European Science Review 2026, No 5–6
ISSN 2310-5577

PREMIER Publishing
ppublishing.org

Section 1. Agriculture

DOI:10.29013/ESR-26-5.6-3-10

THE IMPACT OF MICROPLASTICS ON SOIL DEGRADATION: MECHANISMS, INTERACTIONS, AND IMPLICATIONS FOR ECOSYSTEM HEALTH

Caleb Ojomichegbe, Agbanwu [1]

[1] Undergraduate Student, Federal University of Technology, Minna, Nigeria

Cite: *Caleb Ojomichegbe, Agbanwu. (2026). The Impact of Microplastics on Soil Degradation: Mechanisms, Interactions, and Implications for Ecosystem Health. European Science Review 2026, No 5–6.* https://doi.org/10.29013/ESR-26-5.6-3-10

Abstract

Microplastics (MPs) have emerged as pervasive pollutants in terrestrial ecosystems, with growing evidence indicating their potential to alter soil structure, nutrient cycling, and microbial activity. This paper synthesizes findings from recent studies to explore the multifaceted effects of microplastics on soil degradation. Key mechanisms include physical disruption of soil aggregates, chemical leaching of additives, and alterations in microbial community composition. Interactions with environmental stressors such as drought further modulate these effects. The review highlights polymer-specific and dose-dependent responses, underscoring the need for integrated risk assessments and mitigation strategies to preserve soil health and ecosystem functionality.

Keywords: *Microplastics; soil degradation; nutrient cycling; microbial activity; soil aggregation; drought; polymer type; ecosystem multifunctionality*

1. Introduction

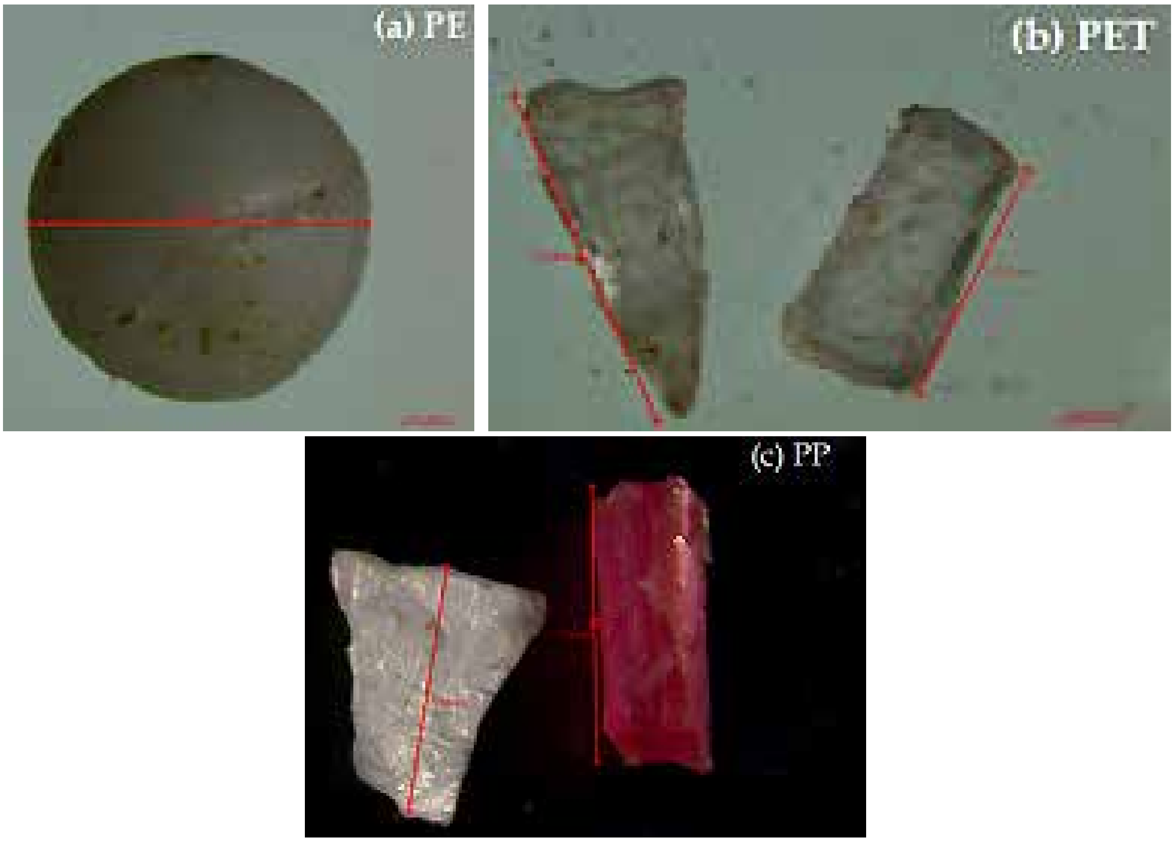
Microplastics – plastic particles less than 5 mm in size – are increasingly recognized as a significant pollutant in terrestrial environments. Introduced through agricultural practices, sewage sludge application, irrigation, and atmospheric deposition, MPs accumulate in soils and interact with biogeochemical processes (Rillig, M.C., 2012). While extensive research has focused on marine systems, the impact of MPs on soil degradation remains less understood (Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E., & Svendsen, C., 2017). Soil degradation encompasses declines in physical structure, chemical fertility, and biological activity, all of which can be exacerbated by MP contamination (de Souza Machado, A.A., Kloas, W., Zarfl, C., Hempel, S., & Rillig, M. C., 2018). This paper reviews current knowledge on how MPs influence soil degradation, drawing on experimental and observational studies to elucidate underlying mechanisms and ecological consequences.

