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Review

The Source, Distribution Characteristics, and Migration Behavior of Microplastic Pollution in Soil Environment in China: A Review

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Abstract

Pollution from microplastics (plastics<5 mm, MPs) has been recognized relatively recently as one of the most urgent and pervasive global environmental problems of the 21st century. MPs are organic particles that are typically characterized by small sizes (µm range), complex molecular structures, prolonged environmental persistence, and strong sorption onto other organic contaminants. The main sources of MPs in the soil environment include plastic film planting, sewage irrigation, and organic fertilizer or sludge applications. These agronomic practices are meant to enhance crop productivity for a hungry world. Ironically, misuse of the same practices can adversely impact human and ecosystem health. Soil MPs do not only change the physical and chemical properties of soil, but also have ecological effects on soil flora, fauna, and microbial communities. Furthermore, MPs can serve as additional carriers of pollutants in soil environments. This paper is a review of current knowledge about the occurrence, abundance, and distribution of MPs in Chinese soils, with brief mentions of parallel global viewpoints on the topics. Mechanistic aspects of migration behavior, factors that influence such behaviors, and prospects for remediating adverse impacts of MPs in soils are reviewed.

Keywords: microplastics, soil environment, pollution status, occurrence characteristics, migration behavior

Introduction

In 2004, an article published in Science (Lost at Sea: where is all the plastic?) sounded perhaps the clearest alarm about the increasingly unacceptable intrusions of microplastics (MPs) in marine environments, and it clearly defined the concept of MPs, namely plastic fragments or particles with a diameter of less than 5 mm [1]. Types of MP polymers mainly include polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC) [2]. Based on how they originate, MPs can be divided into primary or secondary types. Primary MPs are intentionally manufactured as small-sized plastic particles, such as those used as beads in face washes and cosmetics, or those in medical applications. Secondary

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MPs are small-sized plastic fragments formed by physical crushing, chemical or photo-decomposition, and microbial degradation of large plastic wastes [3]. Regardless of their origins, MPs can become carriers of pollutants in environments.

Currently, research on MPs has mostly focused on marine environments. According to the European Ocean Investigation Team, MPs have become pervasive in different marine ecosystems ranging from the Arctic Ocean to the Mariana Trench, the latter known as the last pristine environment in the world, with a depth of 10,927 meters [4]. Ultimately, these marine plastics come from land-based sources. According to Jambeck et al. in 2010, an estimated 275 million metric tons of land-based plastic waste from 192 coastal countries resulted in 4.8 to 12.7 million metric tons entering the ocean [5]. This makes it imperative to focus greater research efforts on characterizing the occurrence, migration behavior, and ecological impacts of MPs in terrestrial ecosystems, such as soil.

Currently, research on MPs in soils has been seriously lacking. The dearth of information about soil MPs is most likely related to the complex nature of terrestrial environments. According to databases of Web of Science and China HowNet, from 2014 to 2021, research on soil MPs only accounts for 9.18% of the total MPs literature. However, this appears to be changing rapidly with increasing recognition of threats that MPs pose to human and ecosystems health. This paper is a review of current knowledge about the occurrence, abundance, and distribution of MPs in Chinese soils, with brief mentions of parallel global viewpoints on the topics. Mechanistic aspects of migration behavior, factors that influence such behaviors, and prospects for remediating adverse impacts of MPs in soils are reviewed.

Distribution of MPs in Global Soil Environments

One consequence of the large-scale use of plastic products in agricultural production is the pervasiveness of MPs in soils worldwide. Unfortunately, until recently, a paucity of research investigation on the phenomenon in soils has also led to a lack of standard approaches for detecting and estimating the abundance and distribution of the substances in those environments. MPs are persistent in soils; accordingly, they can accumulate rapidly to levels that pose threats to the health of soil ecosystems.

At present, global demand for plastics is relatively high; according to recent statistics, the global annual plastic output has increased in 15 years from 230 million tons in 2005 to 348 million tons in 2019, with an average annual growth of 7.87 million tons [6]. It has been suggested that in the absence of effective disposal measures, by 2050, 12 billion plastic wastes generated could accumulate in landfills or natural environments worldwide [7]. The high consumption of plastics on the one hand and on the other hand, the low rate of plastics recycling (6%-26%), ensure that large amounts of plastic waste enter various environmental compartments [8]. Table 1 shows the abundance and distribution of MPs in typical global soil environments.

As shown in Table 1, soils in different parts of the world have been contaminated to different extents by MPs. In diverse countries and regions, there are giant differences in the abundance and distribution of MPs, which can be attributed to local land utilization ways and fertilization conditions. The types of soil polluted by MPs in the world are mainly farmland soil, film soil, sludge soil, and garden soil. For example, Fuller et al. reported that municipal waste and soil samples collected from an industrial area in Sydney, Australia ranged from 300~67,500 $mg \cdot kg^{-1}$ MPs, compared to levels of ordinary soil [9]. According to a survey in Germany, the mean abundance of MPs in traditional farmland was only 0.34±0.36 $ind \cdot kg^{-1}$ [10]. Amrutha et al. reported a study that characterized MPs for a tropical Indian river, namely the Netravathi River. All samples collected showed the presence of MPs with a mean numerical abundance of 288 $pieces \cdot m^{-3}$ (water), 96 $pieces \cdot kg^{-1}$ (sediment), and 84.45 $pieces \cdot kg^{-1}$ (soil) [11]. They concluded that the spatial distribution and abundance of MP particles were consistent with the influence of population distribution, land use, and good household practices of waste management in some areas.

