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Role of earthworms against metal contamination: a review

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Abstract

Heavy metal contamination, occurring due to both natural and anthropogenic activities, is a subject of major concern throughout the globe. Increase in heavy metal content can have an adverse impact on functioning of the soil ecosystem by hampering the activities of soil fauna. Earthworms play an important role in metal pollution monitoring and are widely recognized in terrestrial ecosystems. They have an inherent potential for bioaccumulation of metals in their chloragogenous tissues and can be used as an ecological indicator of soil contamination. The present review is focused on: biology and ecology of earthworms, their role as ecosystem engineers and the mechanism involved in uptake, accumulation and excretion of metals by different species of earthworm under varieties of soil. A brief discussion about kinetics of metal accumulation was also laid importance. The review brings these studies together in order to highlight the ability of earthworms to affect metal mobility and its availability in various contaminated sites and elaborates the potential of various species of earthworm to remediate metal dominant substrates.

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Introduction

Earthworms, the “Earth annelids”, having super-streamlined and stripped down body are fairly highly evolved critters. Charles Darwin accentuated the role of earthworms in history of the world and also referred earthworms as “nature ploughs” because of mixing of soil and organic matter. Earthworms (phylum Annelida, class Oligochaeta) are also called megadriles (or big worms) as opposed to the microdriles (or small worms) in the families *Tubificidae, Lumbriculidae, Enchytraeidae* and among others. The importance of earthworms has been highlighted by several workers in the fields of waste management, environmental conservation, organic farming and sustainable agriculture (Talashikar and Powar, 1998; Senapati, 1992). Earthworms are one of the foremost components of soil communities and have ecological relevance in the formation and maintenance of soil structure. Earthworms function as ‘ecosystem engineers’, by directly and indirectly modifying the chemical, physical and biological properties of the soil and controlling ecosystem structure and functioning (Butenschoen *et al.,* 2009; Jones *et al.,* 1998; Lavelle, 1997).

The total heavy element content in soil is frequently used as a criterion for defining soil contamination. Heavy metals due to their role in biological processes as micronutrient (iron, zinc, copper, cobalt, etc.) or non-essential and toxic elements (Hg, Cd, Pb) are considered (Sary and Sari, 2014). The implication associated with heavy metal contamination is of great concern particularly in agricultural production system (Uzoma *et al.,* 2013). One of the most peculiar and special behavior of earthworms is to accumulate heavy metals in their tissues and gut. Earthworms can bioaccumulate and biotransform many chemical contaminants including heavy metals and organic pollutants in soil and clean-up the contaminated lands for re-development. Earthworms are one of the best bioindicators of trace metals amongst soil invertebrates because they are able to accumulate metal ions in their body tissues. (Nahmani and Lavelle, 2002; Terhivuo *et al.,* 1994). These soil organisms can provide important information for assessing environmental risks, and serve as useful biological indicators of contamination because of the fairly consistent correlation between the concentration of some contaminants in their tissues and those in soil. Mostly earthworms are also often the subject of inoculation programmes during the restoration of degraded lands and inoculation of earthworms to metal-contaminated soils has been suggested (Dickinson, 2000) largely due to the role earthworms are known to play in soil formation at such sites (Frouz *et al.,* 2007). Earthworms have great potential in risk assessment of contaminated land and acts as an indicator for ecosystem health (Nahmani, 2007). Thus, earthworms being the dominant and dynamic macrofauna can do wonderful jobs for man and biosphere.

The purpose of this review is to bring together studies, which focuses on earthworm’s inherent ability to accumulate heavy metals in their bodies and also on their nutrient enriching properties in soil by their composting abilities. This review further emphasizes on: importance of earthworms in ecosystem; their biology and ecology; species associated with metal uptake; mechanism by which earthworms accumulate heavy metals; and a brief discussion about the kinetics of accumulation pattern.

