

Review (Narrative)

Ecological Effects of Soil Microplastic Pollution

Rogers Leed, Ph.D., Moore Smithson, Ph.D.

SUMMARY

As a new type of environmental pollutant, microplastics pose a serious threat to soil ecosystems. We reviewed the classification and source of soil microplastics, separation, detection methods and existing problems. The pollution of soil microplastics and the adsorption effect and mechanism of microplastics on pollutants are summarized. The effects on soil animals, microbial ecology and carbon, nitrogen and other material cycles were analyzed. Furthermore, the ecological effects of microplastics are proposed, which provides new ideas for the study of soil microplastics in the future.■

KEYWORDS

Microplastics; Pollution; Adsorption; Soil Ecosystem

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Author Affiliations: Author affiliations are listed at the end of this article.

Correspondence to: Dr. Rogers Leed, Ph.D., Group of Ecosystem, Division of Biology and Chemistry, The BASE, Chapel Hill, NC 27510, USA. Email: rogers.leed@basehq.org

Or

Dr. Moore Smithson, Ph.D., Group of Environment Protection, Division of Energy and Resources, The BASE, Chapel Hill, NC 27510, USA. Email: moor.smithson@basehq.org

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Microplastics (< 5 mm) have received widespread attention as a new type of contaminant in recent years (1). Microplastics have small particle size, large number, wide distribution, easy to be swallowed by organisms, accumulated in the food chain (2), and have certain adsorption characteristics, which can absorb and enrich pollutants or microorganisms on their surface (1). At present, most of the research focuses on marine ecosystems such as ocean (3-9), coastal tidal flat (10-18), estuary (19-22), and lake (23-31). Microplastics have a negative effect on marine and freshwater fish, birds, etc. (32-34). As a carrier of pollutants, microplastics can be toxic after being ingested by aquatic animals, and can also be transmitted through the food chain (4).

The main problems in the study of the effects of microplastics on soil ecosystems are: (i) From the perspective of research methods, microplastics in the ocean are easier to separate and detect than complex and diverse soil media; (ii) from the perspective of research objects It can be seen that the water-feeding ecosystem has many filter-feeding animals, which makes the organisms easy to accumulate toxicity, which can be used as a typical example of nutrition models. (iii) From the perspective of ecosystems, water ecosystems are different from terrestrial ecosystems, and water ecosystems are studied. The model should not be applied to terrestrial ecosystems (2). However, due to the landfill of waste, industrial production, human life and the development of agricultural technology, microplastics, whether they are nascent microplastics or secondary microplastics, enter the terrestrial ecosystem and will have material circulation and energy flow to terrestrial ecosystems. Due to its adsorption characteristics, microplastics entering the soil can not only adsorb organic pollutants (35), but also serve as a heavy metal carrier to improve the bioavailability of heavy metals (36), accumulating in the soil food chain through food intake by soil animals (37-38). In addition, microplastics can change the physical properties of soil and accumulate a certain concentration in the soil, which has an impact on soil function and biodiversity (2).

CLASSIFICATION, SOURCE AND MIGRATION OF MICROPLASTICS

Microplastics can be divided into primary microplastics and secondary microplastics (4). Primary microplastics mainly refer to micro-sized plastic particles that are

made into micron-sized materials in production, used as raw materials for industrial manufacturing or cosmetic production, such as plastic microbeads added to personal care exfoliants (4). Secondary microplastics include: synthetic fibers discharged with laundry wastewater (11); large plastics used in agricultural production, industrial production, and urban construction, which are divided or degraded in the environment by environmental effects such as light, high temperature, and soil wear, or Through the action of soil animals, it becomes a secondary microplastic particle (2).

Terrestrial microplastics are mainly produced by human activities, mainly from point source pollution and non-point source pollution (25). Point source pollution includes sewage treatment and sewage sludge application, primary microplastics entering industrial wastewater and domestic sewage, and synthetic microfibers in laundry wastewater, which enter the soil ecosystem through sewage discharge, wastewater irrigation and sludge application (25, 39). In agriculture, wastewater-irrigated plants (WWTPs) are one of the main ways in which microplastics enter farmland ecosystems (26, 40, 41). In life, synthetic microfiber and tumble dryers produced during the laundry process are one of the sources of microplastics in farmland ecosystems (2, 11, 39). Non-point source pollution refers to agricultural film, landfill and garbage disposal. The widespread use of mulch in agriculture has become one of the sources of secondary plastic particles in farmland ecosystems (42-43). Particles and microfibers produced by landfills or other surface deposits can be airborne as a carrier through atmospheric deposition (2).

