

WHAT HAPPENS TO MICROPLASTICS IN SOIL AND WATER?

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INTRODUCTION

Microplastic pollution in soil refers to the accumulation of tiny plastic particles in the soil environment. These particles can range in size from 5mm to less than 1 micron and come from a variety of sources including consumer products, agricultural and industrial practices. Microplastics have been found in many different environments, including the oceans, freshwater systems, and even in the soil.

In soil, microplastics can negatively impact plant growth and soil health, leading to reduced biodiversity and decreased crop yields. They can also contaminate the food chain by being taken up by plants and ingested by wildlife, including livestock and humans. Additionally, microplastics can absorb and release toxic chemicals, such as persistent organic pollutants, which can further harm the environment and wildlife.

Given the widespread distribution and persistent nature of microplastics, it is crucial to reduce their use and release into the environment through improved waste management practices, the use of alternative materials, and increased public awareness. Efforts to mitigate microplastic pollution in soil will require a multidisciplinary approach that engages scientists, policymakers, and the public in finding sustainable solutions.

ENVIRONMENTAL FATE OF PLASTIC ADDITIVES IN THE PLASTIC DEBRIS OR MICROPLASTICS

Plastic additives represented one of the most important organic pollutants associated with microplastics; the types, quantification, and migration from the plastic debris or microplastics are addressed here. In addition to the chemical additives, microplastics also

adsorbed hydrophobic or hydrophilic organic pollutants from the environments due to their high surface areas and affinity for these pollutants. The sorption affinity changed by the aging of microplastic surface was of concern in particular. The organic pollutants in the microplastics may cause toxic effects on biotas by releasing into the leachate or by contact exposure directly through microplastics ingestion. Here we reviewed the latest reports on the organic pollutant assay for the leachates from the environmental microplastics and their toxic effects on freshwater species *Daphnia magna*, brown mussel (*Perna perna*), barnacle, and microalgae using different endpoints. Bioaccumulation of organic pollutants and biological toxicology through the vector effects of microplastics were also reviewed in the paper. However, large uncertainties existed among the different studies with respect to the toxic effects of co-exposure with organic pollutants and microplastics. Therefore, further researches are recommended to be done regarding the combined effects of organic pollutants and microplastics under the different exposure scenarios.

MIGRATION AND RELEASE OF CHEMICAL ADDITIVES FROM THE PLASTIC DEBRIS OR MICROPLASTICS

The additives can potentially migrate and be released from polymers during the exposure in environments. Therefore, it is of great interest whether organic chemicals from plastic debris or microplastics cause serious environmental risks. Until now, the majority of studies on the migration and fate of plastic additives associated with plastic particles have focused on leaching of flame retardants, plasticizers, and fluorescent additives.

OCCURRENCE OF ORGANIC POLLUTANTS IN THE ENVIRONMENTAL MICROPLASTICS

Studies on the organic pollutants in the environmental microplastics started from monitoring of persistent organic pollutants (POPs) in the plastic resin pellets (small granules 0.1–0.5 cm in diameter). A range of organic micro-pollutants (including polychlorinated biphenyls (PCBs), DDE, and nonylphenol) have been detected in plastic resin pellets stranded on beaches.

The concentration of organic pollutants in the plastic resin pellets was found having a relationship with the aging time of the pellets in environment. Fifty-five resin pellets from a beach in Tokyo were individually analysed for PCBs and showed discoloured (e.g.,

yellowing) pellets contained more PCBs than others on most of the beaches sampled. Analogous to the results in Tokyo beach, aged and black pellets were also measured higher concentrations for the PCBs, PAHs, and DDT in the beaches of the Portuguese coast. The increase of adsorption of POPs in the plastic pellets with the aging time may result from the increase of specific surface areas and crystallinity after a long-term exposure in environment.

Hydrophobic organic pollutants in microplastics

Microplastics were found having a high affinity for hydrophobic organic pollutants (HOCs) due to their high hydrophobicity and specific surface area. Sorption of HOCs by plastic polymers was mainly governed by hydrophobic interaction mechanism. Liu et al. For the polymers (e.g., PS) with benzene rings in their structure, π - π interaction was supposed to be one of the most important mechanisms for their strong sorption for HOCs. In the same study, the higher sorption of DEP and DBP by PS compared to PE could be resulted from the strong π - π interactions between PS and the two PAEs. The previous study also revealed that sorption of PAH to virgin polystyrene microplastics was higher compared to sorption to nonaromatic polyethylene, polyvinyl chloride, and polypropylene microplastics due to the strong π - π interactions between the PS and PAHs. Velzeboer et al. suggested that the strong sorption of PCBs to nano-PS particles in their experiment could be explained by both hydrophobic and π - π interactions. Sorption experiment with nano-PS and PAHs indicated that the adsorption isotherms were nonlinear and a high distribution coefficient up to 109 L/kg was obtained as a result of the π - π interactions between the planar PAH and the surface of the aromatic polymer polystyrene.