Biology and ecology of earthworms

Earthworms (Annelida, Oligochaeta) are relatively large detritivores (Sims and Gerard, 1985) as well as are soft-bodied, cylindrical, long, narrow, segmented and symmetrical organisms. Their body is dark brown, glistening, covered with soft cuticle. They generally range in weight from 1400-1500 mg after 8-10 weeks. The life-span of earthworms varies from 3-7 years depending upon the type of species and the ecological conditions prevailing there. Earthworm body contains 65% protein (70-80% high quality ‘lysine-rich protein’ on a dry weight basis), 14% fats and 14% carbohydrates. They grow throughout their life and the number of segments continuously proliferates from a growing zone just in front of the anus (Sinha *et al.,* 2008).

Earthworms are burrowing in nature and forms tunnels by literally eating their way through the soil. Their distribution in soil depends on factors like soil moisture, pH, and availability of organic matter. They prefer to live in dark and moist places. Cattle dung, humus, kitchen waste and other organic materials are highly attractive sites for some species. Earthworms are very sensitive to touch, light and dryness. Worms can tolerate a temperature range between 5 and 29°C. Optimum temperature of 20-25°C and moisture content of 50-60% is optimum for earthworm function (Sinha *et al.,* 2008; Edwards and Bohlen 1996).

Role of earthworms as 'ecosystem engineers'

Earthworms in vermicomposting

Vermicomposting, utilizing earthworms, is an eco-biotechnological process that transforms energy rich and complex organic substances into a stabilized humus-like product (Benitez *et al.,* 2000). Vermicomposting (Latin: vermes-worm) is a kindred process to composting, featuring the addition of certain species of earthworms used to enhance the process of waste conversion and produce a better end-product. Commonly used earthworms for vermicomposting are *Eisenia fetida, Perionyx excavatus*, *Lampito mauritii, Lumbricus rubellus, Lumbricus terrestris, Aporrectodea* and *Allolobophora*. Several ecological groups of earthworms are present such as (i) epigeic, (ii) endogeic, and (iii) anecic (Nei *et al.,* 2009).

The vermicomposting process includes two different phases involving the activity of earthworms: (a) an active phase during which earthworms process wastes, thereby modifying their physical state and microbial composition (Lores *et al.,* 2006), and (b) a maturation-like phase marked by the displacement of the earthworms toward fresher layers of undigested waste, during which the microbes take over the decomposition of the earthworm-processed waste (Lazcano *et al.,* 2008; Dominguez, 2004). Earthworms through vermicomposting process degrade different types of wastes, converting them into a valuable fertilizer. They bring about decomposition of the organic waste initially due to its gut-associated processes (GAPs) by ingestion, digestion and assimilation of the organic matter and microorganisms in the gut and by casting i.e., cast-associated processes (CAPs) (Fig. 1).

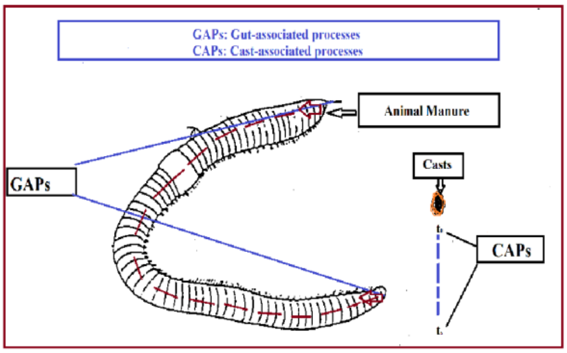

Fig. 1. Earthworms affect the decomposition of the animal manure during vermicomposting through ingestion, digestion and assimilation in the gut (gut-associated processes) and then casting (cast-associated processes), which are more closely related with ageing processes. (Source: Brandon *et al.,* 2013).

Chemical and metal resistance in earthworms

Earthworms are highly resistant to many chemical contaminants such as inorganic, organic pollutants in soil. Earthworms were even able to survive the Seveso chemical plant explosion in 1976 in Italy, in which a large area inhabited by humans was contaminated with certain chemicals including the extremely toxic TCDD (2, 3, 7, 8- tetrachlorodibenzo-p-dioxin) due to which several fauna perished. Earthworm species which ingested TCDD contaminated soils were shown to accumulate dioxin in their tissues and concentrate it on an average of about 14.5-fold. They have the potential to replace the environmentally destructive chemical fertilizers from farm production thereby playing an important role in chemical element transformations (Lee, 1985).