Land-feeding animals such as earthworms, after ingesting brittle plastic waste, are smashed in their stomach pouches, producing secondary microplastics (2, 44). Deep-dwelling earthworms living in vertical caves, after feeding on the surface of the soil, the plastic fragments of the surface layer enter the soil, are discharged with the excrement, or deposited on the wall of the cave, or feed on other soil animals, in the soil food network. Transmission can also be accumulated in the body (2, 37). Medium-sized soil animal communities such as cat-tails or mites may occasionally chew or chip to produce secondary plastic particles and transfer them to the interior of the soil (45), or excavated mammals such as squirrels or moles bring it into the soil (2). Migratory animals such as birds can also be used as carriers for long-distance transportation of microplastics, which

play a role in the migration and diffusion of microplastics.

SEPARATION AND DETECTION OF MICROPLASTICS

The accumulation of microplastics in the soil makes it a part of a complex organic matter mixture or a mineral substituent (46). Soil organic matter (SOM) can be stable in the environment for hundreds of years due to the interaction of organic minerals (47). Plant litter and some organisms remain in the soil. These substances and substances in different stages of bio-organism degradation constitute soil SOM. Therefore, soil SOM components are complex and diverse (47, 48). The complex and diverse soil SOM components and the chemical nature of the microplastics make it difficult to separate and identify soil microplastics. The method used to analyze microplastics in sediments of aquatic ecosystems may be applied to soil, but the content of refractory compounds such as lignin, cork and tannin in soil is high, and soil in some areas contains organisms. The black carbon produced by complete combustion makes it difficult to separate and detect microplastics in the soil (46).

Separation of Soil Microplastics

Screening - Sorting - Removal of Organic Matter and Other Soil Components - Extraction of Microplastics

The sieving is to use the sieve to pass the fine granules in the soil smaller than the sieve holes through the sieve surface, and the coarse granules larger than the sieve holes are left on the sieve surface to complete the separation process of the coarse and fine granule materials. Due to the different standards defined by countries for fines, there is the problem of removing some of the microplastics and larger particles during the microplastic screening process. According to the definition of different particle sizes of microplastics, the soil screening range is generally < 5 mm and < 1 mm (46).

After sieving, the mineral phase of the soil can be removed by density separation. Sodium polytungstate solution is usually used for the separation of different components of soil because it can not only separate free particulate organic matter (fPOM), but also sort different soil organic mineral complexes in SOM (49). How-

ever, this method has not been applied to the separation of microplastics. Since the separation of the organic mineral complex in SOM is related to the extent to which the microplastics remain in the soil agglomerates, the agglomerates can be first broken by ultrasonic treatment before the density separation method is used, and the soil is agglomerated for different particle sizes. Body, using different ultrasonic energy, for example, when dispersing soil aggregates larger than 250 μm , the ultrasonic energy value usually used is 60 J/ml (50)

Since organic matter with a density between 1.0 and 1.4 g/cm is similar in density to some plastic products such as PET, the density separation method is not sufficient to remove all organic matter (46). In order to ensure the reliability of micro-plastic identification and quantification, acid, alkali, oxidation or enzymatic treatment is required to remove residual organic matter, or electrostatic separation is used to remove organic debris (51). Avio et al (52) pretreated the sample with a concentration of 22.5 mol/L HNO_3 , and Dehaut et al. (53) compared six pretreatment methods: concentration 10% KOH, concentration 0.063 mol/L HCl, concentration 14.4 mol/L HNO_3 , concentration 14.4 mol/L HNO_3 and concentration 14.4 mol/L HClO_3 mixed at a volume ratio of 4:1, concentration 10 mol/L NaOH, the concentration of 0.27 mol/L $\text{K}_2\text{S}_2\text{O}_8$ and the concentration of 0.24 mol/L NaOH mixture, the results show that 10% KOH, 60 °C digestion for 24 h is the best. Cole et al (54) digested the samples with different concentrations of acid, alkali and enzyme, and compared the concentrations of 1, 2 mol/L and 10 mol/L NaOH, respectively, and the concentrations were 1, 2 mol/L HCl and proteinase K digestion, the results show that proteinase K removal rate of organic matter is greater than 97%, and does not decompose microplastics. Mintenig et al (55) pretreated the sample by enzyme digestion. After adding sodium lauryl sulfate, protease A-01 (1,800 U/L dissolved in pH 9 PBS) and lipase FE-01 were added in sequence. (2,320 U/L dissolved in pH 10.5 PBS) and cellulase TXL (44 U/L dissolved in pH 5 PBS). Nuelle et al (56) placed the samples in 30% H_2O_2 and 35% H_2O_2 solution for 7 d, and the results showed that the pretreatment effect of 35% H_2O_2 was better.

