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Research on the Effect of Microplastics on Phosphorus in Soil and Water Environment

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Abstract: Microplastics are a kind of emerging pollutants that are very widely distributed in soil and water. Phosphorus in soil and water often exceeds the standard due to phosphorus fertilizer. This paper summarizes the interaction of microplastics on phosphorus in water and soil from the aspects of aging, particle size, and species of microplastics. The results show that phosphorus adsorption of microplastics is related to the particle size and type of microplastics. The larger the particle size of the microplastics, the lower the adsorption capacity of phosphorus. Aging microplastics can improve the adsorption capacity of microplastics. After entering the water and soil environment, they may combine with phosphorus to form complexes, thus changing the migration behavior of phosphorus. Microplastics can be used as the carrier of phosphorus, promoting the migration of phosphorus in the soil and water environment under the action of water flow and wind power, so that the pollution range of phosphorus is expanded. Microplastics may affect the chemical form transformation of phosphorus in the soil and water environment. Due to the different types of microplastics, the adsorption intensity of phosphorus is also different.

Keywords: Microplastics; Phosphorus; Adsorption and transformation

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1. Current situation of phosphorus sources and pollution in water

Phosphorus content in water is one of the important indicators to evaluate water quality. Phosphorus is an essential element for plant growth, but too high a phosphorus content will lead to eutrophication of water and cause algae blooms, which will affect water quality and even endanger the ecological environment and human health. The main sources of phosphorus in water are as follows. Natural sources: rock weathering and soil leaching. Anthropogenic sources: the use of fertilizer application, livestock, and poultry breeding [1]. Livestock and poultry manure contain a large amount of phosphorus. Many industrial production processes contain relatively high concentrations of phosphorus in the wastewater, which will produce phosphorus-containing wastewater. Domestic sewage contains a variety of phosphorus-containing substances.

2. Sources and status of phosphorus pollution in soil

Phosphorus can enter the soil in many ways. The remains of plants and animals are an important source of soil organophosphorus, and the feces and carcasses of animals can also contain a certain amount of phosphorus. The soil contains a large number of microorganisms, and the microorganisms themselves contain some amount of phosphorus [2]. Studies have shown that the highest levels of microplastics are introduced into the soil through mulching, organic fertilizer application, and sludge utilization. In addition, irrigation, flooding, landfill, wastewater discharge, and atmospheric input are also potential sources of plastics in soil [3]. Textile mills produce wastewater containing fibrous microplastics when they produce synthetic fabrics. If this wastewater is not properly treated, the microplastics in it can contaminate the water [4].

Microplastics are difficult to degrade and have a relatively large surface area. The environmental behavior of microplastics after they enter the soil environment is more complex than that of other pollutants, and they may have more profound effects on the soil environment and the behavior of other pollutants in the soil environment. This paper mainly discusses the research progress on the effect of microplastics on phosphorus in water and soil environments.

3. Adsorption of phosphorus in soil and water by microplastics

The effect of microplastics on the adsorption effectiveness of phosphorus will vary depending on aging, species, particle size, and other factors.

3.1. Aging

Kong *et al.* aged three kinds of microplastics by superacid, and showed that after aging, a large number of debris, furls and folds appeared on the surface of microplastics, and the content of oxygen-containing functional groups significantly increased with the increase of specific surface area [5]. Aging will change the surface properties of microplastics, such as the increase of specific surface area and the increase of surface functional groups [6].

Luo *et al.* found that the aging of microplastics (MP) leads to an increase in the carbon-oxygen (C/O) ratio, which produces more oxygen-containing functional groups on its surface, thereby enhancing its surface polarity and hydrophilicity [7]. These changes may affect their adsorption properties, leading to higher adsorption capacity for other pollutants. Additionally, during these processes, some of the aging MP is prone to breaking into smaller nanoplastics for release into the environment. Cui *et al.* studied the adsorption processes of polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC) after aging, and found that it is more in line with the quasi-second-order kinetic model, which can be obtained that the phosphorus adsorption process of microplastics before and after aging is mainly achieved by chemical adsorption [6].