Vermiremediation (Uptake of metals from contaminated sites by earthworms and immobilization)

Earthworms uptake metals from contaminated soil, fly ash, slag through gut uptake. Earthworms accumulate heavy metals and other cations. They are known to be potential bioaccumulators and therefore they have been successfully demonstrated in mitigating the toxicity of industrial and municipal waste by vermicomposting technology.

A number of mechanisms are followed by the earthworms for uptake, immobilization and excretion of other metals (Sinha *et al.,* 2008). They either biotransform or biodegrade the chemical contaminants turning them harmless in their bodies. The biotransformation and biodegradation takes place in the gut before entering of the metals in their tissues. All the contaminants do not follow the path of the gastro-intestinal tract. Some of the contaminants are excreted directly as casts via gut. Those entering the gut can be metabolized, immobilized and excreted or sequestered in tissues or vacuoles. Vermiremediation may prove a very cost-effective and environmentally sustainable way to treat polluted soils and sites contaminated with hydrocarbons.

Earthworms as metal accumulators

Earthworms are numerous large bodied individuals, resistant enough and sensitive enough to contaminants; which make them good bioindicators. They are important micro-organisms in terms of soil functionality (Brown *et al.,* 2000) and consequently play a key role in terrestrial ecotoxicological risk assessment (Weeks *et al.,* 2004; Sheppard *et al.,* 1997). They are exposed by direct dermal contact with heavy metals in the soil solution or by ingestion of pore water, polluted food and/or soil particles (Lanno *et al.,* 2004). Soluble metal concentrations are the best descriptors of bioaccumulation in earthworms. (Peijnenberg *et al.,* 1999; Spurgeon and Hopkin, 1996).

Earthworms are soft-bodied, soil-dwelling organisms exposed to metals either through direct dermal contact with metals in soil solution or by ingestion of bulk soil or specific soil fractions. (Nei *et al.,* 2009; Lanno *et al.,* 2004). Their studies suggest an important role of the gut uptake route (Morgan *et al.,* 2004; Morgan and Morgan, 1992). The main part is voided in casts containing particulate organic material and nutrients excreted, such as urine and mucopolysaccharides. These casts serve as habitat for microorganisms (Tiunov and Scheu, 2000), which mineralize the organic matter therein and release nutrients that contribute to plant nutrition. Various species of earthworms can tolerate and bio-accumulate high concentrations of heavy metals like cadmium (Cd), mercury (Hg), lead (Pb) copper (Cu), manganese (Mn), calcium (Ca), iron (Fe) and zinc (Zn) in their tissues (Table 1 and 2) without affecting their physiology and this particularly occurs when the metals are mostly non-bioavailable. Earthworms accumulate higher concentrations of Zn (II) and Cd (II) ions and lower concentrations of Pb (II) and Cu (II) ions in their bodies. In earthworms, lead is accumulated in muscles, nerve cord, cerebral ganglion, seminal vesicles and chloragocytes.

Mechanism of metal accumulation

Earthworms can bio-accumulate and bio-transform many chemical contaminants including heavy metals and organic pollutants in soil and clean-up the contaminated lands for re-development. Their body work as a ‘biofilter’ and they can ‘purify’ and also ‘disinfect’ and ‘detoxify’ municipal and several industrial wastewater. The influence of metal-contaminated soils on earthworm activity and metal bioaccumulation has been reported many times (Morgan and Morgan, 1999). It has been shown that earthworms can rapidly invade remediated soil (Langdon *et al.,* 2001; Spurgeon and Hopkin, 1999).They ingest soil particles and egest them as surface or subsurface casts. Aristotle called earthworms the “intestines of the earth”. By ingesting organic debris, earthworms have been shown to enhance the bioavailability of soil nutrients such as

Carbon (C), Nitrogen (N) and Phosphorous (P) (Devliegher and Verstraete, 1996). Morgan *et al.,* (1989) have shown that the posterior alimentary canal of earthworms is a major site of metal accumulation, with the chloragogenous tissue separating the absorptive epithelium from the coelom being a major metal depository (Morgan and Morgan, 1989 a, b; Richards and Ireland, 1978).

