Research Progress on Distribution, Sources and Ecological Effects of Phthalate in Soil

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Abstract Phthalate esters (PAEs) are widely used as main plasticizers in plastic products, agricultural regulators, toys, and other fields. This paper reviewed the research progress on the distribution, sources, and ecological effects of PAEs. The effects of PAEs on soil microorganisms, animals, plants and soil properties were explored in sequence, providing effective theoretical basis for future research on PAEs.

Key words Phthalate ester; Distribution; Source; Ecological effect

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Phthalate esters (PAEs) are widely used as main plasticizers in plastic products. Wang *et al.* [1] found that the average concentration of PAEs in Lanzhou City reached 0.217 mg/kg. The vertical distribution of PAEs is related to the physical and chemical properties of soil. The content of PAEs will increase with time[2], but decrease with the increase of pollution source distance and soil depth, and DEP (diethyl phthalate) will increase[3]. Through the distribution law of PAEs in soil, the composition and source of PAEs are understood, and it is found that PAEs will have an impact on the growth of soil animals, microorganisms and plants. In this paper, the distribution, sources and ecological effects of PAEs in soil were reviewed, in order to provide reference for the ecological risk assessment of PAEs in soil.

Distribution of PAEs in Soil

Li[4] detected five kinds of PAEs in the soil of protected vegetable fields in Turpan, among which diisobutyl phthalate (DIBP), dibutyl phthalate (DBP) and diisooctyl phthalate (DEHP) accounted for 60.9%, 18.8% and 17.8% of the total, respectively. Feng *et al.* [5] found that the pollution degree of PAEs in Shaanxi was higher than that in other three investigation areas, and the average contents of PAEs in the soil in the four investigation areas ranked as Shaanxi > Jiangsu > Hebei > Henan. PAEs were detected in 41 soil samples collected by Chen *et al.* [6] in Gansu Province, and the average range of PAEs was 57.8 - 1 042.4 μg/kg.

There are differences in PAE content in different depths of soil. Li *et al.* [7] found that PAE value decreased with the increase of profile depth. Li *et al.* [8] studied PAEs in farmland soil of Gaozhou, indicating that the content of PAEs in topsoil (0 - 20 cm) was high, and it also decreased with the increase of soil depth. Tan *et al.* [9] found that DBP and DEHP were the main components in the surface soil in domestic sewage irrigation areas, and their contents decreased with the increase of soil depth.

The content of PAEs changes with the service life of plastic film. Li *et al.* [10] found that DIBP, DBP and DEHP in facility grape soil in Turpan showed a nonlinear growth trend with the increase of planting years. Yi *et al.* [11] found that the concentration of PAEs in cotton field soil with different plastic film-mulching years in northern Xinjiang ranged from 1.360 to 4.490 mg/kg, and the content of PAEs in samples with plastic film mulching for 5 years was the highest. With the increase of years, the content of PAEs increased at first and then decreased.

Sources of PAEs in Soil

The sources of PAEs in soil are agricultural products such as agricultural film, pesticides and fertilizers, sewage irrigation and atmospheric deposition (dry and wet). Guan *et al.* [12] found that PAEs in woodland soil mainly came from the deposition of PAEs in the atmosphere. Some studies have found that the main reason for PAE accumulation is the residue of agricultural film[13]. Chen *et al.* [14] found that the main sources of PAEs are plastic products such as shed film and mulching film, in which PAEs are accumulated and released in soil through migration, transformation and enrichment. Meng[15] and Wang *et al.* [16] found that plastic film for greenhouses was the main source of PAEs in facility vegetable fields, and the content of PAEs outside the greenhouses was lower than that inside the greenhouses. According to the study of Mo *et al.* [17], PAEs existed in chemical fertilizers, and its content could reach up to 3.0 mg/kg. Zhao *et al.* [18] detected 52 kinds of chemical fertilizers in the market, and found that PAEs were contained in 19 kinds of chemical fertilizers. With the research in recent years, Liu[19] further analyzed the sources of PAEs in soil and found that the sources of PAEs in soil were not only related to fer-

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tilizers, pesticides and plastic films, but also related to the irrigation with wastewater and reclaimed water.

