Applied Soil Ecology 79 (2014) 10–25

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Review

Potential of earthworms to accelerate removal of organic contaminants from soil: A review

Jacobo Rodriguez-Campos[a], Luc Dendooven[b], Dioselina Alvarez-Bernal[c], Silvia Maribel Contreras-Ramos[d,*]

[a] Metrologic and Analytical Service Unit, Centre for Research and Assistance in Technology and Design of the Jalisco state, A.C. (CIATEJ), Mexico
[b] Laboratory of Soil Ecology, ABACUS, Cinvestav, Mexico
[c] Interdisciplinary Research Centre for the Integral Regional Development (CIIDIR-IPN, Michoacán), Mexico
[d] Environmental Technology Unit, Centre for Research and Assistance in Technology and Design of the Jalisco state, A.C. (CIATEJ), Mexico

ARTICLE INFO

Article history:
Received 30 May 2013
Received in revised form 18 February 2014
Accepted 18 February 2014
Available online 25 March 2014

Keywords:
Organic contaminants
Remediation of soil
Vermiremediation

ABSTRACT

Earthworms can accelerate the removal of contaminants from soil. Earthworms change the physical and chemical properties of soil by mixing it with organic material and through their burrowing they improve aeration and render contaminants available for microorganisms. The presence of earthworms in contaminated soil indicate that they can survive a wide range of different organic contaminants, such as pesticides, herbicides, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and crude oil, at least when concentrations of the contaminant are not too high. The improvement of the soil due to their activity and the microorganisms in their digestive track can contribute to the accelerated removal of contaminants from soil, but sometimes their casts adsorb the pollutant so that its dissipation is delayed. There are limits, however, on how earthworms can be used to remediate soil, which will be discussed in this review.

Contents

1. Introduction 11
 1.1. Bioremediation technologies 11
2. Presence of earthworms in contaminated soils 11
3. The use of earthworms to remove contaminants from soil 11
 3.1. Survival and cocoon production of earthworms in contaminated soil 12
  3.1.1. Herbicides, pesticides, insecticides, fungicides 12
  3.1.2. PCBs 12
  3.1.3. PAHs 15
  3.1.4. Oil products 16
 3.2. Removal of contaminants from soil 16
  3.2.1. Herbicides removal 16
  3.2.2. PCBs removal 16
  3.2.3. Pesticides removal 16
  3.2.4. PAHs removal 20
  3.2.5. Crude oil removal 20
 3.3. Possible processes and mechanisms involved in the removal of organic contaminants by earthworms 20
 3.4. Catabolism or metabolism 21

* Corresponding author at: Av. Normalistas 800 Col. Colinas de la Normal, 44270 Guadalajara, Jalisco, México. Tel.: +52 3333455200x1601; fax: +1001.
E-mail addresses: smcontrerasr@gmail.com, smcontreras@ciatej.mx (S.M. Contreras-Ramos).

http://dx.doi.org/10.1016/j.apsoil.2014.02.010

3.4.1. Microorganisms associated with earthworms 21
3.4.2. Enzymatic and metabolism response of earthworms when exposed to contaminants 22
4. Potentials and limitations of the vermiremediation of contaminated soils 23
5. Conclusions 23
References 23

1. Introduction

1.1. Bioremediation technologies

Remediation of soil contaminated with hydrocarbons has focused traditionally on chemical treatments or physical removal, but recently biostimulation, bioaugmentation or phytoremediation has been promoted as it has a far less destructive effect on the environment (Hamdi et al., 2007; Juwarkar et al., 2010). Bioaugmentation adds microorganisms to the soil capable of degrading the targeted contaminant (Lin et al., 2010; Teng et al., 2010), and biostimulation tries to augment autochthonous soil microbial activity by adding a C-substrate rich in nutrients (Lin et al., 2010). In phytoremediation plants are cultivated in the contaminated area whereby the increased microbial activity in the rhizosphere accelerates removal of hydrocarbons (Cebron et al., 2009), or whereby the plants accumulate the contaminant (Techer et al., 2012). However, bioavailability and/or bioaccessibility of contaminants (Johnsen and Karlson, 2007; Latawiec and Reid, 2009), i.e. the accessibility or availability of contaminants for soil microorganisms, is often limited. The contaminants cannot be degraded as they are physically protected within the soil matrix.

The term *vermiremediation* has been used recently to indicate the use of earthworms in the removal of contaminants from soils (Sinha et al., 2008b) or when earthworms help to degrade not recyclable compounds (Gupta and Garg, 2009). The positive effect of earthworms on the removal of contaminants, such as oil, PAHs, PCBs, pesticides, and heavy metals has been reported by several authors (Binet et al., 2006; Contreras-Ramos et al., 2008; Eijsackers et al., 2001; Geissen et al., 2008; Hickman et al., 2008; Kersanté et al., 2006; Luepromchai et al., 2002; Ma et al., 1995; Schaefer and Filser, 2007; Singer et al., 2001; Tejada and Masciandaro, 2011).