Table 1. Studies depicting metal uptake by *Eisenia fetida*.

Type of exposure	Time of exposure (days)/Study	Metals	Soil total content (mg kg^{-1})	Measures *in E. fetida*	References
3 artificial soils OECD + sphagnum peat + $CaCO_3$ + Metal NO_3	1, 3, 7, 10, 14, 17, 24, 28, 35, 42	Zn Cu Cd Pb	20.4 - 1420 1.8 - 115 <0.5 - 13.7 7.95 - 656	Accumulation of heavy metals, excretion rate	Spurgeon and Hopkin, 1999
Artificial soils (ASTM + $CaSO_4$, $PbNO_3$, $ZnSO_4$	0 to 2	Zn Cd Pb	0.078 - 66.1 0.02 - 41.3 0.023 - 43.2	Metal content, pH, mortality	Conder and Lanno, 2000
Artificial soil + copper oxychloride	28	Cu	1.66 - 372	Metal content, weight, survival LC_{50}, cocoon production	Maboeta *et al.,* 2004
Soils from Joplin	0, 12, 14, 24, 44, 144, 192	Pb Zn Cd	1150 - 2800 3500 - 4200 22 - 29	Metal content, uptake and excretion rate	Maenpaa *et al.,* 2002
3 soil samples from contaminated sites	1, 3, 7, 10, 14, 21, 28	Zn Pb Cu Cd	56.6 - 43300 37.9 - 19400 17.4 - 2800 0.084 - 325	Accumulation, Excretion rate	Spurgeon and Hopkins, 1999
20 soils from the Netherlands + artificial soils (OECD)	70	Zn Cd Pb Cr	0.08 - 47.55 <0.001 - 0.44 0.34 - 4.09 0.06 - 3.76	Metal content, initial body weight, BCF	Janssen *et al.,* 1997
Artificial soil + $CdCl_2$ (aqueous)	70	Cd Cu	0 - 5.34 0 - 7.56	Metal content	Spurgeon *et al.,* 2004
Urban wastes such as MSW, MW, FW	60	Cu Pb Zn Mn Cd	0.47 0.31 1.49 5.16 0.05	Metal content	Pattnaik and Reddy, 2011
Fly ash + CD in various ratios: 1:1 (T_1) and 1:3 (T_2).	Field study	Cr Pb Cd	T_1 - 0.04,T_2 -0.11 T_1 - 0.98, T_2 - 0.92 T_1 - 0.12, T_2 - 0.19	Metal content	Bhattacharya *et al.,* 2012

OECD: Guidelines for testing of chemicals by the organization for Economic, Cooperation and Development; ASTM: American Society for Testing and Materials; $ZnSO_4$: Zinc sulphate; $CdCl_2$: Cadmium chloride; $CaCO_3$: Calcium Carbonate; NO_3: Nitrate; BCF: Bioconcentration factor; MSW: Municipal solid waste; MW: Market waste; FW: Flower waste; CD: Cow dung.

Table 2. Studies depicting metal uptake by *Lumbricus rubellus*.