2. Mechanisms of Microplastic-Induced Soil Degradation

2.1 Physical Alteration of Soil Structure

MPs can disrupt soil aggregation – a key indicator of soil health. Fibrous MPs, such as polyester fibers, may entangle soil particles, potentially increasing aggregate stability under certain conditions (Lozano, Y. M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M. C., 2021). However, non-fibrous MPs (e.g., fragments, beads) can reduce aggregate stability by interfering with binding agents like microbial mucilages and organic matter (Lehmann, A., Fitschen, K., & Rillig, M. C., 2019). Changes in soil porosity and water-holding capacity further affect aeration, root penetration, and water infiltration, leading to physical degradation over time (Zhang, G. S., & Liu, Y. F., 2018). The shape and size of MPs play crucial roles in these physical interactions (Figure 1), with fibers generally having more pronounced effects on soil structure than spherical particles (Rillig, M. C., Lehmann, A., Ryo, M., & Bergmann, J., 2019).

Figure 1. *Size, color, and shape characteristics of microplastics used in experimental studies: (a) polyethylene (PE), (b) polyethylene terephthalate (PET), and (c) polypropylene (PP) (Dindar, E., 2025)*



2.2 Chemical Effects on Soil Chemistry

MPs can alter soil pH, nutrient availability, and organic matter dynamics. For instance, polyethylene (PE) and polypropylene (PP) tend to increase soil pH, while polyethylene terephthalate (PET) may release acidic degradation products (Dindar, E., 2025). Additives and adsorbed contaminants leached from MPs (e.g., plasticizers, heavy metals) can introduce toxins into the soil matrix, affecting nutrient cycling and enzyme activities (Hüffer, T., Hofmann, T., & Praetorius, A., 2020). Studies show that MPs can either increase or decrease phosphorus (P) availability depending on polymer type, concentration, and exposure duration (Dindar, E., 2025). The chemical composition of MPs, including the presence of additives such as phthalates and bisphenol A, can have significant implications for soil chemistry and plant health (Wang, J., Liu, X., Li, Y., Powell, T., Wang, X., Wang, G., & Zhang, P., 2019).

2.3 Biological Impacts on Soil Microbiota

Soil microbial communities are highly sensitive to MP contamination. MPs can serve as substrates for microbial colonization, altering community composition and function (Zhu, D., Chen, Q. L., An, X. L., Yang, X. R., Christie, P., Ke, X., ... & Zhu, Y. G., 2018). For example, phosphate-solubilizing bacteria (PSB) may be enriched in MP-contaminated soils, temporarily enhancing P mineralization (Seeley, M. E., Song, B., Passie, R., & Hale, R. C., 2020). However, high MP concentrations often suppress microbial diversity and enzyme activities – particularly phosphatases and dehydrogenases – critical for nutrient transformation (Fei, Y., Huang, S., Zhang, H., Tong, Y., Wen, D., Xia, X., ... & Barcelo, D., 2020, 1). The «phosphorus trap» phenomenon, where P accumulates in unavailable forms due to MP adsorption, further disrupts biogeochemical cycles (Boots, B., Russell, C. W., & Green, D. S., 2019). MPs can also affect soil fauna, including earthworms and nematodes, which play crucial roles in soil structure formation and nutrient cycling (Ju, H., Zhu, D., & Qiao, M., 2019).

