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Uptake of Cadmium, Zinc, Lead, and Copper by Earthworms near a Zinc-smelting Complex: Influence of Soil pH and Organic Matter

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An important consideration in the estimation of pollution hazards by heavy metals in terrestrial environments is the influence of abiotic factors such as soil acidity. Field-plot studies have suggested that pH, organic matter content, and cation exchange capacity of the soil may play a significant role in governing trace metal uptake by lumbricid earthworms (MA 1982).

This study investigates the influence of pH and organic matter on the accumulation of Cd, Zn, Pb, and Cu by earthworms in a natural terrestrial ecosystem. To this end, samples were taken in a region which was locally contaminated with these metals by past emissions from zinc smelting works.

MATERIALS AND METHODS

Sampling was done largely in the Dutch Kempen region located south-east of Eindhoven and north to a complex of several large zinc smelting works. Some samples were taken about 10 km north to this region in order to include data on less polluted sites. All sites were situated in either grassland or heathland on sandy podzolic soil. Thirty-one sites were sampled in total, mainly along transects of 1 to 15 km from the nearest zinc smelter in a general north-south direction.

Soil samples were taken with a grassland probe (2.5 cm diameter) from the upper 2 cm of the A_0 horizon just below the root zone. Sixteen cores were drawn within an area of 2 m radius at each site; the subsamples were mixed to from one sample. The soil was air-dried at $60^{\circ}C$, ground, and sieved (2 mm mesh). Organic matter content was measured from loss-on-ignition ($600^{\circ}C$) and pH was determined in N KCl.

Earthworms were obtained by digging and hand-sorting of the upper 20 cm soil layer. Lumbricus rubellus, being the dominant species in the region investigated, was selected for investigation of trace metal contents. Since previous work (MA 1982) has shown that in earthworms accumulations of Cd, Zn, or Pb may significantly increase with developmental stage only mature adult worms were used for chemical analysis. Worm samples were prepared for analysis by starving for several days on wet filter paper. The average ($\pm$ S.D.) weight of the worms with emptied gut contents was 86 $\pm$ 28 mg (dry wt).

Samples of soil and worms were digested with nitric and sulfuric acids and analyzed for contents of Cd, Zn, Pb, and Cu by atomic absorption spectrophotometry. Data are presented as mg/kg on a dry weight basis.

RESULTS AND DISCUSSION

The concentration of the metal elements in the soil and worm samples showed a considerable variation among sampling sites (Table 1).

Table 1 Range of metal content (mg/kg) of soil and worms, with additional data on pH and organic matter content of 31 sampling sites.

Element	Soil	L. rubellus
Cd	0.1 - 5.7	20 - 202
Zn	10 - 1.220	717 - 3.500
Pb	14 - 430	9 - 670
Cu	1 - 130	12 - 58
Soil pH	$\bar{x} \pm$ S.D. = 4.6 $\pm$ 0.7	(range 3.5 - 6.1)
% Org. matter	$\bar{x} \pm$ S.D. = 5.0 $\pm$ 1.7	(range 2.2 - 8.6)

This could be partly attributed to the varying distance between the sites and the zinc smelting works. As shown in Table 2, the contamination level of the sites tended to increase with decreasing distance from the nearest zinc smelter according to a power function. There was, however, a better correlation with distance for contents of Cd and Zn than for those of Pb or Cu.

Table 2 Regression for metal content (mg/kg) in either soil or worms against distance in km from nearest zinc smelter (x) according to the equation: $\ln y = \ln b + m \ln x$

Metal	y	b	m[1)]	r
Cadmium	Soil	3.909	- 0.77(0.15)	- 0.73***
	L. rubellus	116.9	- 0.47(0.09)	- 0.73***
Lead	Soil	102.5	- 0.56(0.16)	- 0.58**
	L. rubellus	159.0	- 0.47(0.25)	- 0.36*
Zinc	Soil	653.0	- 1.22(0.15)	- 0.86***
	L. rubellus	227.8	- 0.33(0.09)	- 0.59**
Copper	Soil	21.65	- 0.66(0.20)	- 0.56**
	L. rubellus	19.79	- 0.11(0.09)	0.23