Pressurized Fluid Extraction

Fuller et al. (57) used pressurized fluid extraction (PFE) to separate plastics with a particle size of less than 30

µm from the soil. This method is suitable for separating different types of plastics, including PE, PVC, PP, etc. PFE technology separates semi-volatile organic compounds from solids under subcritical temperature and pressure conditions. In laboratories, this method is commonly used to separate organic contaminants from soils, sediments, and wastes (57).

The pressure extraction instrument is a large control system, which mainly includes: main control cabinet system, temperature control module, high pressure control module, cylinder control system, solvent ratio control module and so on. After the sample enters the extraction tank, the solvent from the high-performance liquid phase pump sends the solvent into the extraction tank through the solvent mixing valve. After the pressure of the extraction tank reaches the set value, the liquid phase pump is turned off, and after the set temperature is met, the static extraction starts. After the end of the static extraction, the solvent was purged with high pressure nitrogen to the collection bottle. The dried residue was passed through a Nicolet 6700 Smart Fourier Infrared Spectrometer equipped with a Smart iTR (Multifunctional Attenuated Total Reflection ATR Sampling Accessory) to determine the type of plastic.

DETECTION OF MICROPLASTICS

Fourier transformed infrared spectroscopy (FT-IR), Raman spectroscopy, and Pyr-GC-MS pyrolysis analysis can identify and quantify microplastics in the environment. In the detection of microplastics, pre-screening can be performed using microscopy techniques (51, 58), or surface morphology identification using SEM or ESEM-EDS (59-61). Microscopy may have an overestimation or underestimation of the number estimates, and sometimes microplastics cannot be identified due to technical limitations. SEM is widely used in many fields such as microbial surface morphology identification and material surface morphology analysis. It is characterized by high resolution but charge effect. ESEM-EDS is mainly used for the analysis of elemental composition and surface morphology of microplastics.

According to the size of the microplastics and the complexity of the sample components, Raman spectroscopy (62-63), Fourier infrared spectroscopy (55, 58, 64-65), TED-GC-MS (66-67) can be selected. Raman spectroscopy is generally used in combination with microscopy. It can be used to identify plastic products with

particle sizes >1 µm. Its spatial resolution is higher than FT-IR, which is suitable for a large number of studies, but this method is susceptible to autofluorescence of soil organic matter. Interference and the detection process take a long time. Fourier infrared spectroscopy is suitable for plastic products with particle size > 20 µm. Compared with Raman spectroscopy, FT-IR is not easily interfered by the autofluorescence of soil organic matter, but it is susceptible to organic matter interference and the detection process takes a long time. Pyr-GC-MS is used for the identification of single forms. Compared to Raman spectroscopy and FT-IR, this method has a small particle size limitation, but the pretreatment is time consuming. TGA-solid-phase extraction and TDS-GC-MS are collectively referred to as TED-GC-MS. This method can be used to identify polyethylene, polypropylene and polystyrene in complex soil matrices. Pretreatment does not take time, but it is currently only used in the quantification of polyethylene.

MICROPLASTIC CONTAMINATION

The physical and chemical properties of microplastics determine that they are far more harmful to ecosystems than large plastic waste. Water ecosystems include marine ecosystems, freshwater ecosystems and coastal wetland ecosystems. The effects of microplastics include: interference with marine material circulation; effects on marine animals and marine algae (3-4, 6, 8-9, 23). Many studies have identified terrestrial and freshwater environments as sources and transport pathways for microplastics in marine ecosystems, but since most plastic products are used in terrestrial ecosystems, terrestrial and adjacent freshwater environments are also facing severe microplastic contamination problems (25)

POLLUTION OF MICROPLASTICS THEMSELVES

The main sources of microplastic granules in farmland ecosystems include the widespread use of sewage sludge and mulch. In European farmland, there are more than 1,000 or even more than 4,000 micro-plastic granules per kilogram of sludge (dry mass), and 670 micro-plastic fibers per kilogram of soil (counts) in soils of 0 to 10 cm (68-69). In the solid waste enrichment area of Germany, the plastic content of the roadside soil is 39%, which are

43,454 t/a (70). Forty to sixty percent of the topsoil of Mexican vegetable fields is covered with plastic bags for land cover and flood prevention (38). It is estimated that micro-plastic granules entering the European farmland with sewage and sludge can reach 125-850 t per million inhabitants (sum of treated and untreated), and the total amount of microplastics entering farmland in Europe and North America can reach 63,000, respectively. 430,000 t/a and 44,000 to 300,000 t/a (2).

