Fate and Toxicity of Organic Pollutants in Earthworm Gut: A Review

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Abstract. When organic pollutants enter the earthworm gut, there are many complex processes, including desorption, dissolution, digestion, absorption, metabolism, depuration and excretion. The aim of this review is to briefly explain fate and toxicity of the organic pollutants in the earthworm digestive tract with the different change procedures.

1. Introduction
Soil pollution is a major environmental concern as soil degrades an important and irreplaceable resource. Soil plays the fundamental ecological function in terrestrial ecosystem, including keeping biogeochemical cycling of nutrients, supporting plant growth, and sustaining healthy human habitation [1]. Besides, soil is also a source of nutrients for plenty of terrestrial organisms so that it can sustain biodiversity. However, because of excessive use of fertilizers and pesticides, improper handling of industries’ gaseous emissions, waste water discharges, uncontrolled mineral exploration [2] and abandoned ore tailing, it became more and more serious in recent years. And there are numerous organic contaminants, such as pharmaceuticals, detergent metabolites, fragrances, antimicrobial, pesticides and industrial products [3]. By 2016, polluted soil, including several polluted levels, has risen to 16.1% in China [4].

Earthworms are important members of a terrestrial ecosystem, which are widely distributed and have a profound impact on the soil. Through feeding, digestion, secretion, excretion, burrowing, etc., earthworms can help to establish and maintain the structure of the soil [5], and to promote the material circulation and energy transfer of soil processes [6]. Because of the large $K_{ow}$ of hydrophobic organic contaminants, they are closely combined with soil particles. By devouring, a large amount of soil containing hydrophobic organic contaminants enters the earthworms. After through the digestive tract in earthworms, partial pollutants are bioaccumulated by earthworms. Part of the bioavailability may cause the toxicity effect, even make earthworms die. Because earthworms are the low trophic level in the food chain, the toxins in their bodies gradually move to higher trophic levels, causing biomagnification [7].

The aim of this review is to briefly explain the fate and toxicity of the organic pollutants in the earthworm digestive tract with the different change procedures, including desorption, dissolution, digestion, absorption, metabolism, depuration and excretion.

2. Fate of organic pollutants in earthworm gut
When the organic pollutants enter the soil, they will partition between soil solid phase (e.g., soil particles) [8] and soil pore water. As hydrophobic organic pollutants have large log$K_{ow}$ values, they are of big
hydrophobicity and can only dissolve a little in soil pore water. Most of the pollutants go into earthworms with soil particles. And when they enter the earthworm digestive tract, hydrophobic organic pollutants which are adsorbed by soil will release. This process is called desorption. And hydrophobic organic pollutants will partition between soil particles and earthworms gastrointestinal juice again.

Digestion is the function of the body through the movement of digestive tract and the secretion of digestive enzymes. It can break down complex compounds into small molecules that can be absorbed and have simple molecular structures. Among it, the use of mechanical function, i.e., earthworm intestinal grinding, is called mechanical digestion; the use of digestive enzymes to turn large molecules into small molecules called chemical digestion. The pollutants absorbed by soil particles will continue to undergo digestion after they entered the digestive tract, then be absorbed by the earthworm tissue.

After the desorption and digestion of the organic pollutants in the earthworm gut, the free small molecular substances are absorbed by the earthworm. The area where the earthworms absorb pollutants is mainly intestinal tract [9]. And the absorption occurs mainly in the middle and posterior intestines. But there is also literature supporting the foregut [10].

When the organic pollutants enter the earthworms, after the desorption, digestion, absorption and metabolism in the digestive tract, they will continue to undergo a depuration process. According to the study, there are several possible ways of depuration process in earthworms: A. Pollutants are removed by the passive diffusion of the epidermis or intestinal tract of the earthworms [11]. B. The contaminants are removed by metabolism. C. Through the growth and reproduction, earthworms can dilute the pollutants in the body and pass on to the next generation through reproduction [12]. D. Through the excretion of the earthworm body, the pollutants which are unable to desorb and absorb in the earthworm digestive tract and returned to the digestive tract can be excreted by the earthworms cast.

Through the desorption, dissolution, digestion, absorption, metabolism, depuration and excretion of earthworms, some of the organic pollutants which are ingested from soil are accumulated by earthworm tissues. While other pollutants are returned to the soil again. Biota-sediment accumulation factor (BSAF) is used to describe the ability of earthworms to accumulate different pollutants. Some research also use bioaccumulation factor (BAF) and bioconcentration factor (BCF).

