004). In this study, the results such as the significantly negative correlation between total Pb and the abundance of bacterivores with c-p 1 (Table 4) proved this conclusion.

The second type was the group with positive responses to the highway pollution, which mainly included bacterivores with c-p 2 and fungivores with c-p 3. Significant positive correlation between bacterivores with c-p 2, fungivores with c-p 3 and the total and available Zn indicated that these groups were more tolerant to the highway pollution than others. Our findings were consistent with conclusions of Korthals *et al*. (1998) and Li *et al*. (2006).

The third group had negative or positive responses to different heavy metals. The total Cu and available Pb significantly decreased the abundance of omnivores-predators with c-p 5, but the total and available Zn increased their abundances. The available Cu significantly decreased the abundance of fungivores with c-p 2, but the available Zn increased their abundance. These results were consistent with the result of Nagy (1999), in which Zn had the most apparent positive impacts on structure of nematode assemblage.

The fourth type gave no significant responses to the highway pollution, such as herbivores with c-p 5. There were no significant differences in the group with the distances from the highway increasing. The density of the herbivorous nematodes can be related to biomass and vigor of plants (Bongers and Ferris, 1999; Yeates and Bongers, 1999). Therefore, we can explain the correlation between herbivores with c-p 2 and 3 and available Cu and Zn supposing that the Cu and Zn as microelements affected the herbivores indirectly.

The significant correlation were found not only between heavy metals and nematode guilds but also between soil chemical properties and nematode guilds. For example, significantly positive correlation were found between bacterivores with c-p 2, fungivores with c-p 3 and TOC. However, no significant difference was found in TOC at different sites and only the variation of TOC could not explain the significant differences of bacterivores with c-p 2 and fungivores with c-p 3 at different sites. In addition, other soil chemical properties such as pH and TN were also correlated with certain nematodes guilds. Soil properties not only affect the nematode community structure, but also bioavailability and toxicity of contaminants (Kothals *et al*., 1996). The site-specific character exists in the change of soil nematodes owing to heavy metal pollution (Bakonyi *et al*., 2003). Therefore, the distribution of nematode guilds are probably better explained by the joint action of soil properties and heavy metals.

It could be concluded that the areas from 20 m to 40 m in the vicinity of Shen-Ha highway were heavily polluted by Pb and there was low abundance of soil nematodes. In most cases, the abundance of nematode guilds was inhibited by the heavy metal pollution from the highway, but was stimulated by Zn. The condition of soil heavy metal pollution from the highway can be indicated by the changes in nematode guilds. The nematode guilds may act as a prominent indicator to highway pollution.

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