Table 1 shows that MPs in most soils are less than 5mm in size and they consist of fibers, fragments, and films, with PP and PE being their major compositions [11, 12]. In terms of their presence in different soil layers, the vast majority of the larger plastic particles or fragments are distributed in surface layers with only the small-sized particles being transported deep into the soil profile. However, soil bioturbations caused by disturbances, including farming practices and soil-dwelling animals, can alter this dynamic. For example, Meng et al. investigated the effects of soil surface litter-borne MPs on burrows built by the earthworm, Lumbricus terrestris and they quantified the amount of MPs that were transported and deposited in L. terrestris burrows [13]. They concluded that the high biogenic incorporation rate of the small-fraction MPs from surface litter into earthworm burrows could lead to the leaching of MPs through preferential flow, ultimately into bodies of groundwater.

Abundance and Distribution of MPs in China's Soil Environments

Compared to other parts of Europe and North America, the emphasis being placed on MPs in Chinese environments is a relatively recent and timely development. However, in keeping pace with situations elsewhere in the world, the literature on soil MP

Table 1. Distribution of MPs in typical soils around the world.

Countries and regions	Soil types	MPs				Reference
		Shape	Composition	Abundance (pieces·kg^{-1})	Size (mm)	
Sydney, Australia	Soil in industrial parks	/	PVC, PE, PS	300-67,500 (mg·kg^{-1}), (0-10 cm)	<5	[9]
Germany	Farmland soil	Fragments,films	PS, PE	0.34±0.36	<5	[10]
India	Soil along the river	Fibers, fragments, films	PE, PET, PP	84.45 (0-5 cm)	0.3-5	[11]
Korea	Paddy fields	Fibers, fragments, films	PE, PP, PS, PET	160±93	0.1-2	[12]
	Farmland covered with films			81±77		
	Greenhouse soil			1,880±1.563		
The suburb of Mexico	Garden soil	/	/	870 (0-20 cm)	0.01-1	[13]
Spain	Farmland with sludge applied	Fibers, fragments	PET, PE, PP	302,000±83,000	0.029-2.224	[14]
Mellipilla, Chile	Farmland soil	Fibers	/	600-10,400	0.02×0.97	[15]
Canada	Farmland with sludge applied	Fibers, fragments	PP, PE, PET	18-541	0.1-1	[16]
	Farmland free of sludge			25-298		
Switzerland	Flooded areas	/	PE, PS, PVC	593	0.0125-0.5	[17]
Mexico	Courtyard gardens	/	PE, PS	2,770	5-150	[18]
Pakistan	Farmland soil	Fibers, fragments, films, particles	/	2,200-6,875	0. 5-5	[19]
Iran	Farmland soil	Fibers, fragments,	/	67-400	0.04-0.74	[20]
Danmark	Farmland soil	/	PE, PP, PA	82,000-236,000	0.02-0.5	[21]

pollution in China has continued to grow yearly. MPs have generally been detected in agricultural soils such as farmland, pastoral forests, greenhouses, vegetable fields, and grasslands. The literature suggests that there was an overall decline in the use of agricultural film in China from 2012 to 2021, while the actual production of plastic film in the country continued to show a general increase (Fig. 1). More recently, China issued a policy of "plastic restriction order", which is continuing to raise attention to MPs pollution in the country.

In farmland soil, the types of MP polymers mainly include PE and PP, which are closely related to the selected soil planting method. In addition, the abundance of MPs in farmland soil was generally different in different regions. For example, Wu et al. pointed out that the abundance of MPs in the soil of facility agriculture in Beijing ranges from (440±179.63) to (2,366.67±347.21) n·kg^{-1}, with an overall average abundance of (1,405.19±584.30) n·kg^{-1}, while the abundance of MPs in Xinjiang is as high as (1,075.6±346.8) n·kg^{-1} [10, 22]. The main reason for this difference is that Xinjiang's farmland has been extensively planted with plastic film for a long time, The facility agricultural soil in Beijing mainly relies on measures such as plastic film and organic fertilizer cultivation, as well as agricultural irrigation, which results in a high abundance level of MPs in the agricultural soil in Beijing, and the types and forms of MPs are diverse.

In addition, human activities not only have an impact on the abundance of MPs in soil, but also have a significant impact on changing their particle size. For example, under the influence of high-intensity human activities, the abundance of MPs in the soil along the Bohai Sea coast ranges from 1.3 ind·kg^{-1} to 14,712.5 ind·kg^{-1}. About 60% of MP particles have sizes smaller than 1mm [23]. In the middle and lower reaches of the economically developed Yangtze River, high levels of MPs have been reported in agricultural soils. According to Zhou et al. [24], MP abundance in the farmland of Wuhan ranges up to 43,000~620,000 items·kg^{-1}, compared to only 420~1,290 items·kg^{-1} in Jiangsu [25], which is less developed economically. Morphologically, proportions of MP fragments and fibers were reported to be 52% and 14% respectively at these sites.

