Review paper **IL 3**

A ONE HEALTH PERSPECTIVE ON MICROPLASTICS AND NITRO-PAHS CONTAMINATION ACROSS THE SOIL–PLANT–FOOD CONTINUUM: IMPLICATIONS FOR SOIL HEALTH, CROP QUALITY, FOOD SAFETY, AND HUMAN HEALTH

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ABSTRACT

In the era of the "Plasticene" the extensive production, use, and disposal of plastic materials have emerged as major environmental challenges, particularly because of the progressive fragmentation of discarded plastics into microplastics (MPs). MPs are generally described as plastic particles whose sizes ranging from 0.1- 5 mm and are formed by the breakdown of larger plastic materials through abiotic and biotic processes, such as ultraviolet radiation, temperature variations, mechanical abrasion, and microbial activity and enzyme degradation. As a result, the ubiquitous presence and increasing accumulation of MPs in soils-particularly agricultural soils-has emerged as a major global environmental problem. The annual input of MPs into agricultural soils in the United States has been estimated to be over 70 kilotons, highlighting the significant scale of plastic buildup in terrestrial ecosystems. Similarly, approximately 110-730 kilotons of MPs are added annually to agricultural soils across Europe and North America. Elevated MP concentrations have also been reported in several Asian countries, including Japan, South Korea, and China, further demonstrating the global concern of this emerging contaminant. Due to their small size, high surface-area-to-volume ratio, and hydrophobic surface properties, MPs can interact with and transport a wide range of contaminants, including phthalates, heavy metals, persistent organic pollutants (POPs), microorganisms, antibiotic-resistance genes, and pharmaceuticals. Such contaminant-carrying behavior is often described by the "Trojan Horse" mechanism, whereby MPs can facilitate the transport and potential redistribution of associated contaminants within environmental compartments. Among these co-contaminants, nitro-polycyclic aromatic hydrocarbons (nitro-PAHs) are an important and potentially harmful group of organic pollutants. Nitro-PAHs are PAH derivatives formed due to the nitration

of PAHs, either during combustion or via atmospheric and environmental transformation reactions. They are formed mainly from combustion-related sources, including burning fossil fuels, coal, petroleum-derived materials, and other carbonaceous substances. Their environmental importance arises from their persistence, toxicity, and capacity to generate reactive intermediates and oxidative stress, which may contribute to adverse biological effects. The co-occurrence of MPs and nitro-PAHs in agricultural environments may create complex contaminant interactions and severe effects. Because of their hydrophobic surfaces, MPs may adsorb nitro-PAHs and act as mobile carriers or environmental reservoirs, influencing their transport, persistence, partitioning, and bioavailability. In contrast, environmental aging and surface modification of MPs can alter their adsorption ability and interactions with soil elements. As a result, the presence of MPs can change the environmental fate and bioavailability of nitro-PAHs, potentially influencing how they interact with soil microbes, plant roots, and crops. MPs can alter soil structure, porosity, water-holding capacity, nutrient availability, and microbial community composition, whereas nitro-PAHs can provide extra toxicological stress to soil microorganisms. As a result, co-exposure may impair microbial activities and biochemical processes that are critical for maintaining soil fertility and resilience. Changes in microbial community structure and activity can subsequently influence the degradation and transformation of both contaminants, creating a dynamic feedback relationship between pollutant exposure and soil biological functioning.

The consequences of these changes extend beyond soil and directly affect plant health and crop quality. Plant roots are continuously exposed to contaminated soil and interact with MPs and nitro-PAHs via adsorption, absorption, and rhizosphere-mediated mechanisms. MPs and associated nitro-PAHs may have an impact on root development, nutrient absorption, photosynthesis, cellular redox equilibrium, and overall plant growth. Exposure can stimulate the development of reactive oxygen species (ROS), leading to oxidative stress and the activation of antioxidant defense systems. Furthermore, interactions between MPs and nitro-PAHs may modify contaminant bioavailability and influence their accumulation and mobility throughout plants. This raises particular concern when contaminants reach edible tissues. Ultimately, the soil-root interface can affect crop quality, productivity, and nutritional safety. Furthermore, the accumulation of MPs and nitro-PAHs in edible parts of plants presents a possible pathway for dietary exposure in people and animals, hence connecting environmental pollution and food safety. Following exposure, these pollutants may interact with biological tissues, accumulating or remaining in adipose tissue. Growing data suggest that exposure to MPs and nitro-PAHs can cause serious health consequences, including oxidative stress, inflammation, endocrine disruption, reproductive toxicity, gut microbiota dysbiosis, DNA damage, genotoxicity, and neurotoxicity. These effects may arise through complex interactions involving cellular oxidative imbalance, inflammatory signaling,

