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Heavy Metal Accumulation in the Mole, *Talpa europea*, and Earthworms as an Indicator of Metal Bioavailability in Terrestrial Environments

Wei-chun Ma

Research Institute for Nature Management, P.O. Box 9201, 6800 HB Arnhem, The Netherlands

Bioaccumulation studies in animals can supply valuable information to supplement the data obtained by chemical analysis of pollutants in abiotic samples. With respect to the terrestrial ecosystem, suitable indicator species in the decomposer subsystem can be identified on the basis of functional characteristics and trophic level. Investigations on metal behaviour at the first trophic level, done in lumbricid earthworms (Ma 1982, 1983; Ma et al.1983), showed that the potential for bioaccumulation depends on the degree of contamination as well as on the metal-binding capacity of the soil.

The present study was performed to investigate metal behaviour at a higher trophic level, and the mole (Talpa europea) was chosen as a representative of the terrestrial decomposer subsystem. These animals are predators of soil macroinvertebrates, especially earthworms, and occur over a range of diverse types of habitats (Milner & Ball 1970). As earthworms are the preferred food of moles (Funmilayo 1977, 1979), they provide the major source of ingested metals to these animals. The food chain involving earthworms and moles provides an example of a 'critical pathway' (Moriarty 1983) for potentially toxic non-essential metals such as cadmium and lead.

MATERIALS AND METHODS

Soil, vegetation and animals were sampled in the winter during November to December 1983 at five sites (Table 1). These included three pasture sites and one heathland site near Budel and one pasture site near Arnhem. The area near Budel was contaminated in the past with heavy metals by emissions of nearby smelters (Ma et al.1983). The Arnhem site was chosen as a relatively uncontaminated reference site. The vegetative cover of the pasture sites consisted mainly of Lolium perenne, Agrostis tenuis, Festuca spp., and Poa spp. The heathland site had a main cover of Deschamspia flexuosa. All sites shared a similar type of podzolic sandy soil but differed in organic matter content and soil pH (Table 1). The relatively high pH of the pasture sites at Budel was due to annual applications of lime.

Soil samples comprised 16 corings from a 48-m transect in each site. All corings were 10 cm deep and were taken immediately under the litter layer, if present. The soil was air-dried and sifted through a 2 mm-mesh sieve before analysis. Vegetative clippings of above-ground plant parts were air-dried and ground in an agate ball mill.

Table 1. Properties of soils and mean concentration of metals (ug/g) in soil and vegetation of study sites.

Site nr.	Location	Type	Item	% Org. matter	pH KCl	Cd	Cu	Pb	Zn
1	Budel	pasture	soil	5.0	5.2	1.8	12	38	215
			veg.	-	-	1.5	18	11	346
2	Budel	pasture	soil	7.3	6.0	6.0	25	115	737
			veg.	-	-	2.1	12	6	449
3	Budel	pasture	soil	10.2	6.5	9.2	40	135	1015
			veg.	-	-	2.1	11	5	465
4	Budel	heath	soil	2.0	4.1	0.3	27	149	60
			veg.	-	-	1.6	25	161	508
5	Arnhem	pasture	soil	5.7	4.0	0.1	7	24	35
			veg.	-	-	2.1	13	27	185

Moles were caught by intercepting them alive in their burrows. After the animals were killed, body weight and length were measured and the kidneys and liver organs were dissected. Some data on the animals are given in Table 2.

Earthworms were collected from soil close to the spot where moles had been caught. Adult worms of Lumbricus rubellus were starved for three days on moist filter paper in petri dishes to eliminate the gut contents.

Table 2. Some characteristics (geometric means and ranges) of moles in which the tissue metal content was determined. The numbers collected at each site varied from four to five. Body weights are expressed as fresh weights; kidney and liver as dry weights.