As would be expected, a large difference exists between levels of MPs under different cropping systems.

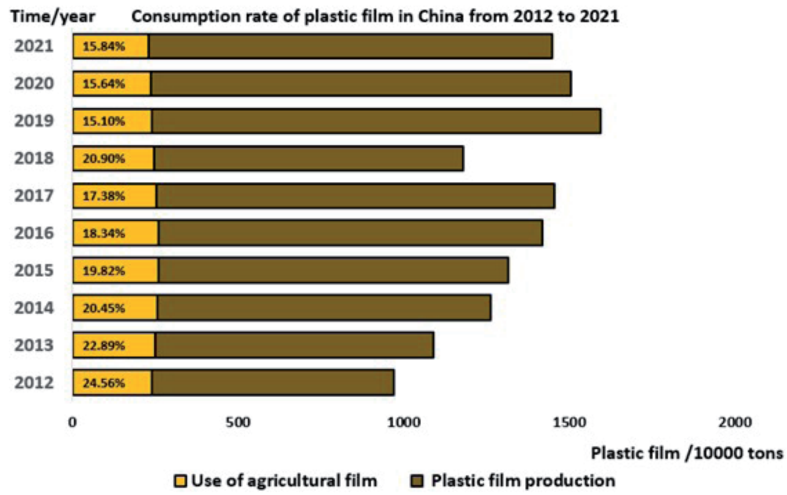

Fig. 1. 2012~2021 consumption of plastic films in China (by the State Statistical Bureau, 2022).

For typical farmland, the mean MP abundance is calculated to be 161±35 ind·kg^{-1}, and in the vegetable land Wuhan, MP abundance ranges between 320 to 12,560 pieces·kg^{-1}, which is significantly below that in the surface soil of greenhouses (780±129 ind·kg^{-1}) but higher than that in the paddy soil (45±12 ind·kg^{-1}) where fish are raised [26]. Existing studies indicate that soil tillage methods and soil materials have an important impact on the difference in MP abundance. For example, Wang et al. [27] have pointed out that agricultural operations can have an important impact on the migration and diffusion of MPs, and MPs can be transported to other environmental systems through migration and diffusion, thus increasing the abundance of MPs in different deep soils.

In addition, due to their small particle sizes and large specific surface areas, MPs tend to sorb readily onto soil materials (such as minerals, organic substances, and metal oxides). Such sorption modifies the physical and chemical properties of the complexes formed, thereby further affecting the distribution depth of the MPs in the soil. For example, the adsorption of metal oxides and organic substances by MPs can change the surface electrical properties and adsorption sites of MPs, thus affecting their migration depth in the soil, and further affecting the difference in the abundance of MPs in the deep soil [28].

At present, research on MPs mainly focuses on aquatic environments, while research on MP pollution in soil environments is relatively scarce. This is mainly because the distribution of MPs in soil environments is relatively complex, and organic matter and recalcitrant compounds in soil can interfere with the qualitative and quantitative analysis of MPs [29]. For example, fluorescence staining is a quantitative method for analyzing MPs using fluorescent dyes, but this method may lead to overestimation of the abundance of MPs [30]. The complex components formed by embedding MPs into soil organic matter not only have adverse effects on the detection of Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy, but also have adverse effects on the flotation and separation of MPs. The density separation method is used to extract MPs from the supernatant, usually using saturated salt solutions (such as NaCl, NaI, and $ZnCl_2$ solutions) for density separation. However, this method may require adjusting the concentration of the solution (without knowing the density of MPs) [31]. In addition, the current representation methods of MP abundance in various research institutions are not unified, which is not conducive to the comparison of MP abundance in soil in different regions. Therefore, it is necessary to develop a fast, efficient, universal, simple, and reliable analytical technique to characterize MPs in soil.

Sources and Pollution Situation of MP in Soil

Like many other countries, major sources of MPs in China's soils include plastic films from agricultural production, irrigation water, organic fertilizers, sludge discharged from sewage treatment plants, plastic waste seepage from the landfill, atmospheric sedimentation, illegally discarded or improperly disposed of waste, plastic products, as well as wearing away vehicle tires (Fig. 2) [32].

Residual Plastic Films/Agricultural Mulching Films

Plastic films have been widely applied in global agricultural production because of their ability to improve temperature and moisture retention, which is essential for enhancing both the quality and yield of agricultural productivity. The main compositions of such plastic or mulching films in China are PE and PVC. In general, under normal conditions, agricultural mulching films in the soil can be degraded through physicochemical and photochemical reactions as well as microbial activities, ultimately into nanometer-scale MP