Type of Exposure	Study/Time of Exposure	Metals	Soil total content (mg kg^{-1})	Measures in *L. rubellus*	References
Soil samples from Broth, Cwmystwyth and Ystwyth, UK	Field study	Zn Ca Cu Cd Mn Pb	100 - 992 998 - 32129 20 - 335 0.4 - 2 164 - 1330 42 - 1314	Metal content, BCF	Ireland, 1979
Soil samples from different areas of Braubach, Germany	Field study	Pb Cd Cu	284 - 1542 0.08 - 1.29 10 - 17	Metal content, Histological examination	Jansen,1989; Kruse and Barrett, 1989
12 contaminated soils from UK	Field study	Cd Cu Pb Zn	0.1 - 350 26 - 2740 170 - 24600 160 - 45000	Metal content, weight	Morgan and Morgan, 1988
Agricultural Soil samples from Wales	Field study	Zn Cd Cu Pb	460 - 1550 2.7 - 14.7 23 - 62 570 - 10110	Metal content	Morgan and Morgan, 1992
Agricultural Soils from Cwmystwyth	At 10th day up to 90 days	Cd Cu Ca Pb Zn	0.2 - 117 8 - 137.2 132 - 127600 3.9 - 6.4 17 - 25425	Metal content, kinetics	Marino and Morgan, 1999a
Soil samples from 7 mines in UK	90 days	Ca Cd Cu Pb Zn	132 - 127600 0.2 - 117 8 - 137.2 3.9 - 6.4 17 - 25425	Metal content	Marino and Morgan, 1999b
Agricultural Soils from Halkyn	Field study	Zn Cu Pd Cd	185 - 1870 21 - 60 158 - 10020 0.8 - 16	Metal content, pH	Morgan and Morgan, 1999
Soil samples from pastures polluted by waste	Field study	Zn Pb Cd	- - -	Metal content	Dai *et al.,* 2004

UK: United Kingdom; BCF: Bioconcentration factor.

The possibility that earthworm activity may raise heavy metal bioavailability is of considerable relevance for the success of soil remediation, especially when the methods that are used (i.e., soil washing, phytoextraction) remove only part of the (presumably labile and bioavailable) heavy metals or heavy metals even remain in the soil immobilized by the addition of various chemicals (solidification/stabilization). It has been reported that, after treatment with earthworms, the distribution of heavy metals in soil fractions was changed significantly, presumably increasing their bioavailability (Wen *et al.,* 2004; Cheng and Wong, 2002; Ma *et al.,* 2002). Pokarzhevskii *et al.,* (1997) showed that earthworms are ecosystemivorous feeding on entire soil microbial ecosystems. For terrestrial 'soft-bodied organisms' (such as earthworms), the concept of equilibrium partitioning (EqP) presumes a direct relationship between the tissue concentration, taken up through the derma and the free metal ion activity.

The capability of earthworms to effectively compartmentalize potentially toxic metals within tissues may provide an insight into the underlying mechanisms which enable the accumulation of high body burden surface soil dwellers and anecic (deep burrowing). Similarly, gut-related processes in earthworms may also increase metal availability as shown in Fig. 2. Metals taken up by earthworms in their gut are bounded by a protein called 'metallothioneins'. Ireland (1979) found that cadmium and lead are particularly concentrated in chloragogen cells in *L. terrestris* and *Dendrobaena rubidus*, where it bounds in the form of Cd-metallothioneins and Pb-metallothioneins. The chloragogen cells in earthworms appear to accumulate heavy metals absorbed by the gut and immobilize the metals in small spheroidal chloragosomes and vesicles found in these cells (Sinha *et al.,* 2008).