Site nr.	Body wt (g) mean	Body wt (g) range	Body length (mm) mean	Body length (mm) range	Kidney wt (mg) mean	Kidney wt (mg) range	Liver wt (mg) mean	Liver wt (mg) range
1	82	77- 89	133	128-142	153	141-178	836	725- 886
2	87	85- 89	128	124-133	178	167-190	993	959-1017
3	93	83-117	142	123-157	198	157-238	978	764-1172
4	106	103-109	148	144-152	187	184-190	1118	1106-1131
5	89	76-104	144	136-156	151	131-177	727	689- 723

Samples of soil, vegetation, and animal tissues were analysed to determine total Cd, Cu, Pb, and Zn by atomic absorption spectrophotometry according to procedures described elsewhere (Ma 1982). All concentrations are reported as ug/g dry matter. The average dry matter percentage ($\pm$ SD) was 25.3 ± 1.9 for kidney and 28.6 ± 1.3 for liver tissue. These dry matter contents can be used for the conversion of dry weight concentrations to wet weight values if desired.

RESULTS AND DISCUSSION

Data on metal concentrations are given in Table 3 and Fig.1 for moles, and in Table 4 for invertebrates. Data on metal levels in earthworms were not available for all sites, but the approximations can be made with multiple regression equations given by Ma et al.(1983). These regression equations include the soil metal and organic matter contents and soil pH as independent variables, and were established specifically for the Budel area. The values calculated from these equations are shown in Table 5.

Cadmium. All sites at the Budel area were contaminated with cadmium (Cd) relative to the uncontaminated site (nr.5) at Arnhem (Table 1). The heathland (site nr.4) contained a much lower soil Cd level than the pasture sites nrs.1, 2 and 3. Mean concentrations of Cd measured in kidney and liver of moles, however, were strongly elevated at all Budel sites (Table 3). Concentrations of Cd in both kidney and liver were elevated, compared to the reference values although levels were generally lower in liver than in kidney tissue. Ten specimens showed hepatic Cd concentrations of more than 100 ug/g, in four of them amounting to more than 200 ug/g or about seven times the average reference value measured in moles from Arnhem.

Six specimens from the Budel area showed Cd concentrations of more than 200 ug/g in kidney tissue. In four of these animals the concentration exceeded 300 ug/g, which is five times the mean value for moles from Arnhem. One specimen from Budel (site nr.2) even had a kidney Cd concentration of more than 400 ug/g. Laboratory studies have shown that Cd concentrations of 110-260 ug/g in kidneys of vertebrates are associated with severe ultrastructural nephrotoxic lesions and certain enzymatic changes (Nicholson et al.1983).

Table 3. Geometric mean concentration (ug/g) with range for the four metals in kidneys and liver of moles.

Site	Organ	Cd		Cu		Pb		Zn	
nr.		mean	range	mean	range	mean	range	mean	range
1	kidney	112	94-134	27	23-30	31	23- 41	191	183-209
	liver	94	82-110	23	20-24	10	9- 12	137	134-139
2	kidney	224	88-419	28	27-29	29	25- 38	324	251-374
	liver	227	214-234	27	22-30	11	10- 12	191	160-220
3	kidney	221	104-352	32	25-37	18	8- 35	373	291-449
	liver	172	122-214	27	22-30	8	5- 11	232	198-244
4	kidney	186	171-200	27	26-27	338	238-438	242	234-250
	liver	145	136-154	26	20-21	34	28- 40	189	156-222
5	kidney	59	30-125	25	22-27	22	17- 31	131	105-152
	liver	30	25- 48	23	21-26	9	6- 11	115	111-120

The bioavailability of the soil Cd contamination was apparently much greater for the heathland site than the pasture sites. In spite of the relatively low soil Cd level (Table 1), renal and hepatic Cd values of moles from the heathland site were strongly elevated (Table 3). The presence of elevated tissue Cd levels in moles corresponded with similarly elevated Cd levels in earthworms (Tables 4 and 5).