Farmland mulching is mainly used to increase temperature, resist pests and diseases, promote crop root development, and improve crop quality (71). After a growth cycle of the crop, the residual mulch is broken down into pieces during the process of loosening the soil before the new crop is planted, part of which remains on the surface of the soil and part of which is buried inside the soil. The part buried in the soil is less affected by light and temperature and is difficult to decompose, which may interfere with the root development of the crop and cause serious soil environmental problems (72). The part remaining on the surface of the soil is difficult to remove from the soil after being exposed to light, high temperature, etc. The high-density polymer remains in the soil and migrates vertically downwards, and is finally transported to the deep soil; the low-density polymer passes wind and water, Horizontal migration to other areas of the land or water surface (25). The chemical substances contained in plastic mulch and their changes are affected by many factors, such as temperature, oxygen content, acid/base conditions and the influence of soluble organic matter (73, 74).

Plastic products themselves contain harmful substances that, under certain conditions, are released into the soil. Harmful substances contained in microplastics such as bisphenol-A, phthalates (such as phthalic acid diesters), PBDEs, and heavy metals used for coloring (73, 75), which are based on UV radiation, temperature, Under the influence of oxygen content, soil acidity and alkalinity and soluble organic matter content, toxic substances loosely bound to high polymers are released into the environment (46), and enter the soil through leaching (42, 73, 74), on the soil. The effects of ecosystems, such as phthalic acid diesters contained in plastic products, are a carcinogenic, mutagenic, and endocrine disrupting substance (76) that, when released into the environment, inhibit soil microbial activity (77), It can also be threatened by human health through the absorption of plants into the food chain (78).

Phthalates (PAEs) are widely used in the production of plastic products, personal care products, food packaging and medical products (79-82). PAEs can enter the soil ecosystem through processes such as plastics production, use and plastic waste treatment (83). The use of farmland mulch and poultry manure is the main sources of soil phthalates (84).

ADSORPTION OF CONTAMINANTS BY MICROPLASTICS

Microplastics can absorb hydrophobic organic compounds (HOCs) such as organochlorine pesticides, PAHs, PCBs, PBDEs, and heavy metals (36, 75, 85). Due to the wide application of pesticides in farmland, oil exploitation and land transportation, and sewage discharge, these organic pollutants and heavy metals have many types and high concentrations in soil ecosystems, which have serious impacts on terrestrial ecosystems (86-92).). HOCs have a high octanol/water partition coefficient (K_{ow}) and are hydrophobic, while high molecular polymer-microplastics also have such characteristics, combined with large specific surface area, rough surface and bio-sludge formation. The two are easily adsorbed to each other and can be absorbed by organic matter and soil particles as part of the soil agglomerate (2, 25).

Adsorption includes physical adsorption and chemical adsorption: physical adsorption is the interaction between adsorbate and adsorbent under van der Waals force, mainly depending on the specific surface area; chemical adsorption, mainly because of organic pollution compared to water environment The hydrophobicity of the material is more similar to the hydrophobic surface of the microplastic (8, 93). The adsorption of microplastic particles is related to their own characteristics, such as material, specific surface area, amount of surface adsorption sites, and hydrophobicity. Plastic is a high molecular polymer, a long chain molecule composed of repeating structural monomers. For example, $(-CH_2-CH_2-)_n$ stands for polyethylene (PE), the value of n is different, the state of PE is different, and its properties are different. The van der Waals force of long-chain molecules is stronger, and the force between chains is stronger. Better performance, such as modulus, strength and fracture toughness (94). In addition, the source of microplastics and its age also have an effect on its adsorption. For example, terrestrial microplastic particles are affected by weathering and ultraviolet radiation, and

the surface is rough and the specific surface area is large, which makes them more micro-plastic easier to adsorb organic pollutants than the ocean (73, 95). Different environmental conditions, such as pH, salinity, metal cation concentration, etc., also affect the adsorption of microplastics.

The adsorption of organic pollutants by microplastic particles mainly includes surface adsorption and distribution determined by specific surface area and van der Waals force, and pore-filling of polymer structure. CB-17 is a trichloro PCB, which is a kind of PCBs homologue. Velzeboer et al. (96) studied nano-scale microplastic polystyrene PS (particle size 70 nm, surface carboxyl group functionalization) and micron-sized microplastic PE (particle size 10-180 μm) in simulated freshwater and seawater environments. The adsorption effect of CB-17 shows that the adsorption of microplastics is related to salinity. The adsorption of PCBs by PE and the adsorption of organic matter in sediments are similar, based on linear hydrophobic partitioning, while PS is based on PCBs. The adsorption is nonlinear and stronger than the adsorption of PE. This is because PS has higher aromaticity and specific surface area, and its adsorption mechanism is π - π bond interaction. Rochman et al. (97) studied the adsorption of PA and other five high molecular polymers (PET, HDPE, PVC, LDPE, PP) on PAHs. The results showed that the adsorption of PS to PAHs was greater than that in the first month. The non-expanded PS is in a glassy state, and its basic structural unit contains a benzene ring. The chemical formula of PE is $(-\text{CH}_2-\text{CH}_2-)_n$, that is, the position of the benzene ring in the PS is substituted with -H. The benzene ring hinders the movement of the segments, but increases the distance between adjacent polymer chains, making the chemical substances more easily diffused into the polymer (98), so although the segmental mobility of PE is stronger, the two The adsorption amount of PAHs is similar. In addition, due to the π - π bond and strong hydrophobicity, PS foam is commonly used in SPE, and aromatic substances such as PAHs in the environment are easily adsorbed with PS (97).