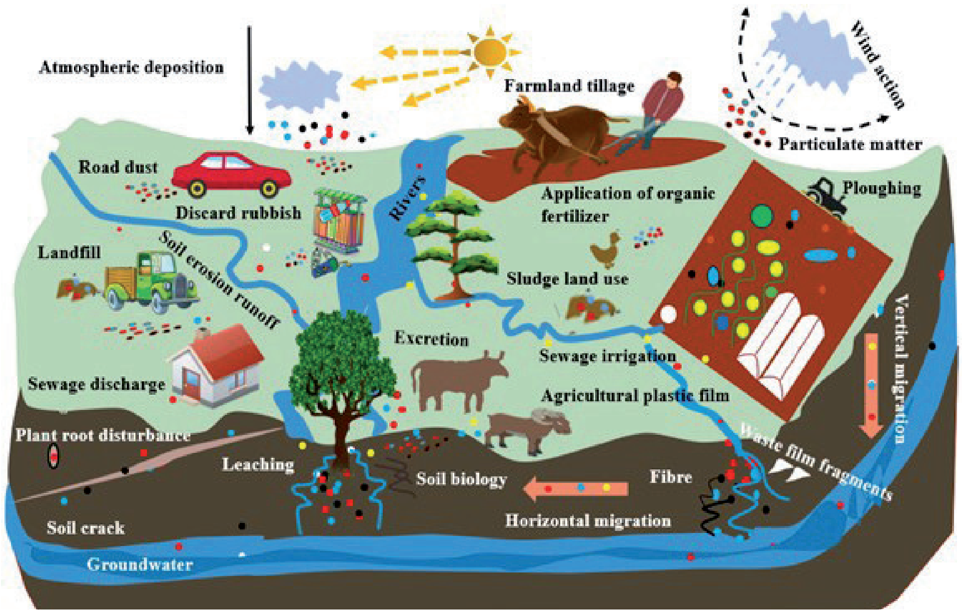

Fig. 2. MP sources in the soil and the status quo of MP pollution.

particles that cause highly undesirable accumulations in environmental compartments [33]. In some regions of China, plastic mulching films discarded after soil tillage have been presented in Fig. 3. It is reported that coverage with mulching films in northern China enables MPs to extensively accumulate in the farmland. From 1991 to 2011, the agricultural mulching film application amount rose by about 3 times from 0.32 million tons to 1.25 million tons in China [34]. A survey from farmland in Hangzhou Bay, Zhejiang Province, showed that the soil MP content of mulched farmland was 2.2 times higher than that of non-mulched [35].

Application of Organic Fertilizers

Large-scale application of organic fertilizers in agriculture has been reported as a major source of MPs in soil [36, 37]. These fertilizers are mostly produced from aerobic composting or anaerobic digestion processes using various manures, sewage sludge, and food wastes [38]. In one study, Li et al. [39] investigated organic fertilizers as sources of MPs in the environment. The investigators pointed out the lack of detailed studies about the production and initial entry of MPs into terrestrial ecosystems. Using organic fertilizer from bio-waste fermentation and composting, these investigations concluded that the application of organic fertilizers from the sources that they used could indeed contribute to MP loads in the environment.

Sewage Irrigation

The direct introduction of MPs through agricultural irrigation is another important source of MPs in the soil environment. Particularly in many developing countries where water resources are chronically scarce, large amounts of sewage water are used to irrigate agricultural land, thereby introducing MPs from sewage water into the soil environment [40]. Water for agricultural irrigation often comes from domestic wastewater. Sewage irrigation can solve water problems in arid and semi-arid areas, but the wastewater contains large amounts of MPs in untreated form. It has been reported that washing machines release 124~308 mg of MPs for 1 kg of laundry, and the corresponding number of MPs in the discharged effluent is as high as 0.64~1.5 million [41]. On the other hand, water is often diverted from surface freshwater such as rivers and lakes during irrigation in agricultural fields, and MPs are widely present in these water bodies. For example, the abundance of MPs in shallow agricultural soil (0-5 cm) and deep agricultural soil (10-15 cm) located along the Yellow River in Ningxia is 278.68 pieces·kg^{-1} and 263.37 pieces·kg^{-1}, respectively [42].

Other Sources

In addition to the sources described above, atmospheric sedimentation, waste seepage from the landfill, illegal dumping and improper disposal of garbage, and automobile products such as worn-out or disintegrating tires are all major sources of MPs in soil. For example, weathering fragments of plastic garbage may be found in areas where domestic garbage is not properly disposed of [43]. With economic and social development and the spread of agricultural machinery, per capita ownership of cars and all types of agricultural machinery continues to increase, and tire wear particles are gradually being found in soils [44-46]. In addition, large amounts of fibrous MPs have also been detected in the atmosphere of cities such as Dongguan and Shanghai [47, 48]. This suggests that tire wear particles and atmospheric deposition are also potential sources of MPs that cannot be ignored.

Occurrence Characteristics of MPs in Soil

In recent years, research on the current status of MP contamination in soils has received close attention, and in particular there has been a rapid development in the reporting of studies on the distribution characteristics of MPs in soils. To further understand the fugitive characteristics of MPs in Chinese soils, we collected the abundance, size, and composition of MPs from soils in some typical areas (shown in Table 2 below). From Table 2, it can be seen that Chinese soils are currently contaminated with MPs to varying degrees. In different regions, MPs in soil show different compositions, abundance levels, and sizes. Such a phenomenon may be caused by various factors, including soil types, soil depth, tillage methods, and sampling locations. In addition, it is also clear in Table 2 that PE and PP are major compositions of MPs; and especially PE takes a considerably high proportion. Moreover, PVC and PS may also play a major role in some cases.