*** p<0.001; ** p<0.01; * p<0.05; [1)] with S.E. in brackets

Substituting a distance value of 4 km into the relevant regression equation would yield estimated values in L. rubellus of 61, 83, and 1436 mg/kg of Cd, Pb, and Zn, respectively. These values are of a similar level to those reported for several earthworms species from pasture situated at an equal distance of 4 km from the Avonmouth smelter in England (WRIGHT & STRINGER 1980). These authors reported a range between 49 and 63 mg/kg for Cd, from 43 to 83 mg/kg for Pb, and from 634 to 1398 mg/kg for Zn. It is not possible, however, to state whether the soil contamination levels are also similar because of differences in sampling methods and soil types involved in both surveys.

In the present study, the soil samples showed relatively low pH values and a wide range in organic matter content (Table 1). The relative importance of pH and organic matter content in affecting metal uptake by L. rubellus was investigated through multiple regression analysis. Stepwise regression equations for log transformed data are presented in Table 3. Copper deviated from the other three metal elements in that the relation between worm Cu and soil Cu was better described by a linear rather than by a non-linear function.

Table 3 Multiple regression equations of the relationships between metal concentration (mg/kg) in adult L.rubellus (y) and various soil variables, including soil metal concentration in mg/kg (x), percentage organic matter (OM) and pH. V^2 = percentage variance in worm metal content accounted for.

Metal	Regression equations	V^2
Cadmium	$\ln y = 3.740 + 0.486 \ln x$	34.8
	$\ln y = 4.233 + 0.612 \ln x - 0.107$ % OM	38.3
	$\ln y$ [1)] $= 5.538 + 0.664 \ln x - 0.404$ pH	47.5
	$\ln y = 6.018 + 0.787 \ln x - 0.106$ % OM $- 0.402$ pH	51.5
Lead	$\ln y = 0.525 + 0.999 \ln x$	38.6
	$\ln y = 1.261 + 1.146 \ln x - 0.297$ % OM	53.3
	$\ln y = 4.355 + 1.056 \ln x - 0.925$ pH	62.8
	$\ln y$ [1)] $= 4.157 + 1.131 \ln x - 0.176$ % OM $- 0.746$ pH	66.5
Zinc	$\ln y = 6.047 + 0.241 \ln x$	33.6
	$\ln y = 6.056 + 0.313 \ln x - 0.073$ % OM	36.6
	$\ln y$ [1)] $= 6.791 + 0.343 \ln x - 0.270$ pH	43.0
	$\ln y = 6.878 + 0.439 \ln x - 0.088$ % OM $- 0.298$ pH	49.0
Copper	y [1)] $= 14.88 + 0.344\, x$	57.5
	$y = 21.56 + 0.349\, x - 1.272$ % OM	60.0
	$y = 18.43 + 0.340\, x - 0.738$ pH	56.1
	$y = 20.57 + 0.350\, x - 1.301$ % OM $+ 0.238$ pH	58.4

1) Best-fit equation as tested by F-test; regression data of the best-fit equations are all statistically significant (t-test)

Cd, Zn, and Pb appeared to be more strongly accumulated by L. rubellus when present in soil with a low pH value. Cu was the only exception in this regard; its uptake by L. rubellus was not significantly influenced by soil pH. This agrees with the results obtained from observations on Allolobophora caliginosa (MA 1982), which similarly have suggested that lowering of pH strongly promotes the uptake of the metal elements Cd, Zn, and Pb, while leaving the uptake of Cu unaffected.

The organic matter content of the soil played a significant role only in the worm uptake of Pb (Table 3). Soil Pb content, soil pH, and soil organic matter content together accounted for almost 70% of the variance in worm Pb content. The results indicate that L. rubellus accumulates Pb more strongly in soil with a low pH and low organic matter content that in soil with higher values of these parameters. The demonstrated influence of pH and organic matter content on element concentration in earthworms emphasizes the importance of soil factors in governing the entrance of toxic metal elements into the food web. The mechanisms involved may relate to the effect of these soil factors on metal availability to organisms in the terrestrial ecosystem.

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