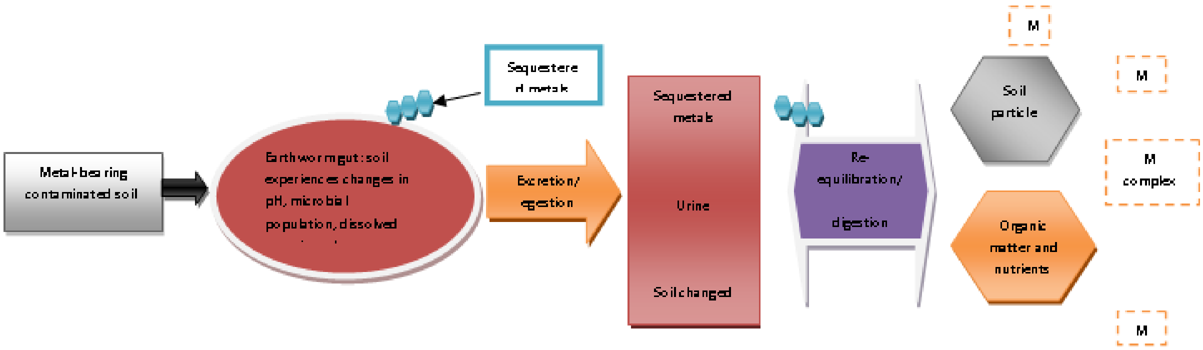

Fig. 2. Conceptual model of mechanism of metal uptake and their excretion by earthworms exposed to contaminated site. Ingested contaminated soil travels through the gut and is egested. The egested soil may differ in pH, bacterial population and dissolved organic carbon content, all of which may modify soil + organic matter. Modified bacterial populations may impact on organic matter sorbed metals. pH and dissolved organic matter changes due to egestion of soil and excretion of mucus and urine may impact on sorbed metals. Some metals may be sequestered in earthworm tissues and are subsequently excreted in a form different from the ingested metal. (Adopted and modified from Sizmur and Hodson, 2009).

A suggested mechanism for an increase in the availability of metals is the stimulation of bacterial populations which enzymatically degrade organic matter, releasing the organically bound metals into solution (Rada *et al.,* 1996). An increase in the biomass of bacteria, actinomycetes and fungi has been found in the earthworm casts of soil where increase in the availability of metals to plants has been observed (Wen *et al.,* 2004). The ability of a microbial species to survive these processes depends on its ability to adapt to the conditions a particular earthworm may induce (Brown, 1995).

Uptake patterns, accumulation and excretion

Cd, Cu, Pb and Zn burdens are generally accumulated by the earthworms. Different time-dependent patterns of uptake are found for non-essential and essential elements. In case of essential elements, Cu and Zn, equilibrium is reached within first seven days of exposure in all soils. Neuhauser *et al.,* (1995) found similar patterns of uptake and excretion by *E. fetida* exposed to these metals added singly to natural soils. Nannoni *et al.,* (2011) could not observe any significant differences in terms of metal uptake and bioaccumulation between different species within a same ecological group. The metal bioavailability of earthworms can be evaluated in terms of relative toxicity (as lethality) index and through bioaccumulation determinations, yielding bioconcentration factors (BCF) and possibly tissue concentration limits (Abdul Rida and Bouche, 1994). Heavy element fractionation among soil components represents one of the most significant factors influencing their mobility in soil and uptake by soil organisms. such as isopods, amphipods and earthworms (e.g., Hobbelen *et al.,* 2006; Becquer *et al.,* 2005; Dai *et al.,* 2004; Lanno *et al.,* 2004).

Kinetics of accumulation of heavy metals

According to authors, kinetic experiments indicate that during the uptake phase, certain metals such as Pb, Cd, and Cu do not reach steady state in earthworms irrespective of exposure duration. An appropriate duration for experiment with heavy metals that do not reach steady state is 28 days. For elements in which plateau stage is already reached; 40 days is an appropriate duration. The studies involving the kinetics of uptake and excretion of heavy metals using species of earthworms*: L. terrestris, E. fetida/E. andrei and Dendrobaena veneta* has been shown in Table 3. Radiotracers are generally used to follow the uptake and excretion of metals by the same earthworm (Nahmani *et al.*, 2007; Sheppard *et al.,* 1997). Studies indicate that metal accumulation and excretion rates are species dependent. Peijnenberg *et al.,* (1999) studied about the rapid uptake and equilibration with Cr, Cu, Ni, Zn but little uptake of As, Cd, Pb and non-essential elements. Modeling of uptake rates is usually done involving the one compartment model of Atkins (1969) (Peijnenburg *et al.,* 1999; Spurgeon and Hopkin, 1999; Marinussen *et al.,* 1997). Kinetics model assumes that an animal constitutes a homogeneous system with a constant excretion rate. The model has a general formula:

$Q_t = C_o + (a/k)\ (1\text{-}e^{kt})$

Where:

Co = concentration of residual metal in the animal

Q_t = concentration of metal in the animal

a = accumulation rate

k = excretion rate

t = time

Table 3. Studies and the derived equations that predicts uptake of metals and excretion kinetics by earthworms.