Sorption of HOCs to microplastics might be limited by diffusion in the plastic phase, which could be described as biphasic process, the fast sorption/desorption in the outer layer followed by slow diffusion into the inner plastic phase. This biphasic model is frequently used for sorption of HOCs to soils or sediments. A recent study showed that the sorption process of HOCs to the micro-sized PS included two stages: the fast sorption stage for the HOCs diffusing through aqueous boundary layer and the slow one for the HOCs penetrating inside the PS particle, while the mass transfer rates were extremely slow for the second sorption phase.

Several factors have impacts on the sorption of HOCs onto the microplastics. In terms of the plastic polymers, physical structures have been found to play an important role in the HOC sorption. Guo et al. examined the sorption behavior of four hydrophobic organic contaminants by the different polymers and found that the organic carbon content-normalized sorption coefficients (K_{oc}) of phenanthrene, lindane, and naphthalene by PEs of same composition but distinct physical makeup of domains increased with their crystallinity reduction.

Weathering in environments of the microplastics changes their surface properties and hence alters their sorption behavior for HOCs. The weathered plastics would increase the adsorption capacity than virgin plastics. This might be mainly attributed to the increase in surface area due to polymer weathering that would increase the effective diffusivity and the additional sorbents attached to the plastic debris for hydrophobic contaminants. An increase in the surface area due to weathering could also increase polarity of the polymer surface by introducing oxygen-containing groups, which could decrease the affinity for hydrophobic compounds. Sorption coefficients of naphthalene by polystyrene microplastics following aging were found up to one order of magnitude lower than for pristine particles.

External factors, such as temperature, salinity, and composition of the water phase (e.g., particulate and dissolved organic matter), can also influence the sorption behavior of HOCs by microplastics in waters. The temperature has an impact on the sorption of HOCs in the microplastics through changing the surface tension of solution and the solubility of HOCs in the solution. Zhan et al. observed that increasing temperature decreased the sorption of PCB by PP in pure water. The salinity would impact the solubility of hydrophobic organic compounds by natural sorbents such as soils, clays, and sediments. Recent experiment results revealed that the sorption capacity of PCB, phenanthrene, and PAEs in the simulated seawater is higher than those in the ultrapure water, which indicates that salinity acts as one main factor affecting sorption capacity.

Hydrophilic organic pollutants in microplastics

Compounds with more hydrophilic properties have been much less considered in comparison to the highly hydrophobic compounds with respect to their adsorption and desorption in the microplastics. Pharmaceuticals and personal care products (PPCPs), as emerging contaminants (ECs) in terrestrial environments, threaten the aquatic and soil

resources. Most of the PPCPs have hydrophilic properties and have a high possibility of interacting with microplastics, especially aged microplastics, because of their hydrophilic, oxygen-containing functional groups. The mechanism governed adsorption of pharmaceuticals in the microplastics included the partitioning, electrostatic interactions, intermolecular hydrogen bonding, and π - π interactions. A study regarding the adsorption of antibiotics on the different types of microplastics showed that the adsorption capacities of ciprofloxacin (CIP), trimethoprim (TMP), and sulfadiazine (SDZ) on PS are higher than those on PE, suggesting the π - π interactions dominated the adsorption of the three antibiotics at the aromatic surface of the PS. In another study which examined the adsorption of oxytetracycline to microplastic polystyrene, the results revealed that electrostatic interaction regulated the adsorption; meanwhile H-bonding and multivalent cationic bridging mechanisms may also have affected the adsorption. Aging has a pronounced effect on the adsorption enhancement by microplastics owing to the increasing of surface areas, hydrophilic properties of the surface, and oxygen-containing functional groups after aging.

Impacts of pH, ionic strength, and dissolved organic on the adsorption have been examined in the present studies. In contrast to the negligible effects of pH on the adsorption of HOCs by microplastics, the solution pH has a pronounced effect on the antibiotic adsorption by microplastics because various antibiotics will exhibit different speciation of the cation, zwitterion, and anion in a specific pH condition.

Ionic strength of the solution plays an important role in the regulation of antibiotic adsorption by microplastics. Usually, a reduction of adsorption will be observed with the increasing of ionic strength owing to the competing with antibiotics on the adsorption sites on the plastic surface. However, the ions of different valence state may have different influence on the adsorption. The depression of oxytetracycline sorption to the aged PS foams can be offset in the presence of Ca^{2+} through formation of ternary complexes between the cations and oxytetracycline and the surface functional groups.

The effects of DOM on the antibiotic adsorption were not consistent among the different studies. Xu, Liu, Brookes, and Xu found the increasing concentration of fulvic acid inhibited the sorption of tetracycline on three microplastics, decreasing them by more than 90% at the fulvic acid concentration of 20 mg/L. However, in the study of Zhang et

al. both fulvic acid and humic acid promoted the adsorption of oxytetracycline in the aged PS foams, and humic acid has more pronounced effect than fulvic acid.