Lead. Soil levels of lead (Pb) were elevated at all Budel sites, especially at pasture sites nrs. 2 and 3 and at the heathland site (nr.4) (Table 1). Surprisingly, however, tissue levels of Pb were strongly elevated only in moles from the heathland site (Table 3). Whereas moles from pasture soils showed an average ($\pm$SE) kidney concentration of Pb amounting to 25.0 ± 3.1 ug/g, moles from the heathland site all contained more than 200 ug/g. Both renal and hepatic Pb concentrations in heathland moles were elevated, although the average kidney concentration of Pb (338 ug/g) was one order of magnitude higher than the average level in liver (34 ug/g). One specimen even had a concentration of more than 400 ug/g (438 ug/g), or twenty times the reference value. Pb levels of 120 ug/g in kidney have been associated with significant reductions of body weight and intracellular alterations in the kidney cortex (Goyer et al.1970).

The heathland site can be compared with a pasture site (nr.3) having a similar soil Pb level (Table 1). However, moles from the heathland site had eighteen and four times higher renal and hepatic Pb levels, respectively. This illustrates the much higher bioavailability of Pb at the heathland site.
According to the predicted values obtained for Pb in earthworms (Table 5), Pb levels in the earthworms from the heathland would be more than ten times higher than those in the worms from the pasture sites. The latter worms would not show any appreciably increased accumulation of Pb. This prediction for earthworms agrees well with the highly elevated tissue Pb level found in moles and offers an explanation of the high body burden of Pb found in moles from the heathland site.

Zinc. Moles from the contaminated Budel area showed elevated tissue levels of Zn, compared to moles from the reference site (Table 3). However, moles from the heathland site showed higher tissue Zn levels than would be expected from the relatively low Zn contamination of the soil at this site (Table 1). This corresponds with the predicted levels of Zn in earthworms (Table 5), which show that earthworms from the heathland would have similar Zn levels as those from the pasture soils.

Copper. None of the study sites was contaminated with copper (Table 1). However, mammals receiving Cd in the diet may have altered concentrations of Cu in soft tissues (Bremner 1978, Ashby et al.1981). In view of this possibility that Cd accumulation can interfere with copper metabolism, measurements on tissue Cu in moles were included in this study. The results shown in Table 3, however, do not suggest that Cu concentrations in the kidneys and liver of moles differ widely between sites. Levels of Cu in earthworms also did not vary much either between sites (Tables 4 and 5).

Table 4. Geometric mean concentration of metals (ug/g) with range in invertebrate samples. The number of samples of each site was five, each sample was composed of at least ten specimens.

Site nr.	Item	Cd mean	Cd range	Cu mean	Cu range	Pb mean	Pb range	Zn mean	Zn range
2	earthworms	79	72- 85	28	26-30	25	20-28	1474	1414-1564
3	earthworms	114	99-123	28	26-29	25	21-30	1789	1542-2065
5	earthworms	19	18- 21	20	20-21	12	10-13	730	717- 742

Table 5. Predicted values of metal concentrations in earthworm tissues, as calculated from Ma et al.(1983)

Site nr.	Cd	Cu	Pb	Zn
1	47	19	32	1380
2	69	21	41	1525
3	57	23	20	1164
4	25	28	590	1437
5	8	17	41	837

The present study shows that the accumulation of Cd, Pb, and Zn in moles reflects the bioavailability of these metals to earthworms. Accumulated levels in earthworms and moles do not consistently reflect the metal contamination level present in the soil. In acidic sandy soils Cd can accumulate in earthworms to a considerable extent, and critical levels of Cd toxicity in moles can be exceeded even when the soil contamination level is relatively low. Earthworms and moles also accumulate much more Pb from contaminated acidic sandy soils than from soils which have been limed. At the same soil contamination level Pb can exceed critical levels of Pb toxicity in moles living in acidic sandy soils, while showing no elevated tissue levels at limed sites. The study further shows that there is no evidence to suggest that the accumulation of Cd, Pb, and Zn affects the normal tissue level of Cu in either earthworms or moles.

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