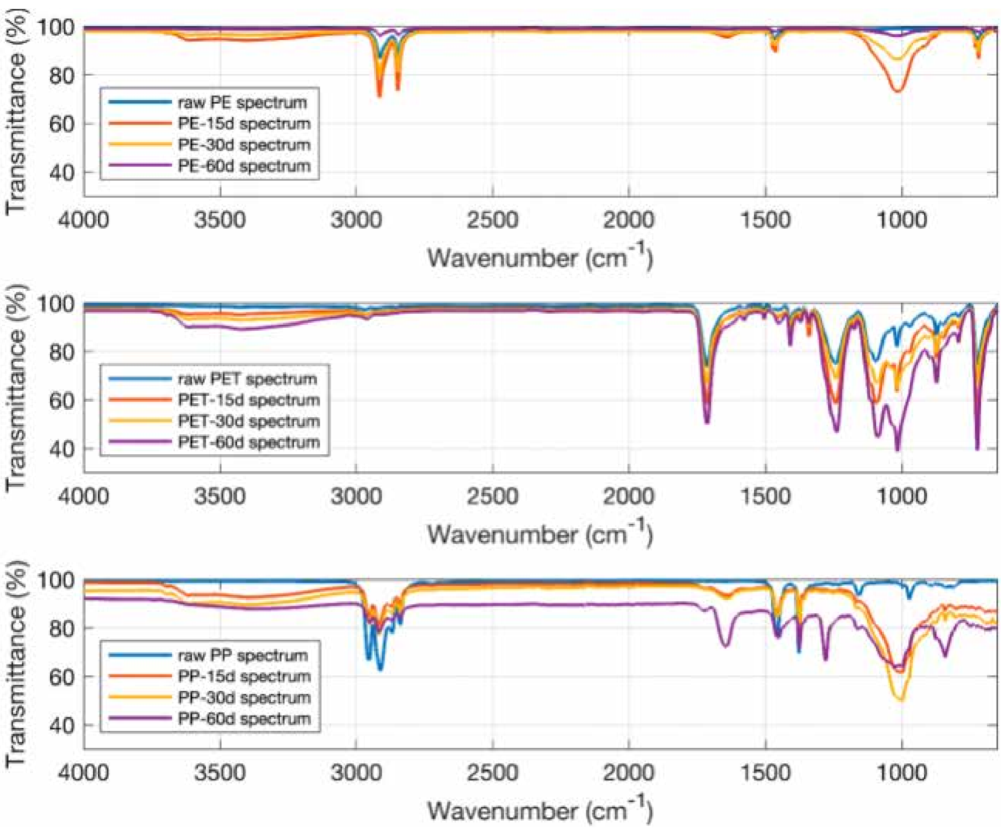
3. Polymer-Specific and Dose-Dependent Responses

Different polymers exhibit distinct degradation behaviors and ecological impacts (Figure 2):

– **PET**: Highly susceptible to hydrolysis and photooxidation, releasing carboxyl and hydroxyl groups that can complex with nutrients. Low doses (0.5% w/w) may stimulate enzyme activity and P availability, while high doses (5% w/w) often inhibit microbial functions (Dindar, E., 2025);

– **PE and PP**: More resistant to degradation due to their saturated hydrocarbon backbones (Figure 3). PE tends to reduce enzyme activity and nutrient availability at high concentrations, while PP shows variable effects on P dynamics (Dindar, E., 2025);

Figure 2. *FTIR spectra showing chemical degradation patterns of PE, PET, and PP microplastics after 60 days of soil incubation (Dindar, E., 2025)*