Earthworms burrow through the soil, mixing it constantly in their gut (Eijsackers et al., 2001) and they are able to change the physical and chemical properties of soil by (i) increasing the available carbon and nitrogen in the soil with urine, mucus excreted; (ii) ingesting and mixing soil with organic material during its gut transit; (iii) affecting the soil structure through their burrowing activities; and (iv) changing the soil bacterial and fungal communities by modifying the structure and size of soil microagregates (Curry and Schmidt, 2007; Drake and Horn, 2007; Jayasinghe and Parkinson, 2009; Tiunov and Dobrovolskaya, 2002; Tiunov and Scheu, 2000). As such, earthworms facilitate and increase the contact between a contaminant and soil microorganisms (Hickman and Reid, 2008c). Also, adding earthworms to a soil could increase the removal of a contaminant. Some studies, however, found that earthworm casts can adsorb a contaminant, such as atrazine, presumably by a hydrophobic interaction between the contaminant and soil organic matter, thereby delaying the removal of the pollutant (Alekseeva et al., 2006; Binet et al., 2006; Shan et al., 2011).

The objective of this review was to review the potential use of earthworms in the remediation of organic contaminants from soil. First, the presence, survival and reproduction in contaminated soils, will be discussed. Second, the effect of earthworms on removal, catabolism or metabolism using PAHs as model will be reported. Third the potentials and limitations of earthworms in the remediation of contaminated soil will be reviewed.

2. Presence of earthworms in contaminated soils

There are not many reports of earthworms in soil contaminated with organic contaminants. Eijsackers, 2010 reported an analysis of earthworms that colonized contaminated soils. He indicated that several factors control the colonization of a contaminated soil by earthworms, such as the physicochemical characteristics, earthworm ecology (endogeic, epigec, anecic) and the presence of a suitable amount of organic matter to ensure the survival of earthworms and hatching of cocoons. The most common coloniser species in mining deposits, heavy metal contaminated soil, waste deposits (fly-ash, sludge, refuse or colliery mine heaps) and remediated soil were *Lumbricus rubellus*, followed by *Dendrobaena octaedra* and *Aporrectodea caliginosa* (Eijsackers, 2010). Zavala-Cruz et al., 2013 reported on the population of earthworms in a site polluted with weathered crude oil for 20 y and with a maximum concentration of hydrocarbons (TPH) of 12,000 mg TPH kg^{-1}. The endogeic species *Pontoscolex corethrurus* was the most abundant, followed by *Gossodrillus* sp. and *Dichogaster saliens*. The abundance of earthworms and their biomass were affected negatively by the highest concentrations of the contaminant and correlated with texture and nutrient levels in the soil. Similar results were found by Hernández-Castellanos et al., 2013b in an area with a lot of oil spills due to oil extraction for 20 y. A concentration of 39 mg kg^{-1} benzo(a)pyrene (BaP) was detected. In this environment *P. corethrurus* (75%) was the dominant species representing 88% of total biomass. Earthworm abundance and total biomass was positively correlated with total nitrogen and silt content. The absence of earthworms is commonly indicative of a disturbed ecosystem or a contaminated soil (De Silva and van Gestel, 2009; Geissen et al., 2008). However the colonization, presence and in some cases high abundance of earthworms in contaminated environments suggests their high tolerance and plasticity. For instance, 121 individuals m^{-2} of *L. rubellus* were found in an aged colliery soil (Dungera et al., 2001), while 319 individuals m^{-2} were found of *P. corethrurus* in soil 20 y after an oil spill (Hernández-Castellanos et al., 2013b).

3. The use of earthworms to remove contaminants from soil

The Organization for Economic Cooperation and Development (OECD) proposed *Eisenia fetida* as the reference earthworm in standardized toxicity tests (OECD, 2004), because it can be easily cultivated in the laboratory, matures in eight weeks and has a high reproductive rate. However, the selection of *E. fetida* for toxicity tests has been questioned for two reasons. First, it is not a natural soil species. Its habitat is litter, compost, manures and organic wastes (Bouché, 1972; Edwards and Bohlen, 1996). Second, some authors found that it is less sensitive to contaminants than other species and can tolerate high concentrations of certain contaminants that other earthworms do not (Contreras-Ramos et al., 2006; Fitzpatrick et al., 1992; Langdon et al., 2005; Safawat and Weaver, 2002; Tejada et al., 2011). Tejada et al., 2011 stated that the sensitivity of earthworms towards a contaminant, i.e. chloropyrifos, could be explained by several factors, such as chemical nature of the contaminant, soil type, soil condition, soil microbial community, and their interactions.