Exposure	Species	Time of exposure (days)	Model parameters	Equation Results	References
Soil from Netherlands	*D. veneta*	1, 2, 3, 7, 14, 28, 56, 112	$C_{cu(t)}$= Cu concentration in the organism (mg kg^{-1}). $C_{cu(o)}$ = Copper initial concentration in the organism (mg kg^{-1}) $^{\alpha}cu$= Cu uptake rate (mg $kg^{-1}d^{-1}$) ^{k}cu = Cu excretion rate (d^{-1})	$C_{cu(t)} = C_{cu(o)} + {}^{\alpha}cu/{}^{k}cu\ [1\text{-}e^{-kcu(t)}]$	Marinussen *et al.,* 1997
OECD soil + $PbCl_2$ or $CdCl_2$	*E. fetida*	7, 14, 21, 35, 42, 49, 56	Y= metal concentration in the worm at time x (mg kg^{-1}) x= time(days) C= constant A= coefficient	For Pb = 100 and 2000 mg kg^{-1} and Cd = 8 mg kg^{-1} Y = C+Ax For Cd = 80 mg kg^{-1} $Y = C+A_1x + A_2x^2 + A_3e^{(-A4xexp3)}$	Scaps *et al.,* 1997
Commercial potting soil	*L. terrestris*	1, 3, 6, 10, 14 , 20	A = Fraction of the radiotracer left in the gut subject to a gut clearance depuration rate constant ƛg. 1-A = remaining fraction subject to a slower depuration rate constant ƛp ƛp= a rapid depuration rate	Depuration $C= A(e^{-ƛgt}) + (1\text{-}A)\ (e^{-ƛpt})$ Uptake $C=B[A(1\text{-}e^{-ƛpt}) + (1\text{-}A)(e^{-ƛpt})]$	Sheppard *et al.,* 1997

Exposure	Species	Time of exposure (days)	Model parameters	Equation Results	References
20 samples from Dutch soils and 1 OECD	*E. andrei*	0, 1, 3, 4, 7, 14, 21, 28, 42, 63	C_w=metal concentration in worms (mmol kg^{-1} dry weight) $C_{w(0)}$ = initial concentration in the organism $K_1(x)$ = uptake constant rate (kg_{soil} $kg^{-1}_{earthworm}$ dry weight day^{-1}). K_2 = elimination rate constant (day^{-1}) Cx= Metal concentration in soil (mmol kg^{-1})	$Cw(t) = Cw(0)e^{-k2t}+((k_1(x)C_x)/K_2)(1-e^{-k2t})$	Peijenburg *et al.*, 1999
ASTM soil + $Cd(NO_3)_2$	*E. fetida*	2, 4, 7, 14	C_t = earthworm pellet fraction concentration (mmol metal kg^{-1}) M_s = concentration of metal M in the soil (mmol kg^{-1}) K_u = uptake rate constant (kg $mmol^{-1}$ day^{-1}) Ke = the elimination rate constant (day^{-1}) T = time (day)	$C_t = (K_u/K_e)M_s(1-e^{-ket})$	Conder *et al.*, 2002

OECD: Guidelines for testing of chemicals by the organization for Economic, Cooperation and Development; ASTM: American Society for Testing and Materials; $Pbcl_2$: Lead chloride; $CdCl_2$: Cadmium chloride; $Cd(NO_3)_2$: Cadmium nitrate.

Conclusion

The increase in pollution levels in soil has lowered the quality of soil thus affecting crop productivity. The vermicasts produced by most earthworm species are known to contain hormones and enzymes, which stimulate plant growth and discourage pathogens. Moreover, most important is the earthworms' potential of metal accumulation, which has maintained the ecosystem in a balanced state. They by their metal accumulating and nutrient enriching abilities have done wonders in maintaining the soil ecosystem. Earthworms can survive in heavy metal contaminated soils and can even accumulate metals such as Cd, Cu, Zn, Pb and various other metals in their tissues. It has been reported in several studies that by following treatment with earthworms, the distribution of heavy metals in soil fractions was significantly changed. Thus adopting this vermicomposting technology will not only provide greater availability of plant mineral nutrients but also promises more effective waste utilization for agricultural benefits by taking the advantage of increased microbial activities provided by earthworms. Moreover removal of heavy metals by biological means is more specific, eco-friendly and economical.

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