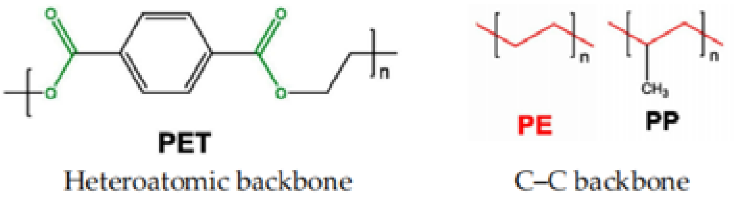


– **Fibers vs. Fragments**: Shape matters – fibers often enhance aggregation but may reduce microbial habitat connectivity, whereas fragments can physically hinder root growth and water movement (Lozano,

Y. M., Lehnert, T., Linck, L. T., Lehmann, A., & Rillig, M. C., 2021);

– **Polystyrene (PS) and Polyvinyl Chloride (PVC)**: These polymers often show more pronounced negative effects on soil biota due to their chemical composition and potential for additive leaching (Qi, R., Jones, D. L., Li, Z., Liu, Q., & Yan, C., 2020).

Figure 3. *Chemical backbone structures of selected plastic polymers. C–C backbone: polyethylene (PE), polypropylene (PP). Heteroatomic backbone: polyethylene terephthalate (PET) (Dindar, E., 2025)*