mitochondrial dysfunction, and disruption of normal metabolic and physiological processes.

These possible consequences highlight the need to assess MPs and nitro-PAHs contamination from both an environmental standpoint and an integrated food-safety and One Health framework. Addressing this emerging challenge requires the development of integrated, sustainable, and evidence-based mitigation strategies that can simultaneously reduce contaminant burden and restore ecosystem health. In addition to improving soil biological functioning and encouraging plant growth, biological interventions-particularly microbial bioremediation and phytoremediation approaches offer sustainable and eco-friendly ways to lower the bioavailability and remediation of MPs and nitro-PAHs. Similarly, biochar, nanomaterials, and other cutting-edge soil amendments also enhance the immobilization of contaminants, alter their bioavailability, and aid in the restoration of deteriorated soil qualities. Future studies should integrate advanced omics tools-such as metagenomics, transcriptomics, proteomics, and metabolomics with phytoremediation and microbial bioremediation approaches in order to improve these strategies' efficacy and mechanistic understanding. Together, these methods can deliver a broad view of shifts in microbial community composition, functional genes, gene expression patterns, protein responses, and metabolic pathways linked to contaminant degradation and plant-microbe interactions. Furthermore, coupling multi-omics datasets with artificial intelligence (AI) and machine-learning methods may help identify the key microbial taxa, metabolic pathways, biomarkers, and environmental drivers that control contaminant transformation and removal. Technology-enabled remediation frameworks could support the design of more targeted, efficient, and predictive strategies to mitigate the adverse effects of MP and nitro-PAH contamination. These technical measures should be reinforced by public education, responsible plastic management, sustainable agricultural practices, and effective environmental policies that reduce contaminant inputs at their source. However, the success of these mitigation strategies should not be assessed solely on the basis of reductions in total contaminant concentrations. A comprehensive evaluation should also consider changes in contaminant bioavailability, soil microbial diversity and functionality, plant uptake and translocation, crop quality, residual toxicity, ecosystem recovery, and potential transfer of contaminants into the food chain. Such a holistic assessment will be essential for ensuring that remediation strategies are not only effective in reducing contamination but also contribute to long-term soil health, food safety, environmental sustainability, and human health within a One Health framework.

REFERENCES

X. Kong, J. Zhang, Q. Ji, C. Li, X. Chen, X. Cao, F. Zhu, S. Yang, S. Li and H. He, *Chemosphere*, 2023, 320, 138050.

C. He, X. Cao, Z. Tu, Y. Lyu, K. Tang, J. Lin, H. Su, S. Hu, X. Zhang, Z. Liu and Z. Zhou, *Environ. Chem. Ecotoxicol.*, 2026, 8, 497–510.

Z. Shafi, I. Bose, S. Husain, S. Sharma and R. Singh, *Food Biosci.*, 2026, 81, 109113.

M. Rasta, N. S. Lashkaryan, X. Shi, M. S. Taleshi, A. H. Vayghan, A. Ahmadi, M. A. Kakakhel, J. Manke, L. Liu and Y. Wu, *Food Chem.*, 2026, 509, 148610.

Y.H. Lai, T.Y. Song, Y.H. S. Wu, C.C. Liao, J.-T. Lin and D.-J. Yang, *Food Res. Int.*, 2026, 232, 118877.

W. Zhu, Y. Chen, X. Hong, Y. Chen, W. Chen, Z. Ouyang, S. Gui and R. Fan, *Toxicol. Environ. Health Sci.*, 2026, 18, 303–318.