In China, soil in Yunnan contains MPs with the highest abundance, which may be caused by local climatic conditions and soil properties, since humid weather facilitates both MPs' transfer in soil and their migration towards the basement soil. In a review by Sang et al. [56], it is reported that unlike the central or northern regions of Shaanxi Province, Southern Shaanxi features high temperatures, high precipitation, and a moist climate. In the surface soil there, the MP content is comparatively low and small-sized for the following reasons: high temperature and precipitation in Southern Shaanxi may promote aging, fragmentation, and decomposition of MPs on one hand; and on the other hand, rain wash accelerates the migration of MPs towards deeper soil layers. However, the MP abundance in the soil of the Loess Plateau is the lowest, which is closely related to the climate on the Plateau. Driven by a dry and arid climate as well as the wind, MPs in the yellow sand on the surface of the Loess Plateau can be distantly migrated.

Occurrence characteristics of MPs in soil are associated with soil depth. The deeper the soil layer is, the lower the MP abundance and the smaller its particle sizes will be. This phenomenon is also related to the migration capability of MPs. As reported by Zhou et al. for the first time, MP content turns out to be 634 pieces·kg^{-1} in the coastal soil 0-2 cm deep of Hebei Province [49]. It is pointed out by Duan et al. that while MP abundance in wetland soil of Shandong is 136~2,060 pieces·kg^{-1} (0-2 cm deep) [57], that in 0-10 cm deep soil of a campus lawn in Tianjin is detected to 95 pieces·kg^{-1} [58]. This indicates that different occurrence characteristics of MPs can be found in soils from different regions and diverse depths.

Besides, their occurrence characteristics are also correlated to the age limit of film coverage. The longer the age limit is, the higher the MP abundance and the smaller its particle size will be. This phenomenon is caused by weathering and decomposition of MPs in soil, as shown by Shihezi film mulching farmlands in Xinjiang in Table 2. Similarly, MPs are also detected in abundance near industrial and agricultural production areas, which may closely relate to plastic films used for

Table 2. The effect of soil depth on distribution of MPs in China's soils

Country and region	Soil depth (cm)	MPs				Reference
		Abundance (pieces·kg^{-1})	Soil types	Composition	Size (mm)	
Shandong Province, China	/	50-1,000	Sludge	PE, PP, PS, PEU	<1 (60%)	[23]
Hebei Province, China	0-2	634	Beaches	PE, PP, PVC	1.56±0.63	[49]
Loess Plateau, China	0-10	40±126	Farmlands	PE	>0.1	[50]
	10-30	100±141				
Yunnan Province, China	0-10	7,100-42,960	Projected farmlands	PE, PP	0.05-10	[51]
Shanghai, China	0-3	78.00±12.91	Farmlands in the suburb	PE, PP, PES	0.03-16	[52]
	3-6	62.50±12.97				
Harbin, China	0-30	89	Farmlands	PE, PP	<5	[53]
Daliao River, China	/	73.33±327.6	Watershed soil	PE, PP, PS, PA	<5	[54]
Shihezi, Xinjiang	0-40	80.3±49.3 (L)	Farmlands with mulching films	PE	0-5	[55]
		308±138.1 (M)				
		1,075.6±346.8 (N)				

Notes: "L", the mean film mulching for 5 years; "M", that for 15 years; and "N", that for 24 years.

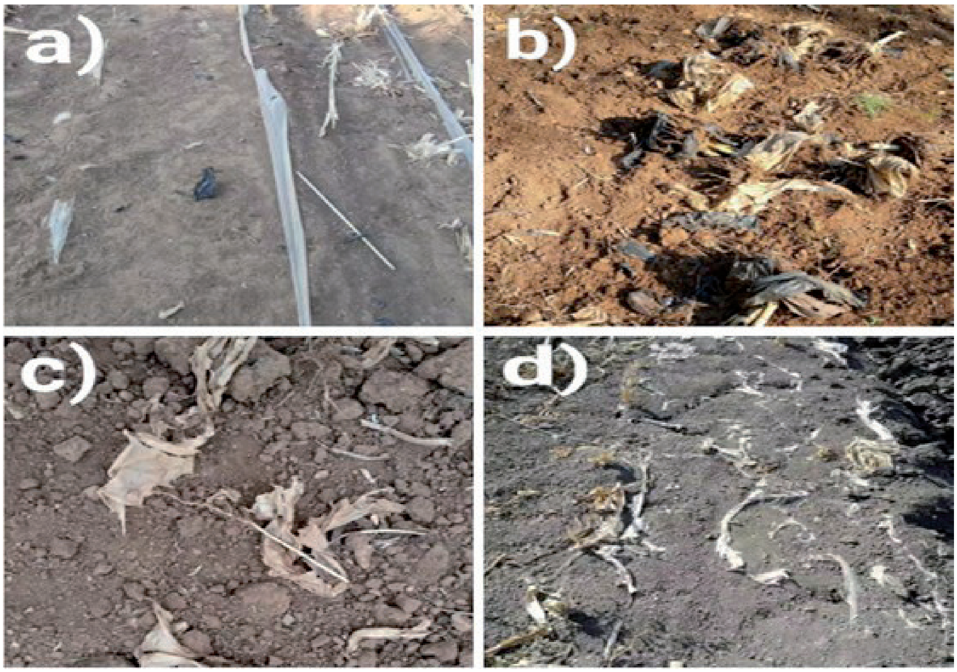

Fig. 3. Bijie City, China a), Qujing City, China b), Kashgar City, China c), and Chifeng, China d).

agricultural purposes, plastic degradation inhibition by the arid climate, and the accumulation of plastic garbage as industrial waste. To date, the research on MP distribution in China still remains at a preliminary stage. The spatial distribution and abundance of MPs are still unclarified, yet. Therefore, it is urgent to establish complete and standard determining techniques and reliable measurement criteria to effectively control soil MP pollution.