Simultaneously, according to the fitting results of the Freundlich model, it is further proved that aging can improve the adsorption capacity of microplastics. Aging of microplastics will have many effects on phosphorus adsorption, such as increase of specific surface area. During the aging process, the physical structure of microplastics will change, such as cracks, surface roughness and other phenomena. These changes will increase the specific surface area of microplastics, provide more adsorption sites for phosphorus adsorption, thus enhancing the adsorption capacity of phosphorus. Next, is pore structure change. Aging may lead to changes in the pore structure inside microplastics, porosity increase or pore size change. This will affect the diffusion and adsorption of phosphorus inside the microplastics. If the pores are increased and the pore size is suitable, phosphorus is easier to enter the pores inside the microplastics and be adsorbed on the pore wall, thus increasing the adsorption capacity. On the contrary, if the pore structure is destroyed or blocked, the adsorption of phosphorus may be hindered.

3.2. Particle size

The particle size of microplastics has an important effect on phosphorus adsorption. Generally speaking, microplastics with smaller particle size have larger specific surface area and can provide more adsorption sites, which is more conducive to phosphorus adsorption. On the contrary, microplastics with larger particle size may have relatively weak adsorption capacity for phosphorus due to relatively few adsorption sites available on the surface.

The smaller the particle size of microplastics contained in the soil, the weaker the inhibition effect of low polystyrene microplastics (PS-MPs) on the phosphorus adsorption of microplastic-soil system, and the stronger the promotion effect of high PS-MPs on the phosphorus adsorption of microplastic-soil system. The microplastics will wear or degrade in the soil, the particle size will decrease, and the phosphorus adsorption capacity of the microplastics-soil system will gradually increase. Studies have shown that with the increase of microplastic particle size, the reduction of available phosphorus continues to decline. This phenomenon may be caused by the fact that with the increase of microplastic particle size, the specific surface area of PS-MPs decreases by about ten times, resulting in the reduction of adsorption sites on the surface of microplastics, and thus the adsorption amount of available phosphorus decreases.

3.3. Types

The influence of the type of microplastics on phosphorus adsorption is mainly reflected in the following aspects: chemical structure, surface properties, and polarity. The pore structure of microplastics varies according to the type. Like some microplastics with porous structures, this large specific surface area can provide more sites for phosphorus adsorption, thereby improving the adsorption. In contrast, microplastics with smooth surfaces and few pores have a weaker ability to adsorb phosphorus. The specific surface area, total pore volume, and surface morphology of phosphorus are closely related to the adsorption capacity of microplastics [8]. The surface charge of different kinds of microplastics in the environment is different. When the environment's pH value and other conditions are certain, in the acidic environment, some microplastics may be positively charged on the surface, and phosphorus may exist in the form of phosphate ions in the solution (negatively charged), then electrostatic attraction will be generated to promote the adsorption of phosphorus.

Crystallinity is also an important characteristic of microplastics, but Zhu studied the adsorption behavior of microplastics to ciprofloxacin in water and found that the adsorption capacity of unaged microplastics decreases with the increase of crystallinity, while aged microplastics show the opposite trend [9]. This suggests that crystallinity may not be the dominant factor affecting the adsorption of microplastics.

4. Phosphorus conversion by microplastics

The effect of microplastics on phosphorus conversion is mainly reflected in the effect on phosphorus adsorption and release, as well as the effect on phosphorus conversion by changing the microbial community structure. In addition to the migration caused by physical or biological factors, a series of physical, chemical, and biological transformations occur under external factors such as environmental pressure, ultraviolet radiation, and microbial interactions.

4.1. Effects on phosphorus transformation in soil

Studies have found that microplastics can adsorb phosphorus in soil. Different types of microplastics have different adsorption capacities due to their different characteristics such as specific surface area and surface morphology. For example, loose and porous microplastics often have stronger adsorption performance and larger adsorption capacity, which will adsorb the mobile phosphorus in the soil to the surface of the microplastics, reduce the migration of phosphorus in the soil, and then may affect the absorption and utilization of phosphorus by plants [10]. Different contents of the same kind of microplastics in the soil will also have a certain impact on the adsorption of phosphorus in the soil. For example, research by Tang *et al.* shows that in the soil, when the content of microplastics is less than 1%, the adsorption capacity of soil phosphorus will be significantly reduced, but more than 5% of microplastics will significantly increase the adsorption capacity of soil phosphorus [11].

The presence of microplastics may affect the type and concentration distribution of cations in the soil, thus interfering with the equilibrium between the fixation and release of inorganic phosphorus [12]. For example, some microplastics may interact with cations such as iron, aluminum, and calcium in the soil, affecting their binding or dissociation with phosphate, and changing the fixed state and releasability of inorganic phosphorus.