Ashton et al. (99) studied PE (particle size 4 mm) for major metal elements (Al, Fe, Mn) and trace metals (Cu, Zn, Pb, Ag, Cd, Co, Cr, Mo, Sb, The adsorption mechanism of Sn and U) may be: direct adsorption of metal cations, metal ions interact with the charged or neutral regions of the plastic surface, and adsorb or coprecipitate with iron and manganese oxides. Kim et al

(100) studied the adsorption of Ni and the toxic effects on two kinds of polystyrene microplastic particles with no functional group (PS) and carboxyl functional groups (PS-COOH). The results show that the toxic effect of Ni in the coexistence of Ni and PS is lower than that in the presence of Ni, indicating that PS has a certain antagonistic effect on the toxicity of Ni; the toxicity of Ni in the coexistence of Ni and PS-COOH The effect is higher than the toxic effect only in the presence of Ni, indicating that PS-COOH has a certain synergistic effect on the toxicity of Ni. The difference in the adsorption amount of PS between PS and PS-COOH is not significant, which may be determined by the hydrophobic properties of Ni, rather than the adsorption characteristics. Therefore, the interaction between microplastics and contaminants and the nature of the contaminants and the surface functional groups of microplastics related. Hodson et al. (101) studied the adsorption of Zn^{2+} by cultivated soil, forest soil and microplastic high-density polyethylene (HDPE). The results showed that the adsorption accords with the Langmuir and Freundlich equations. Because the forest soil contains more organic matter, its adsorption value is the largest. In the earthworm body, the Zn^{2+} supported by the microplastic particles is more easily desorbed, indicating that the microplastic particles can improve the bioavailability of Zn^{2+} . The particle size, specific surface area and surface characteristics affect the adsorption of microplastic particles and metal ions. Holmes et al (102-103) have shown that the adsorption of metal by microplastic particles conforms to the Langmuir and Freundlich equations, and the adsorption of metal elements by unaged and aged plastics can quickly reach equilibrium. The interaction between divalent metal ions and oxygen ions, the wear of plastic surfaces, the presence of charged contaminants and adsorbed substances all have an effect on their adsorption effects. Adsorption can also be produced by non-specific binding of the neutral metal-organic complex to the hydrophobic character of the plastic surface. The age of plastics also has an effect on its adsorption. Under the natural conditions, the aged aging micro-plastic particles are more likely to adsorb metal. The aged plastics can produce oxygen on the surface due to changes in their structure, such as photooxidation and weathering. The group thereby increased the polarity of the polymer, as well as the deposition of surface biofilms and chemicals. For example, the accumulation of hydrogen deposits can increase the

surface charge, surface roughness, porosity and hydrophilicity.

Microplastic surfaces may form biofilms (104) that can act as carriers of potential pathogens or alien species, posing a threat to soil organisms and the environment. In addition, the availability of nutrients also affects the adsorption of microplastics. Foulon et al. (105) studied the colonization ability of *Vibrio sp. V. crassostreae*, J2-9 strains in different media (Zobell medium and artificial seawater) with or without natural marine aggregates. The study found that Zobell culture in the base, the percentage of particulate matter colonized by J2-9 strain is the highest, and the availability of nutrients plays an important role in colonization. The more nutrients that can be used for flagella and extracellular polysaccharide production, the more favorable the colonization of bacteria. .

ECOLOGICAL EFFECTS OF MICROPLASTICS

Impact on Soil Animals

There are few studies on the effects of microplastics on soil animals (25). The soil animals currently used for research include earthworm (25, 37-38, 106, 107), nematodes (108) and tailworm (45). When studying the effects of microplastics on soil animals, they can be used to study the effects of aquatic ecosystems on animals. Soil animals derived from aquatic ecosystems, such as filter-feeding animals, live in thin water film on the surface of the soil. Animals such as annelids, mollusks, arthropods and nematodes exist in both freshwater and marine ecosystems. In the soil, soil animals that belong to the same category in different ecosystems have similar feeding habits (25), so the effects of microplastics on marine life can be partially applied to soil animals (2).