A plastisphere is defined as a unique ecological niche formed by the rapid colonization of bacteria, fungi, algae, and small invertebrates on the surface of plastic fragments after they enter the aquatic environment, known as the "plastisphere". Similarly, bacteria and other microorganisms quickly colonize the surface of plastic fragments to form a special soil plastisphere [59] (Fig. 4). The soil plastisphere is composed of plastic fragments and particles, as well as a specific environment composed of microbial communities colonized in the plastisphere environment [60]. The relationship between MPs and microbial communities in the soil is extremely complex and a long-term dynamic process. Microorganisms not only play a role in degrading and aging plastic fragments, but also the nutrients produced during the plastic aging process provide various carbon sources and energy needed by microorganisms. The interaction process between MPs and microorganisms is as follows: first, microorganisms attach to MPs, and then colonize and form biofilms on their surfaces. The extracellular polymeric substances (EPS) secreted by microorganisms provide a viscous substrate for colonization, providing stable support for biofilms and facilitating their adhesion to MPs surfaces, followed by biodegradation on the surface of microplastics (soil under the influence of roots) [61]. The internal and external enzymes secreted by microorganisms promote the depolymerization process of MPs, causing their polymers to break and form smaller molecules, which may be accompanied by the release of additives [62]. Finally, these small molecule polymers can be used by microorganisms as carbon sources and energy absorption metabolism, producing products such as CO_2, H_2O, and CH_4 [63]. This process is not only beneficial for the remediation of MP pollutants but also has significant implications for the circulation of geochemical substances.

Migration Behavior of MPs in Soil

Upon entering soils, plastics are subjected to various forces that ultimately determine their fates in particular soils (Fig. 2). Depending on the nature of the plastic material, soil physicochemical processes, soil biota, and climate, plastics can undergo weathering to render them even more reactive [64]. In turn, this will influence the sorption and migration behaviors of the plastics as well as their abilities to transport pollutants in soil profiles [65]. The same factors and their interaction are also responsible for threats posed by plastics to plant, animal, and microbial systems [66] and in fact, human and ecosystem health as well (Figs. 4, 5 and 6) [67].

Migration of MPs under Human and Animal Activities

Daily human activities continuously influence and lead to the migration of MPs into the soil [68]. For example, agricultural cultivation methods are not only a factor in promoting the deep migration of MPs in soil profiles, but also a key factor in the migration of MPs on the surface of soil particles [69]. Research has shown that the migration of MPs with larger particle sizes mainly depends on mechanical disturbances. For example, cultivating or harvesting root and tuber crops may cause relatively large plastic fragments to migrate from the soil surface to deeper soil layers [70]. Agricultural practices such as cultivation and irrigation play a crucial role in the fragmentation and transport of plastics, and in particular, have a significant impact on the increase in abundance and accumulation of MPs in deep soils [71].