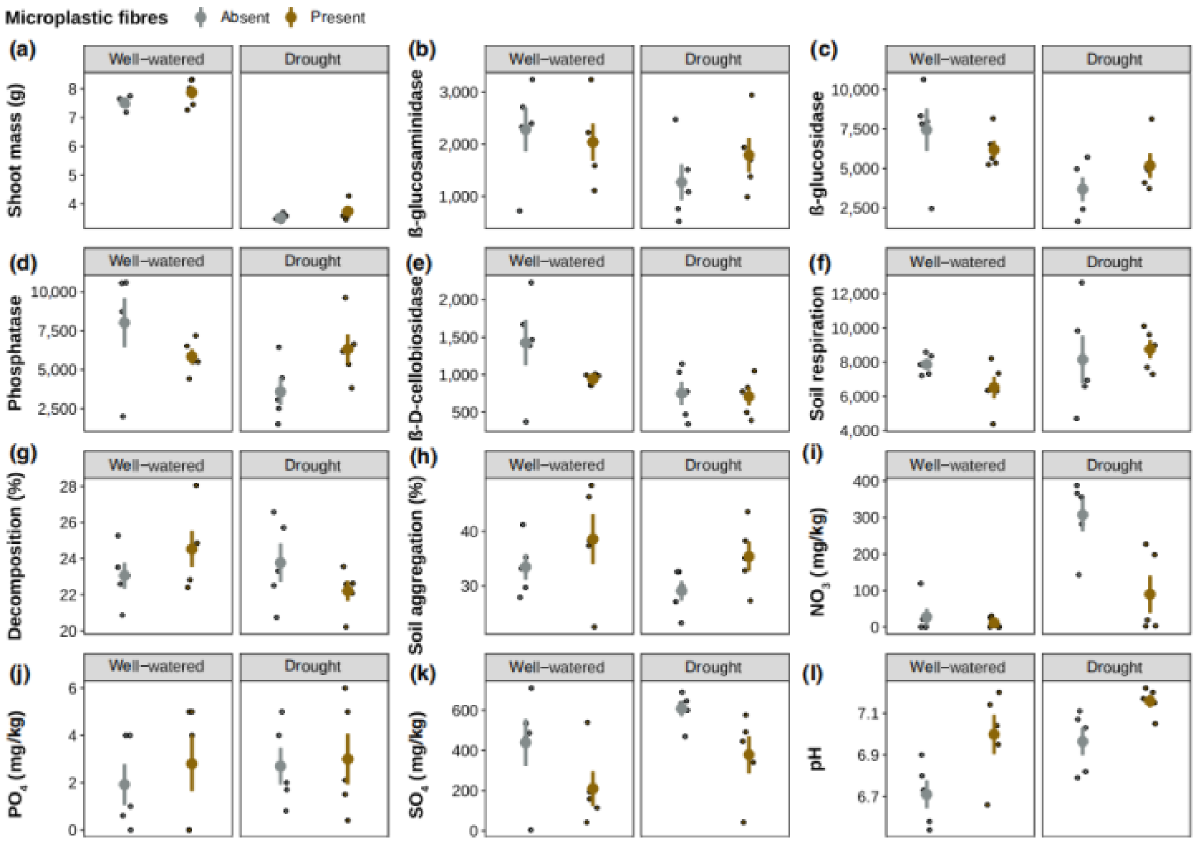


Dose-dependent effects are evident across studies. Low MP concentrations (≤0.5% w/w) may transiently stimulate microbial activity, whereas higher concentrations (≥1% w/w) typically induce toxicity, reducing enzyme activities, nutrient cycling, and plant growth (Wan, L., Cheng, H., Liu, Y., Shen, Y., Liu, G., Su, X., 2023). The threshold concentrations at which MPs transition from stimulatory to inhibitory effects vary depending on soil type, polymer characteristics, and environmental conditions (Zhou, J., Wen, Y., Marshall, M. R., Zhao, J., Gui, H., Yang, Y., ... & Jones, D. L., 2021).

4. Interactions with Abiotic Stressors: The Case of Drought

Microplastics can interact with drought to amplify or mitigate soil degradation.

Figure 4. *Microplastic fibers and drought effects on 12 ecosystem functions: (a) shoot mass, (b) β-glucosaminidase, (c) β-glucosidase, (d) phosphatase, (e) β-D-cellobiosidase, (f) soil respiration, (g) litter decomposition, (h) soil aggregation, (i) NO_3, (j) PO_4, (k) SO_4, (l) soil pH (Lozano, Y. M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M. C., 2021)*

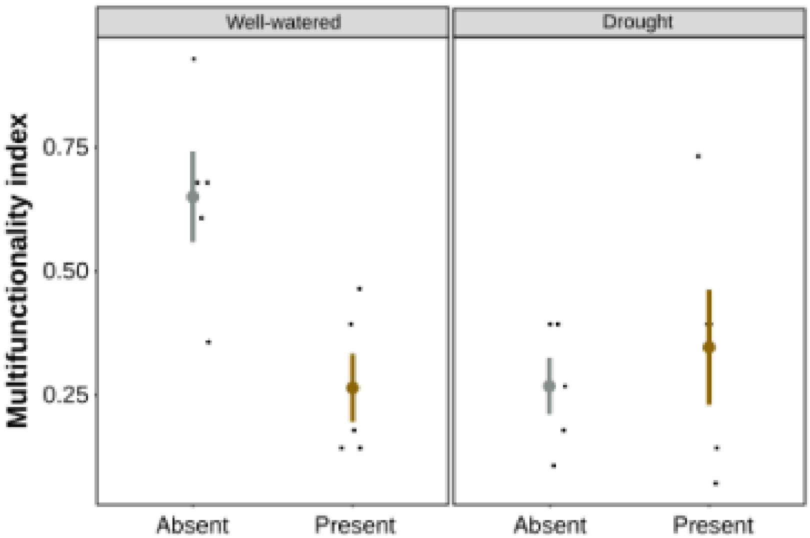


Lozano et al. (Lozano, Y.M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M.C., 2021) found that under well-watered conditions, MPs reduced enzyme activities and soil respiration, but under drought, MPs sometimes alleviated stress by improving water retention and aggregation (Figure 4). However, MP fibers combined with drought reduced litter decomposition – a key process in carbon cycling (Liu, H., Yang, X., Liu, G., Liang, C., Xue, S., Chen, H., ... & Geissen, V., 2017). These interactions highlight the context-dependent nature of MP impacts and the need to consider co-occurring global change factors. The combined effects of MPs and drought on soil microbial communities can be particularly complex, with outcomes depending on the specific microbial taxa involved and their tolerance to both stressors (Sanaullah, M., Blagodatskaya, E., Chabbi, A., Rumpel, C., & Kuzyakov, Y., 2011).

5. Implications for Ecosystem Multifunctionality

Soil multifunctionality – the simultaneous provision of multiple ecosystem services – is increasingly used to assess MP impacts. Studies indicate that MPs can reduce multifunctionality to an extent comparable to drought, particularly under well-watered conditions (Figure 5) (Lozano, Y. M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M.C., 2021). Functions most affected include nutrient cycling (e.g., phosphatase activity), carbon decomposition, and soil respiration (Manning, P., van der Plas, F., Soliveres, S., Allan, E., Maestre, F.T., Mace, G., ... & Fischer, M., 2018). The decline in multifunctionality underscores the broad ecological risks posed by MP pollution. Different ecosystem functions respond differently to MP contamination, with some showing greater sensitivity than others (Van der Plas, F., Manning, P., Allan, E., Scherer-Lorenzen, M., Verheyen, K., Wirth, C.,... & Fischer, M., 2016). This differential sensitivity has implications for the stability and resilience of soil ecosystems in the face of MP pollution.

