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MICROPLASTICS IN SOIL ECOSYSTEMS: IMPACTS ON MICROBIAL COMMUNITIES, NUTRIENT CYCLING, AND AGRONOMIC SUSTAINABILITY

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INTRODUCTION

- Plastic has permeated every aspect of our lives in a matter of decades (packaging, synthetic textile fibers, throwaway plastic items, components, and structural portions of cars), and in recent years, its production has grown exponentially faster than that of any other material (Amobonye et al., 2021). The benefits of plastic in daily life, including its strength, durability, practicality, adaptability, and affordability, are widely acknowledged (Geyer et al., 2017). Global plastic output since the 1950s reached 400.3 million tons in 2022, up almost 1.6% from the year before. Approximately 12,000 megatons of plastic will be scattered throughout the ecosystem by 2050, mostly on agricultural soil and in the oceans. One of the top ten environmental issues that need to be resolved is marine pollution caused by plastic trash, according to the first United Nations Environment Assembly in 2014. Only 9% of plastic is recycled; the remainder is burned, buried, or dumped into the environment (Bremer , 2022).

Plastic residues are building up in the environment, where they can linger for extended periods of time and break down into tiny plastic particles, because of their poor recovery and strong resistance to destruction (Wright and Kelly, 2017). "White pollution" is the term for this phenomenon (Chen et al., 2022). Microscopic plastic trash is now present everywhere, from crowded beaches to isolated Arctic ice, from aquatic ecosystems to land. The term "microplastic" (MP).

Today, microplastics (MPs), defined as plastic particles smaller than 5 mm, have emerged as one of the most pressing environmental pollutants of the 21st century. While initial research focused on aquatic ecosystems, recent studies highlight that soils are equally, if not more, significant reservoirs of microplastic contamination (Garbounis et al., 2026).

MICROPLASTIC–MICROBE INTERACTIONS AND THE PLASTISPHERE

Soil is a dynamic habitat for microorganisms, and MPs provide novel surfaces for colonization. Microorganisms attach to MPs via extracellular polymeric substances (EPS), forming biofilms that protect against UV radiation and toxic compounds (Aralappanavar et al., 2024). These biofilms facilitate metabolite exchange and genetic transfer, leading to selective enrichment of specific microbial taxa.

MPs also increase the proportion of pathogenic bacteria and antibiotic-resistance genes (ARGs), raising concerns about soil health and biosecurity.

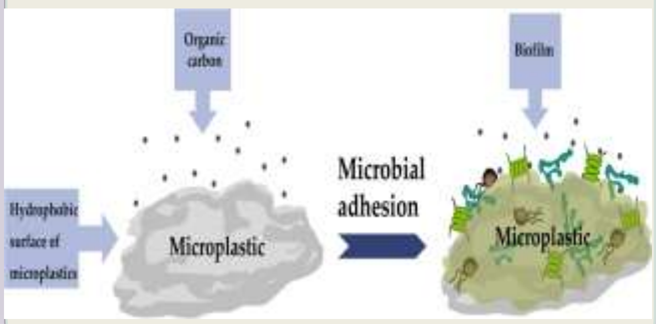

Figure 2. Development of biofilms on MP surfaces and microbial colonization (from Qin et al., 2024).

ORIGINS AND PATHWAYS OF MICROPLASTICS IN SOIL

Microplastics (MPs), defined as synthetic polymer particles smaller than 5 mm, are now recognized as pervasive contaminants in terrestrial ecosystems. Their origin can be traced to primary MPs**,** intentionally manufactured for industrial and commercial purposes (e.g., cosmetic microbeads, industrial abrasives, textile fibers), and secondary MPs**,** which are formed through fragmentation of larger plastic debris under the influence of ultraviolet radiation, mechanical abrasion, and microbial degradation (Omidoyin & Jho, 2023).