INTERACTION OF MICROPLASTICS AND HEAVY METALS

The toxicity of MPs to terrestrial organisms, such as earthworms, mice, and other, has been conducted. It has been confirmed that MPs with particle size less than 1 mm are easily ingested by soil organisms. Lwanga et al. found that MP exposure could affect the growth and movement of earthworm *Lumbricus terrestris* (*L. terrestris*). The results showed that microorganisms in the earthworm gut significantly decreased low density polyethylene (LDPE) particle size. Other studies have also shown the toxic effects of various MPs on other soil organisms. Furthermore, particle size is one of the most important characteristics of MPs toxicity. For example, 1 μm is the most common size of filter food organ interception in crustaceans, so crustaceans prefer to ingest MPs with particle size less than 1 μm . Smaller particles have a greater possibility of biological intake than larger size particles, which may enter the cells through endocytosis. Although it has been assumed that the toxicity of MPs is significantly related to its particle size, there is no unified view on what kind of particle size MPs is more toxic. The toxic effects of 0.05 μm , 0.5 μm , and 6 μm MPs on rotifer *Brachionus koreanus* were compared, and it was concluded that small particle size MPs had more significant toxic effects. The antioxidant enzyme activity and mitogen-activated protein kinase (MAPK) signaling pathway in rotifer changed with different particle size of MPs. Likewise, another study found that MPs with particle size larger than 50 μm had no significant toxic effect on Grass shrimp (*Palaemonetes pugio*), while the fatality rate of acute toxicity test was higher when the size less than 50 μm . It was indicated that MPs have size-dependent effects on the same species.

The interaction between MPs and other pollutants is present in the environment. Therefore, in order to evaluate the ecological risk of MPs, the interaction between MPs and other pollutants should be considered, and the toxic effects of combined exposure on various organisms should be addressed. However, there is still lack of research on the toxic effects of MPs in combination with other pollutants, especially MPs and heavy metals. There are only a few articles published that deal with the combined toxic effects of MPs and heavy metals. Combined exposure of Cr^{6+} and MPs enhanced the toxicity of the juveniles of common goby – *Pomatoschistus microps* and caused strong lipid

peroxidation damage in larvae. By contrast, another study has shown that the combined exposure of 1 μm MPs and Cu to microalgae did not show any toxicity. These studies showed that the combined exposure of MPs and heavy metals is affected not only by the particle size but also by the selected biological species. Moreover, MPs can also interact with heavy metals in the soil environment. Hodson et al. studied the adsorption behavior of high density polyethylene (HDPE) on Zn^{2+} in soil. They found that HDPE had stronger adsorption capacity for Zn^{2+} in soil with more abundant organic matter. The adsorption behavior was in accordance with Langmuir and Freundlich equation. The aged MPs in soil also had a significant effect on the adsorption of heavy metals. Nicole et al. exposed HDPE, polyvinyl chloride (PVC), and polystyrene to artificial aging conditions (2000 h, photo-oxidation and thermal oxidation) to simulate their aging process using a column percolation test. Their results showed that the aged MPs not only significantly increased the adsorption of TOC, Cl, Ca, Cu, and Zn but also weakened the desorption and release of heavy metals, which indicated that the aged MPs had stronger fixation ability to heavy metals. In addition, the functional groups in the soil are adsorbed to the surface of the MPs and may change the adsorption capacity of heavy metals. Kim et al. investigated the adsorption of Ni by the functional group-coated polystyrene. Results showed that the functional groups change the surface hydrophobicity of the polystyrene microplastic and heavy metal and then alter the adsorption of the heavy metal. Turner et al. also studied the adsorption properties of polyethylene microplastics (PE-MPs) for heavy metal ions (Ag, Cd, Co, Cr, Cu, Hg, Ni, Pb, and Zn). The adsorption kinetics experiments showed that the adsorption efficiency of aged PE-MPs in river water was higher than that of original PE-MPs, which may be due to the change of the surface structure of aged PE-MPs to reach surface charge equilibrium. Holmes et al. also found that the adsorption capacity of aged polyethylene in seawater for heavy metals was stronger than that of the original polyethylene. Therefore, once the MPs in the soil are weathered and aged, they can be effective carriers of heavy metal in the soil environment what can cause even greater damage to the health of the soil ecosystem.

CONCLUSION

Microplastics are small plastic particles that are less than 5mm in size. These particles can come from various sources such as microbeads in personal care products, plastic fibres from clothing, and plastic fragments from larger items that have broken down over time.

When MPs enter soil and water, they can have a number of different impacts depending on their size, shape, and chemical composition. Microplastics can accumulate in soil and water over time. This can lead to the build-up of these particles in the environment, which can have negative impacts on the ecosystem. Microplastics can be transported by water and wind, which can cause them to move from one location to another. This can lead to contamination of new areas and can also impact the distribution of microplastics in the environment. Microplastics can contain additives and chemicals that can leach into soil and water. These chemicals can have negative impacts on soil and water quality and can also affect the health of organisms that live in these environments. Microplastics can affect the structure of soil by altering its physical properties. This can impact the ability of soil to hold water and nutrients, which can affect plant growth and soil fertility. Overall, microplastics can have a number of negative impacts on soil and water quality. As such, it is important to reduce the use of plastic products and to properly dispose of plastic waste to help prevent the build up of microplastics in the environment.

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