Figure 5. *Microplastic fibers and drought effects on ecosystem multifunctionality (Lozano, Y. M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M. C., 2021)*



6. Transport and Fate of Microplastics in Soil Systems

Understanding the movement and persistence of MPs in soil systems is crucial for assessing their long-term impacts. MPs can be transported vertically through soil profiles via leaching and bioturbation, and horizontally through erosion and runoff (O'Connor, D., Pan, S., Shen, Z., Song, Y., Jin, Y., Wu, W. M., & Hou, D., 2019). The persistence of different polymer types varies significantly, with some MPs remaining in soils for decades or longer (Chae, Y., & An, Y. J., 2018). The fragmentation of larger plastic items into secondary MPs represents an ongoing source of contamination in agricultural and natural soils (Bläsing, M., & Amelung, W., 2018). The interaction between MPs and soil organic matter affects both the mobility of MPs and the cycling of organic carbon in soil systems (Rillig, M. C., Lehmann, A., de Souza Machado, A. A., & Yang, G., 2019).

7. Effects on Plant Health and Agricultural Productivity

MP contamination has direct and indirect effects on plant health and agricultural productivity. MPs can affect seed germination, root development, and nutrient uptake in various crop species (de Souza Machado, A. A., Lau, C. W., Kloas, W., Bergmann, J., Bachelier, J. B., Faltin, E., ... & Rillig, M. C., 2019). The physical presence of MPs in the rhizosphere can alter root architecture and function, potentially affecting water and nutrient acquisition (Li, L., Luo, Y., Li, R., Zhou, Q., Peijnenburg, W. J., Yin, N., ... & Zhang, S., 2020). Some studies have reported reduced crop yields in MP-contaminated soils, particularly at higher contamination levels (Jiang, X., Chen, H., Liao, Y., Ye, Z., Li, M., & Klobučar, G., 2019). However, responses vary significantly among plant species and cultivars, suggesting that genetic factors may influence plant tolerance to MP stress (Pignattelli, S., Broccoli, A., & Renzi, M., 2020).

8. Knowledge Gaps and Future Research Directions

– **Long-Term Studies**: Most experiments are short-term (<60 days); long-term field studies are needed to assess chronic exposure effects (Rillig, M. C., & Bonkowski, M., 2018);

– **Mechanistic Insights**: The molecular mechanisms linking MP degradation to microbial gene expression and metabolic pathways remain unclear (Zhu, F., Zhu, C., Wang, C., & Gu, C., 2019).

– **Real-World Concentrations**: More data on environmentally relevant MP concentrations in different soil types and land-use systems are essential for risk assessment (Xu, B., Liu, F., Cryder, Z., Huang, D., Lu, Z., He, Y., ... & Xu, J., 2020);

– **Interactive Effects**: Research on MP interactions with other pollutants (e.g., pesticides, heavy metals) and climate variables (e.g., temperature, precipitation) is limited (Liu, M., Lu, S., Song, Y., Lei, L., Hu, J., Lv, W., ... & He, D., 2018);

– **Standardized Methods**: Development of standardized methods for MP extraction, identification, and quantification in soil matrices is needed to enable comparisons across studies (Hurley, R. R., & Nizzetto, L., 2018);

– **Remediation Strategies**: Research on effective remediation techniques for MP-contaminated soils, including biological, chemical, and physical approaches, is still in its infancy (Guo, J. J., Huang, X. P., Xiang, L., Wang, Y. Z., Li, Y. W., Li, H., ... & Wong, M. H., 2020).

9. Conclusion

Microplastics represent a novel and persistent threat to soil health, contributing to physical, chemical, and biological degradation. Their impacts are mediated by polymer type, concentration, shape, and environmental context. While low doses may occasionally stimulate microbial processes, higher concentrations generally impair ecosystem functions. The interaction of MPs with drought and other stressors further complicates risk prediction. Addressing MP pollution requires integrated strategies – including improved waste management, biodegradable alternatives, and remediation technologies – to safeguard soil ecosystems and the services they provide. Future research should prioritize field-based studies, mechanistic investigations, and the development of standardized assessment protocols to better understand and mitigate the impacts of MPs on soil systems.