Microplastics affect the individual growth, reproduction and diversity of animals. When microplastics enter the animal body, it can cause physical tears of organs and tissues. The body also produces an inflammatory response to the invading heterogeneous substances. Because the microplastics ingested replace the food, it also causes the nutrients and energy supply of the organism. Insufficient, the toxic effects of toxic substances and adsorbed pollutants released by microplastics will have different effects on individuals and species diversity (109, 110). The effect of microplastics on animals is

related to many factors such as particle size, concentration, and physiological characteristics of animals.

At present, there are few studies on the influence of particle size of microplastics on soil animals, but the influence of particle size on marine organisms of different types has been widely confirmed (111-113). The ratio of particle size to the size of the animal's mouth affects the feeding of microplastics by animals (25). Microplastic particles with a particle size of less than 1 mm are easily ingested by soil animals. After being ingested into microplastics, soil animals can be excreted into the surrounding environment or left in the body (2). Studies have shown that microplastics are not only more likely to remain in the intestine than other ingested substances, but can also pass through the intestinal wall and be transported to other tissues of the organism (114-115). The accumulation, transfer and toxic effects of microplastics in tissues and organs of animals are also related to particle size. Microplastic particles with a particle size >1 mm remain in the intestine or are excreted with excretion, while small particles are more likely to metastasize, accumulate, and phagocytose by cells, which may be related to the spatial finiteness of intracellular phagosomes (116). HDPE with a particle size of 0-80 μm causes a strong inflammatory response of the blue mussel (*Mytilus edulis*) (109), and nano-scale PS (particle size 30 nm) reduces the biological filtration activity (117), PS monomer will Causes DNA damage in mussel cells (118). Lee et al. (112) studied the toxic effects of three PSs with particle sizes of 0.05, 0.5 μm and 6 μm on the Brachiopod (*T. japonicus*) at different concentrations. The results showed that the particle size was 0.5 μm and The 6 μm PS showed a significant decrease in egg production at all concentrations, indicating that micron and nanoscale microplastic particles have a negative effect on marine copepods.

The effect of microplastics on living things is also related to their concentration. It is widely distributed and sensitive to soil pollution stress. It is often used as an indicator of soil quality and as one of the recommended species in the international standard of ecotoxicology. Huerta Lwanga et al (37-38) studied the growth rate and abundance of different concentrations of microplastics (polyethylene, < 150 μm) on *Lumbricus terrestris L.*, the highest mortality rate when the concentration of polyethylene reached 60%. The growth rate showed a negative value. Compared with the control and low concentration, high concentration polyethylene (28% and 45%) adversely affected its mortality

and growth rate. Cao et al. (44) studied the effects of different concentrations of microplastics (PS, 58 μm) on *E. foetida* and found that low concentrations of microplastics (< 0.5% (m/m)) had little effect on abundance. High concentrations (1% and 2%) significantly inhibited their growth and increased their mortality. Rodriguez-Seijo et al. (106) studied the toxic effects of different concentrations of microplastic particles on terrestrial earthworms (*E. Andrei*). The microplastics used PE particles with a particle size range of 250-1000 μm , and the average number of particles per 100 mg of microplastics was (396 \pm 52) (STDEV), although the effects of different concentrations of microplastic particles on the survival and quantity of *E. Andrei* and its quality after 28 days of experimental period were not significant, but the results of intestinal pathology showed that in microplastics When the concentration is > 125 mg/kg, it will cause obvious tissue damage. Different concentrations of micro-plastic particles will also stimulate different degrees of immune response.

The effects of microplastics on animals are also related to the physiological and behavioral characteristics of the animals themselves. This effect has been widely demonstrated in marine microplastics research (3, 20). Marine organisms that ingest microplastics are distributed at a wide range of trophic levels and have different feeding strategies, including crumbs, filter feeders, and predators (25). Filter feeders are prone to accumulate toxicity and serve as a model for nutritional models in aquatic ecosystems. Microplastics accumulate in low-nutrient organisms (4, 114-115), directly affecting key animal species in the soil and affecting the food web. Small and medium-sized fauna soil animals, such as the ammunition, aphids or earthworm, eat microplastics and accumulate them in the soil detritus food network (2). The earthworm connects the soil circle with the atmosphere, and communicates the relationship between the soil organism and the above-ground organisms. The moles, badgers, birds and other feeding earthworm allow the microplastics accumulated in the earthworm to pass between different species through the food chain. Affect other soil animals (115, 119, 120). Nematodes feed on microorganisms in their natural state and feed on *E. coli* under laboratory conditions. Kiyama et al (108) showed that in the absence of food, 0.5 μm and 1 μm PS particles are more likely to accumulate in the nematode (*Caenorhabditis elegans*), when the ratio of bacteria to nematodes is 1:100 or 1:10, The accumulation of PS particles with a particle size of 0.5 μm

was significantly reduced, which may be related to the feeding strategy of nematodes.