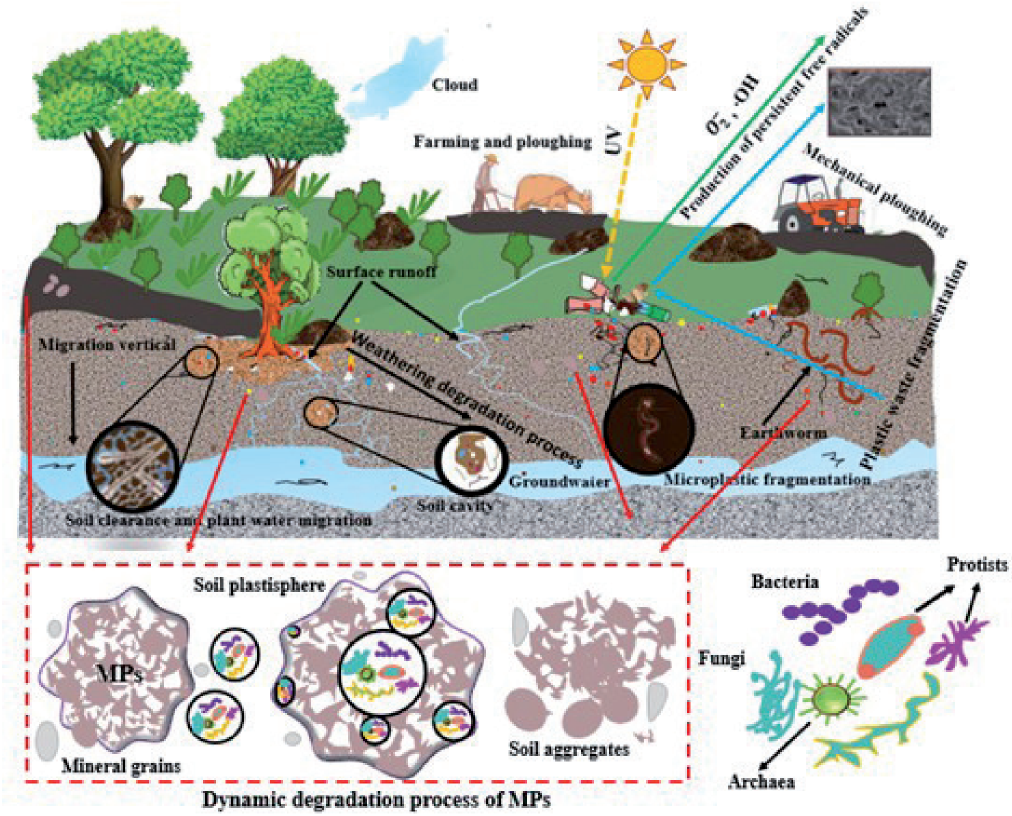

Fig. 4. MPs migration behavior and paths in soil.

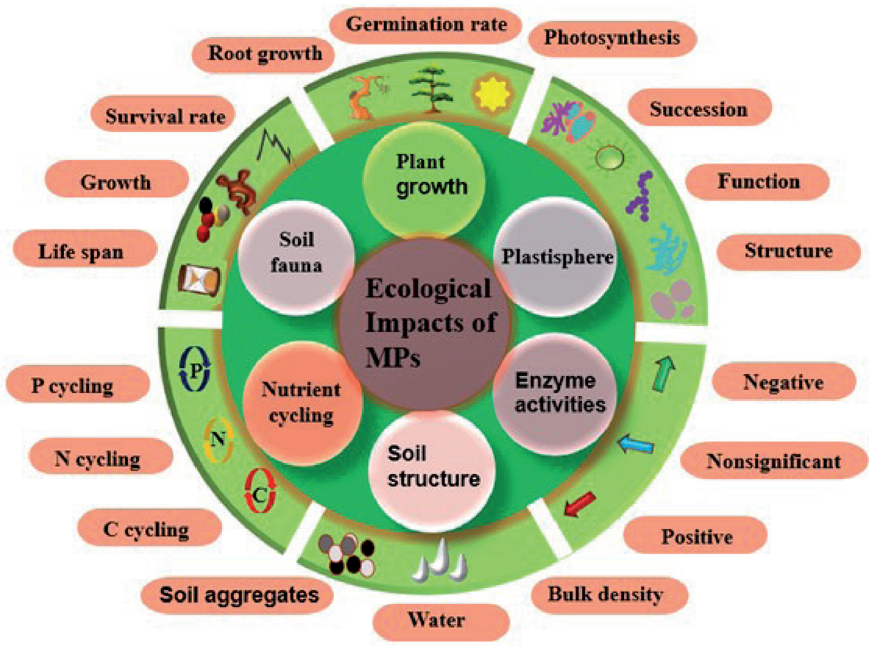

Fig. 5. Impacts of MPs on soil ecosystem.

Instead of farm equipment, disturbances from soil animals such as earthworms and springtails have been shown to cause migration and transportation of MPs; they can also alter morphologies of the particles during their movements [72]. In particular, soil perturbations by earthworms are renowned for being involved in the movement and redistribution of MP particles in soil. In one study, Rillig et al. [69] reported that earthworms were able to move MP particles (710～850 μm in size) 10 cm deep into the soil, while large particle-size MPs are enriched in the middle soil layers. The burrowing behavior of earthworms improves both the porosity and water permeability of the soil; in turn, this provides channels for MPs migration and creates conditions for water flows to enable MPs to migrate deeper into the soil [13].

MP Migration During Plant Growth

In MP-contaminated soil, plants can absorb these MP particles, which will have a negative impact on their ability to absorb nutrients, thereby reducing crop productivity and quality [73]. Furthermore, plant root systems can accumulate MPs, which can alter the dynamics of the distribution of MPs in soil (Fig. 7). For example, the decomposition of root systems can lead to the generation of large pores that are conducive to the transportation of MPs in soil [74]. Li et al. studied the absorption and migration of PS in lettuces [75]. They concluded that lettuce absorbs MPs and also transports them to various stems and leaves. Accordingly, lettuce from MPs-contaminated soil MPs is a direct threat to human health.

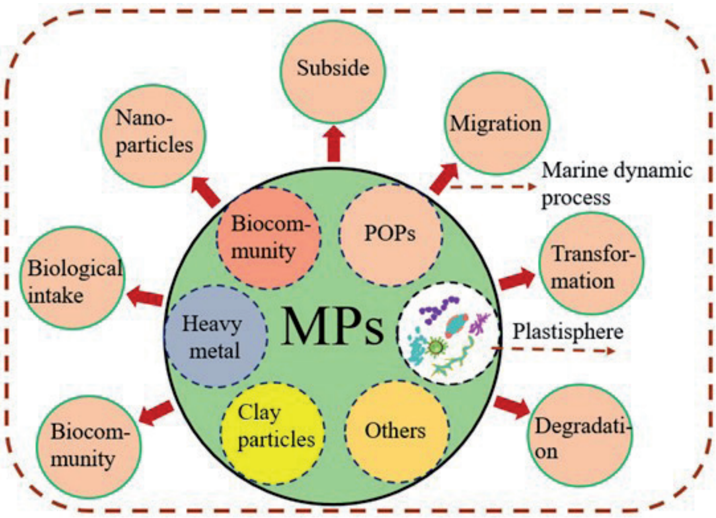

Fig. 6. Behavior of MPs in marine environment.