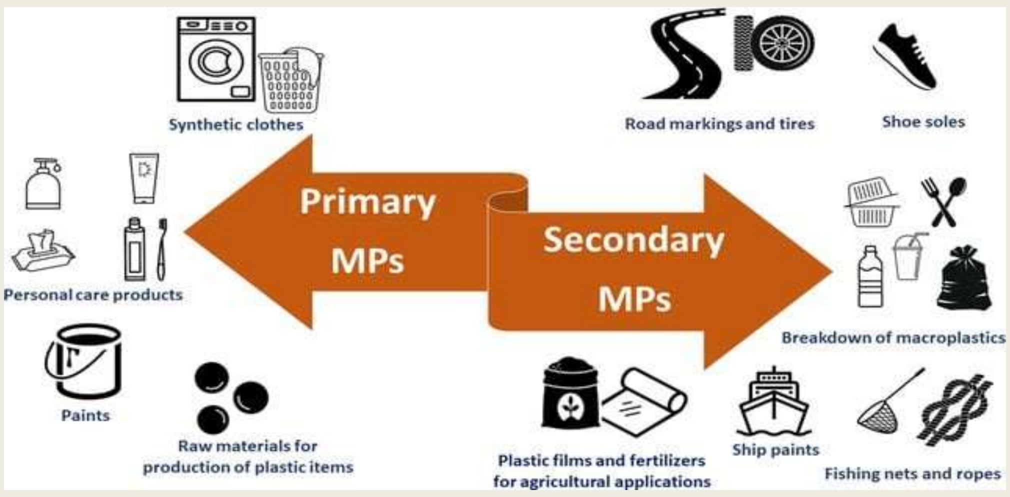

Figure 1. Sources of primary and secondary MPs.

TYPES AND MORPHOLOGY OF MICROPLASTICS IN SOIL

The most common polymers detected in soils are **polyethylene (PE)** and **polypropylene (PP),** associated with agricultural films and packaging, while **polystyrene (PS)** and **polyvinyl chloride (PVC)** dominate in urban and industrial soils (Omidoyin & Jho, 2023). Morphologically, MPs occur as fragments, fibers, films, and pellets. Their distribution within soil horizons depends on particle size: larger fragments tend to remain in surface layers, whereas smaller MPs penetrate deeper, increasing their bioavailability and potential for microbial interaction (Aralappanavar et al., 2024).

Source	Type of Plastic	Concentration Range	Remarks	References
Plastic Mulching	PE	500–2000 particles/kg	Major contributor	Steinmetz et al. 2016
Sewage Sludge	PE, PP, PET	1000–24000 particles/kg	High contamination	Nizzetto et al. 2016; Corradini et al. 2019
Compost	PE, PP	200–900 particles/kg	Secondary source	Weithmann et al. 2018
Irrigation Water	Mixed	10–10000 particles/m^3	Diffuse input	Li et al. 2018;
Atmospheric Deposition	Fibers	50–700 particles/m^2/day	Continuous input	Dris et al. 2016; Allen et al. 2019

Table 1. Sources of MPs in Agricultural Soils.

EFFECTS ON BENEFICIAL SOIL MICROORGANISMS

Soil microorganisms are essential for nutrient cycling, organic matter decomposition, and plant health. MPs disrupt these processes in several ways:

Figure 3. Effects of microplastics on key soil microbial functional groups. Microplastics (MPs) alter microbial processes essential for soil fertility and plant health. At low concentrations, MPs may increase the abundance of nitrogen-fixing and phosphate-solubilizing bacteria, while higher levels reduce nitrifier activity and interfere with arbuscular mycorrhizal fungi (AMF) colonization, ultimately impairing nutrient cycling and plant growth.

CONCLUSION

Microplastics represent an emerging and complex threat to soil ecosystems. Their persistence and widespread distribution compromise soil structure, alter microbial diversity, and disrupt biogeochemical cycles essential for ecosystem resilience and agricultural productivity. Evidence consistently shows that MPs impair beneficial microbial functions, reduce plant–microbe symbioses, and increase pollutant bioavailability, thereby undermining soil fertility and food security.