Microplastics have an adsorption effect on heavy metals, organic pollutants and pathogenic bacteria in soil solution and its surrounding soil environment. After the animals ingest the microplastics as the carrier of the pollutants, the toxic effects of the pollutants will have an impact on the animal's physiology, which in turn may pose a threat to the soil ecosystem through the accumulation of food chains/nets. The retention time of microplastics also has a certain effect on its toxicity. The longer it remains, the more significant its toxicity. As the retention time increases, the microplastics are affected by the climate (such as weathering, light, etc.), and the surface properties will change, so that the adsorption of pollutants will be enhanced, thereby increasing the toxicity. The role of environmental factors in microplastics also involves leaching its own toxic substances into the soil (104, 121), leaching into the soil's toxic pollutants, which will have a direct impact on soil animals.

Effects on Soil Microbes

Microplastics are brought into the soil by soil animals. Heavy metals, pollutants and pathogens adsorbed on the surface of the soil are also involved in the soil, which will have different effects on soil micro-flora, soil physical and chemical properties and even plant growth. Currently, there are no reports on the role of soil microplastics and microbes, and there are only a few reports on the role of marine microplastics and coastal seabed sediments and microbes (5, 106, 122). Foulon et al. (105) found *V. crassostreae*, a strain of J2-9 that can colonize particulate matter. *V. crassostreae*, J2-9 strain is an oyster pathogen (123). The marine fungus *Zalerion maritimum* can use PE under low nutrient conditions to degrade PE and reduce the quality and particle size of PE (5). Harrison et al. (122) found that in coastal sediments, *Arcobacter* and *Colwellia* can be rapidly colonized on LDPE (Low-density polyethylene), which are associated with the degradation of petroleum hydrocarbon contaminants in low temperature seawater environments.

Impact on Soil Material Cycling

At present, there are few studies on microplastics on soil material circulation. Therefore, they have to be solved for the promotion or inhibition of soil material circulation and its mechanism of action. Because microplastics are difficult to degrade, they can remain in the soil for a long time. Once accumulated to a certain concentration, they will have an impact on soil and even terrestrial ecosystem functions and biodiversity (2).

Microplastics can directly affect the physical and chemical properties of the soil and the circulation of matter (124). Liu et al (124) studied two concentrations of microplastics (polypropylene, < 180 μm) on soil soluble organic carbon (DOC), soluble organic nitrogen (DON), soluble organic phosphorus (DOP) and PO_4^{3-} concentration and FDA hydrolase. The effect of phenol oxidase activity on the 30th day of the addition of microplastic particles, low concentration of microplastics to organic carbon, inorganic nitrogen, total phosphorus, high molecular weight humic substances and fulvic acid in soluble organic matter (DOM). The effect is small, and high concentration of microplastics significantly increases DOC, DON, DOP, PO_4^{3-} , NO_3^- , high molecular weight humic substances and fulvic acid in DOM (124). Microplastics can absorb harmful substances in soil solutions and change soil physical properties, such as increasing porosity, changing aggregate structure or becoming part of soil aggregates (2, 37-38), and these changes can change microbial activity (125, 126). As a representative of microbial activity and nutrient availability, enzyme activity plays an important role in soil material circulation. The enhancement of microbial activity increases the secretion of extracellular enzymes and releases nutrients such as soil C, N and P. Promote the role of nutrients in plant-soil migration (124, 127).

Soil animals play an extremely important role in the material cycle of soil ecosystems (69). Microplastics may also affect soil material cycling through the effects on soil species diversity. In the process of ingestion and discharge of microplastics by soil animals, the microplastics that enter the soil with excreta can be ingested by other organisms or degraded (5, 42, 128), thus affecting the primary and secondary soils, grade productivity, organic matter degradation, and nutrient cycling (38).

Earthworms play an important role in soil formation, soil structure and fertility maintenance. Huerta Lwanga et al (37-38) used in the study *Lumbricus terrestris* L. belongs to a kind of deep-dwelling carp, with a cave depth of 1 m and a diameter of 3-10 mm

(129). *L. terrestris* feeds on the soil surface, and the ingested microplastics are deposited on the walls of the caves through the digestive tract (130, 131). During the ingestion-discharge process of the microplastics, the microplastics enter the soil. The large number of amphibian species present in the soil is seen as a potential medium for microplastic transport (132). Arthropods reached their maximum density at 10 cm in the soil surface. Although the range of activity was relatively small (133), they played an important role in transporting microplastics on the soil surface into the soil (45). Microplastic particles entering the soil pose a threat to more soil animals (134), indirectly affecting soil material degradation and nutrient cycling by affecting soil species diversity. These microplastic particles may also affect the soil structure. If incorporated into the soil agglomerate structure, the bioavailability of the adsorbed organic and inorganic pollutants will be affected (2), which will affect the soil structure and material cycle.