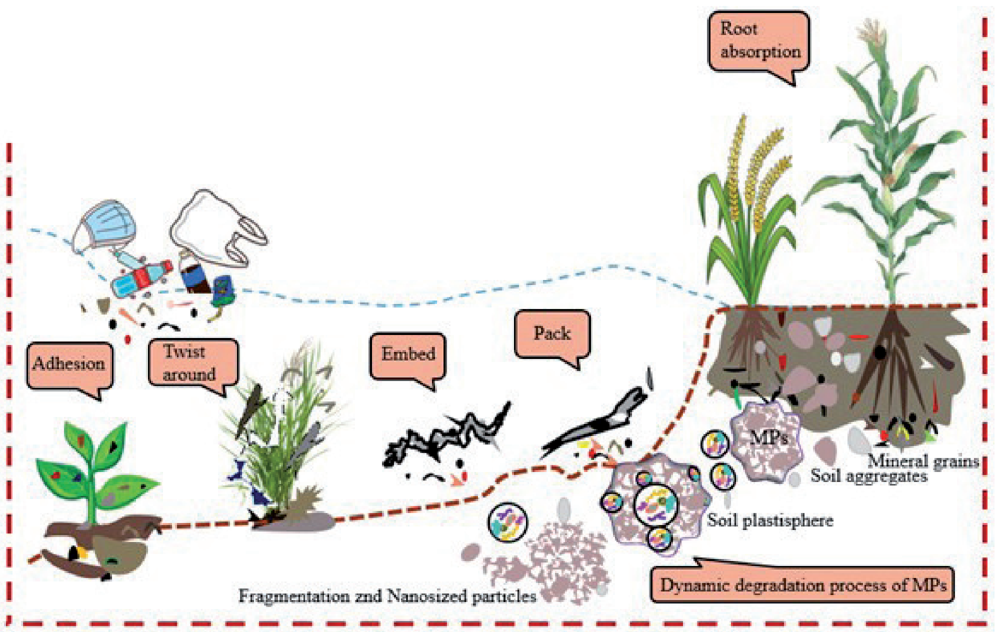

Fig. 7. The way of MPs entering plant.

Factors that Influence MP Migration in Soil

Several factors influence the migration of MPs in soil, including soil physicochemical properties, electrostatic interaction, MP chemistry, human and soil biota activity, and climatic conditions (mainly rainfall and wind). Soil properties (e.g. soil porosity) have an important influence on the migration of MPs in soil [76]. For MPs at the soil surface to migrate deeper into the soil, their size needs to be smaller than the porosity of the soil; otherwise, they will be trapped at the soil surface or in shallow soils, and the greater the porosity of the soil, the more likely it is that MPs will migrate deeper into the soil and cause deeper contamination of the soil.

Other physicochemical factors that are important in the migration of MPs in soil include the size and hydrophobicity of the particles. For example, O'Connor et al. [77] reported the mobility of different sizes and densities of PE and PP particles in the soil. They concluded that the smallest-sized PE MPs (21 μm) possessed the greatest movement potential. Furthermore, these MPs were subjected to greater numbers of wet-dry cycles, a phenomenon that also corresponds to increased depth of infiltration in the soil. Based on their data about the wet-dry weather cycle for 347 cities across China, these investigators were able to forecast 100-year penetration depth of MPs in soil for the country, with Beijing Municipality and Hebei, Henan, and Hubei provinces being the most vulnerable to MP vertical dispersion [77]. In addition, wind is an important factor affecting the lateral migration of MPs, allowing them to spread in the soil; precipitation also affects the vertical migration of MPs, helping them to invade groundwater and even migrate to the ocean [78]. At present, there is a lack of research on the factors affecting MP transport, and further research is needed on the mechanisms affecting MP transport in soil.

Conclusions and Prospects

Soil pollution by MPs has become a matter of great concern in China and the world. Under joint influences of soil properties, soil biota, and climatic factors as well as the nature of MPs themselves, these pollutants may migrate, accumulate, or otherwise distribute in soil compartments in ways that threaten human and ecosystem health. The rapidly growing focus on the environmental risks posed by the substances is a relatively recent development. Accordingly, research communities worldwide are faced with challenges in addressing the unique impacts of the particles in the environment, including the following:

1. A need for standardized methods for measuring and reporting levels of MPs in soil. Addressing this can facilitate relevant comparisons and therefore allow more environmentally sound decisions to be made about the particles on the regional, national, or global scales.
2. A greater understanding of the factors that influence MP behaviors is polluted matrices and their complex interactions thereof.
3. Microorganisms have strong environmental adaptability and the ability to decompose different MP pollutants. Therefore, it is still necessary to conduct research on the degradation mechanism of MPs by microorganisms in actual soil environments (the soil plastisphere), in order to achieve efficient microbial remediation of MP pollution.
4. Research and formulation of relevant laws and regulations on soil MPs pollution.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in the paper.

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