3. Metabolism and toxicity of organic pollutants in earthworm gut

In the whole process of digestion and absorption, the metabolites of the original substances can be detected in earthworms. However, the metabolic products of various pollutants are complex, and the specific situation of them is still unclear. In the studies, usually, the non-polar metabolites can be determined and the polar metabolites cannot be determined specifically. For examples, the non-polar metabolite of 4-nonylphenol (4-NP) is 2-nitro-4-NP [9]. But polar metabolites can be converted into non-polar metabolites. The different properties between the metabolites and the original substance will also affect the absorption. N-methylbentazon is the main metabolite of bentazon, but it is more hydrophilic, so it is more easily absorbed than bentazon by earthworms [13]. Of course, there are also metabolites more hydrophobic than the original substances [14]. In addition, it is still controversial whether the metabolites of the original substances are initially produced in soil or earthworms.

When earthworms absorb pollutants and metabolites, they may have a toxic effect on earthworms, affecting the growth, development, reproduction and even death of earthworms. Toxicity is divided into acute toxicity and chronic toxicity. Acute toxicity is mainly characterized by 48 hours or 72 hours of LC50 (Table 1), and most of the acute toxicity is caused by the original substance rather than metabolites produced during chronic exposure [14]. At present, the determination of acute toxicity has been established, i.e., filter paper contact test. Chronic toxicity is a long-term effect on earthworms. The causes of chronic toxicity include not only the original contaminants, but also their metabolites. The study [14] found that acute toxicity and chronic toxicity have different toxicity effect patterns. The main hazard of pollutants to earthworm is that it induces a large number of free radicals, which can cause oxidative damage to biological macromolecules [15]. Therefore, earthworms body produces a variety of antioxidant enzymes, such as superoxide dismutase (SOD), catalase (CAT). Using them as biomarkers, it can measure the oxidative stress of an organism. For examples, malondialdehyde (MDA)
is commonly used to be the molecular markers for the lipid peroxidation of earthworms. Oxidative damage caused by pollutants will eventually affect the growth of earthworms. At the same time, the nanoparticles can also cause the joint toxicity with organic pollutants, increasing or decreasing the toxic effects of organic pollutants.

Table 1. LC₅₀ values of the organic pollutants.

| Pollutants         | LC₅₀ (μg/cm²) | Time (h) | Method   | Reference |
|--------------------|---------------|----------|----------|-----------|
| (+)-ethofumesate   | 4.51          | 48       |          | [16]      |
| racemate           | 5.93          |          |          |           |
| (-)-ethofumesate   | 7.98          |          |          |           |
| R-furalaxyl        | 2.27          |          |          |           |
| rac-furalaxyl      | 2.08          | 48       | OECD207  |           |
| S-furalaxyl        | 1.22          |          |          | [17]      |
| R-furalaxyl        | 1.90          |          |          |           |
| rac-furalaxyl      | 1.54          | 72       |          |           |
| S-furalaxyl        | 1.00          |          |          |           |
| α-CYP              | >1000ᵃ        |          |          |           |
| CFVP               | 204ᵃ          | 48       | OECD222  | [14]      |
| α-CYP              | >1000ᵃ        |          |          |           |
| CFVP               | >250ᵃ         |          |          |           |
| bromadiolone       | 145.70        | 24       | OECD207  | [15]      |
|                    | 25.03         | 48       |          |           |

ᵃ /= the data’s unit is mg/kg.

4. Summary

Organic pollutants, especially hydrophobic organic pollutants, are highly adsorbed by soil particles in soils due to high logK_{ow} values. They enter the earthworms through the ingestion. When they pass through the digestive tract of earthworms, they can be desorbed from the soil particles. Under the gut physical grinding, surfactants, digestive enzymes and microbes, the pollutants can be digested (including physical and chemical digestion) and decompose into the small molecules that can be absorbed by organisms. Through the passive diffusion of the intestinal wall, the pollutants are absorbed by earthworms. After that, different pollutants and metabolites may cause different toxic effects. The earthworm tissues can be detoxified through depuration, which mainly includes excretion, passive diffusion of intestinal tract, reproduction, growth and secretion of mucus. Finally, the pollutants and metabolites that cannot be absorbed by earthworms can be expelled from the body through the earthworms cast and return to the soil again.

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