4.2. Effect on phosphorus conversion in water bodies

Microplastics may affect the equilibrium of phosphorus precipitation and dissolution through interaction with cations in water bodies. Some cations may be adsorbed on the surface of microplastics, thus changing the binding state of cations and phosphate, and promoting or inhibiting the formation of phosphate precipitation [13]. Wang *et al.*] showed that in sewage treatment, microplastics below 0.3 mg/L have no obvious effect on the biological phosphorus removal process, but microplastics exceeding 3.0 mg/L will reduce the removal rate of Chemical Oxygen Demand (COD), ammonium nitrogen ($NH4^+$-N), and total phosphorus (TP) [14]. In addition, the physical and chemical properties of microplastics themselves may also affect the local environment of the water body to a certain extent. And then, indirectly affect the precipitation and dissolution of phosphorus. Microplastics may be ingested by aquatic organisms, and after entering the body of organisms, it may affect the absorption, utilization, and release of phosphorus by organisms. On the one hand, microplastics may occupy the space in the organism or interact with the substances in the organism, interfering with the normal physiological function of the organism, thus affecting its metabolism of phosphorus. On the other hand, phosphorus adsorbed on microplastics may be released or transformed with the life activities of organisms.

5. Leaching of phosphorus by microplastics

Zheng *et al.* showed that the addition of microplastics increased the leaching amount of nitrogen and phosphorus in soil and it increased with the increase of the addition amount of microplastics. Concurrently, the study also showed that under the condition of adding straw, with the increase of microplastics added amount, the soil nitrogen leaching amount decreased, while the soil phosphorus leaching amount increased. This may be because microplastics can interact with soil particles, affect the porosity and aggregate structure of the soil, and promote the transfer of water, so that phosphorus is more easily leached down with water. Moreover, since the hydrophobicity of microplastics themselves will affect the storage of soil water, the vertical migration of water in the soil is also an important driving force for nitrogen and phosphorus leaching, resulting in the decrease of soil water holding capacity, resulting in the increase of soil nitrogen and phosphorus leaching with the increase of microplastics input [15].

In some experiments, under the input of microplastics, the soil pH value increased with the increase of the input amount, which may be due to the aging of microplastics after repeated leaching and the release of other substances leading to the increase of soil pH.

Xie *et al.* showed that the effect of adding 1% polyethylene (PE) in soil on the leaching loss of water-soluble phosphorus was mainly manifested as the "pore effect" and the leaching loss of water-soluble phosphorus in soil was affected by affecting the leaching loss of soil leaching solution, while the effect of other PE additions on the leaching loss of water-soluble phosphorus was mainly manifested as "adsorption effect" [16]. Simultaneously, the increase in PE particle size had no significant effect on the total leaching loss of water-soluble phosphorus. The effect of PE particle size on the leaching loss of soil phosphorous was less than the effect of PE content.

6. Phosphorus removal by microplastics

The effects of microplastics (MPs) on enhanced biological phosphorus removal processes (EBPR) are common. EBPR has the characteristics of simultaneous removal of pollutants and nutrients, and exogenous MPs can affect the performance of EBPR. The removal of TP in EBPR also inhibits the removal of TP in EBPR systems with low-concentration MPs. The effect of MPs on the operation efficiency of EBPR is closely related to the exposure concentration, and the higher the exposure concentration of MPs, the more significant the removal inhibition of pollutants and nutrients [17].

7. Conclusion

The effect of microplastics on the adsorption efficiency of phosphorus varies with the variety, concentration, particle size, aging, and other factors. The smaller the particle size of the microplastics contained in the soil, the smaller the particle size of the microplastics will be worn or degraded in the soil, and the phosphorus adsorption capacity of the microplastics-soil system will gradually increase. Studies have shown that with the increase of microplastic particle size, the reduction range of available phosphorus continues to decline. The research further proves that aging can improve the adsorption capacity of microplastics. Microplastics may also indirectly affect the mineralization process of organophosphorus by changing the physical structure and microbial community structure of the soil. They may also be ingested by aquatic organisms, and after entering the organisms, they may affect the absorption, utilization, and release of phosphorus by organisms. Microplastics may affect the balance between precipitation and dissolution of phosphorus by interacting with cations in water bodies.

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Disclosure statement

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