Ecological Effects of PAEs in Soil

Effects of PAEs on soil properties

Zhou[20] found that PAEs in soil of typical facility vegetable fields in Shouguang City promoted the activities of catalase and sucrase, but inhibited the activity of soil dehydrogenase and urease. Wang[16] found that DBP and DEHP could inhibit soil urease activity, but activate soil phosphatase. Wang *et al.* [21] found that different concentrations of DEHP had different effects on soil catalase activity. When the concentration was higher than 500 mg/kg, DEHP had a single inhibitory effect on invertase. Liu *et al.* [22] found that DEHP and PAEs were positively correlated with the organic matter content, and the organic matter content would increase with the content of DEHP and PAEs.

Effects of PAEs on soil microorganisms

The higher the concentration of PAEs, the lower the α diversity of bacterial community, and the higher the degradation efficiency of mixed bacteria (two kinds of bacteria with PAEs as carbon source and energy source), and the two kinds of bacteria in mixed bacteria will have a synergistic effect, and their degradation efficiency will be better than that of single bacteria[23]. Xu *et al.* [24] found that DBP pollution increased the metabolic diversity of soil microbial community in a short period of time. Guo *et al.* [25] found that the combined pollution of three kinds of PAEs significantly reduced the diversity of soil microorganisms and improved the basic respiration of soil to some extent. The types of PAEs are the main factors affecting the growth of microorganisms, and DnOP among them will significantly change the structure of microbial community[26]. Dou *et al.* [27] found that PAE pollution reduced the diversity of bacterial communities in soil, thus reducing soil quality. Zhou *et al.* [28] found that PAEs could have toxic effects on microorganisms.

Effects of PAEs on soil animals

PAEs can accumulate in soil animals and have toxic effects on the growth and development of animals[29]. Ma *et al.* [30] found that earthworms lived in the soil polluted by DBP, and their cells were damaged, and they had toxic effects on earthworms and damaged their DNA. Liu *et al.* [31] showed that low PAE concentration activated the defense system of earthworms, and reactive oxygen free radicals (ROS) and malondialdehyde (MDA) in earthworms increased with the increase of PAEs. With the increase of ROS and MDA, the degree of exposure increased, which led to the increase of earthworm DNA damage. Li[32] found that DBP and DEHP could damage the DNA of earthworm somatic cells. Chen *et al.* [33] found that DEHP could inhibit the metabolic activity of soil animals.

Effects of PAEs on soil plants

DEHP and DBP have a long degradation time and strong enrichment, and are generally easy to accumulate in the soil and be absorbed by plants[34]. Kong *et al.* [35] found that the reason for the decline in vegetable quality might be that PAEs in the soil were absorbed by plants and accumulated in plant tissues. PAEs have a significant oxidative stress effect on plants, usually damaging the cell wall and causing oxidative damage. DBP inhibits the activity of antioxidant enzymes, further induces cell damage and reduces plant root activity, thereby affecting soil nutrient absorption and hindering plant growth[36]. DBP can inhibit seed germination and reduce the survival rate of some plant seedlings, and the accumulation of PAEs in plants can also reduce fruit yield and quality[37]. PAEs can accumulate in plants, and high concentrations can affect plant metabolism, thereby affecting plant life activities[38].

Conclusions

With the widespread use of plasticizers, the pollution range of PAEs has almost covered all parts of China. PAEs have certain impacts on soil properties and soil organisms (including microorganisms, animals and plants). PAEs have an inhibitory effect on soil enzyme activity, an inhibitory and a promoting effect on microbial diversity, and an inhibitory effect on microbial species. PAEs have toxic effects on soil animals, causing damage to their DNA. PAEs affect the growth metabolism of soil plants and hinder their growth.

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