After the pollutants adsorbed on the microplastics and the toxic substances produced by the microplastics enter the animal, the toxic effects affect the physiological and biochemical, growth and reproduction of the animals, thereby affecting the diversity of the soil species, thereby affecting plant growth and soil material circulation. Athmann et al. (135) showed that *L. terrestris* can improve the bio-pores of subsoil occupied by plant roots, increase microbial biomass and enzyme activity, increase the input of C and nutrients, and provide plants with more available nutrients such as P, thereby promoting plant growth and soil material circulation. Once the growth and quantity of soil animals that play an important role in the material cycle are affected, the material circulation and energy flow between the soil and the aboveground plants will be affected, which will affect the whole ecosystem.

PERSPECTIVES

Due to the landfill, industrial production, human life and agricultural technology development of microplastics, whether it is a primary micro-plastic or a secondary micro-plastic into the terrestrial ecosystem, the material circulation and energy flow of the terrestrial ecosystem will be generated. However, there are few studies on the effects of microplastics on soil ecosystems. The types of microplastics are complex and the composition is complex. The influence of soil physical and chemical properties, soil animals and soil material ener-

gy turnover is restricted by many environmental factors. In the future research, the following aspects need to be solved:

The soil structure is complex, the micro-plastic particles in the soil are widely sourced and some large plastics, such as the mulch film, are decomposed into small plastics after being exposed to light and high temperature, which is difficult to separate and poses a serious threat to the soil ecosystem. Therefore, the separation and detection of soil microplastics is an urgent problem to be solved. The separation and identification of microplastic particles in soil can be attempted by means of existing separation and detection methods for beach, sediment and sediment micro-plastic particles.

The environmental effects of micro-plastic particles of different sources and different types are different. The changes of micro-plastic particles to the soil mainly include changes in soil porosity and adsorption. Some large plastics, such as mulch films, will release toxic substances after being degraded by the environment, posing a threat to the soil ecosystem. Therefore, in studying the environmental effects of microplastics, it is necessary to separately consider the environmental effects of microplastic particles from different sources. In addition, different types of micro-plastic granules have different adsorption characteristics for different pollutants due to their different basic structures. Therefore, different types of microplastics of different uses can be used in the experiment to study their environmental effects.

The environmental effects of micro-plastic particles of different particle sizes are different. Since the toxic effects of micro-plastic particles of different particle sizes on soil organisms are not clear, toxicity tests are needed, such as biomarking to determine the toxicity mechanism of microplastics in soil. Whether the primary microplastic particles or secondary microplastic particles enter the environment, they will continue to decompose into smaller particles. These small particles interact with the chemical surface and have a large surface area and are likely to be ingested. Therefore, the health of living organisms poses a great threat. At pre-

sent, the environmental behavior of nanoparticles has been deeply studied. Because of the similarities of nanoparticles, the existing detection methods and risk assessments are applied to the study of nano-microplastic particles, which helps to fully understand their environmental behavior. .

Terrestrial microplastics have a wide range of sources, large production volume, difficult to regulate and difficult to estimate their concentration. At present, some studies have established models for the circulation cycle of plastics in the water life cycle of waters, and some studies have conducted quantitative research on the discharge of microplastics in waters through the life cycle assessment of products. However, there is no research on the retention model of microplastics in the terrestrial region. The environmental impact assessment of plastic products can be carried out by means of the LCA system.

The pollution effect of microplastic particles is also related to many other factors, such as soil structure and composition, climate and environmental factors. Different climatic conditions (such as ultraviolet radiation, temperature, etc.) and environmental conditions (such as different types of soil) have different effects on the surface properties of microplastics, which have different effects on their pollution effects. Therefore, when studying the pollution effects, the impact of different environmental conditions on its pollution effects needs to be considered.

The pollution effects of microplastic particles on soil ecosystem mainly include the following aspects: it may increase soil porosity, adsorb pollutants in soil solution, promote enzyme activity, affect material turnover, and adsorb pathogenic bacteria on microplastic surface. Contaminants may also adversely affect soil animals and microbial communities. At present, microplastics have little research on soil effects. In the future, the pollution effects of micro-plastic particles can be studied from the effects of microplastics on main plants, the effects on microbial and material circulation, and the combined pollution effects of microplastics. ■

ARTICLE INFORMATION

Author Affiliations: Group of Ecosystem, Division of Biology and Chemistry (Leed), Group of Environment Protection, Division of Energy and Resources (Smithson), The BASE, Chapel Hill, NC 27510, USA

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