References

Lozano, Y. M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M. C. (2021). Effects of microplastics and drought on soil ecosystem functions and multifunctionality. *Journal of Applied Ecology*, – 58(5). – P. 988–996.

Lehmann, A., Fitschen, K., & Rillig, M. C. (2019). Abiotic and biotic factors influencing the effect of microplastics on soil aggregation. *Soil Systems*, 3(1). – 21 p.

Dindar, E. (2025). Impact of Microplastic Contamination on Phosphorus Availability, Alkaline Phosphatase Activity, and Polymer Degradation in Soil. *Polymers*, 17(10). – 1586 p.

Fei, Y., Huang, S., Zhang, H., Tong, Y., Wen, D., Xia, X., ... & Barcelo, D. (2020). Response of soil enzyme activities and bacterial communities to the accumulation of microplastics in an acid cropped soil. *Science of The Total Environment*, – 707. – 135634 p.

Wan, L., Cheng, H., Liu, Y., Shen, Y., Liu, G., Su, X. (2023). Global meta-analysis reveals differential effects of microplastics on soil ecosystem. *Science of The Total Environment*, – 867. – 161403 p.

Rillig, M. C. (2012). Microplastic in terrestrial ecosystems and the soil? *Environmental Science & Technology*, – 46(12). – P. 6453–6454.

Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E., & Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of The Total Environment*, – 586. – P. 127–141.

de Souza Machado, A. A., Kloas, W., Zarfl, C., Hempel, S., & Rillig, M. C. (2018). Microplastics as an emerging threat to terrestrial ecosystems. *Global Change Biology*, – 24(4). – P. 1405–1416.

Zhang, G. S., & Liu, Y. F. (2018). The distribution of microplastics in soil aggregate fractions in southwestern China. *Science of The Total Environment*, – 642. – 12–20.

Rillig, M. C., Lehmann, A., Ryo, M., & Bergmann, J. (2019). Shaping up: Toward considering the shape and form of pollutants. *Environmental Science & Technology*, – 53(14). – P. 7925–7926.

Hüffer, T., Hofmann, T., & Praetorius, A. (2020). Microplastic in terrestrial ecosystems. *Science*, – 368(6498). – P. 1430–1431.

Wang, J., Liu, X., Li, Y., Powell, T., Wang, X., Wang, G., & Zhang, P. (2019). Microplastics as contaminants in the soil environment: A mini-review. *Science of The Total Environment*, – 691. – P. 848–857.

Zhu, D., Chen, Q. L., An, X. L., Yang, X. R., Christie, P., Ke, X., ... & Zhu, Y. G. (2018). Exposure of soil collembolans to microplastics perturbs their gut microbiota and alters their isotopic composition. *Soil Biology and Biochemistr*y, – 116. – P. 302–310.

Seeley, M. E., Song, B., Passie, R., & Hale, R. C. (2020). Microplastics affect sedimentary microbial communities and nitrogen cycling. *Nature Communications*, – 11(1). – P. 1–10.

Boots, B., Russell, C. W., & Green, D. S. (2019). Effects of microplastics in soil ecosystems: Above and below ground. *Environmental Science & Technology*, – 53(19). – P. 11496–11506.

Ju, H., Zhu, D., & Qiao, M. (2019). Effects of polyethylene microplastics on the gut microbial community, reproduction and avoidance behaviors of the soil springtail, Folsomia candida. *Environmental Pollution*, – 247. – P. 890–897.

Lozano, Y. M., Lehnert, T., Linck, L. T., Lehmann, A., & Rillig, M. C. (2021). Microplastic shape, polymer type, and concentration affect soil properties and plant biomass. *Frontiers in Plant Scienc*e, – 12. – 616645 p.

Qi, R., Jones, D. L., Li, Z., Liu, Q., & Yan, C. (2020). Behavior of microplastics and plastic film residues in the soil environment: A critical review. *Science of The Total Environment*, – 703. – 134722 p.

Zhou, J., Wen, Y., Marshall, M. R., Zhao, J., Gui, H., Yang, Y., ... & Jones, D. L. (2021). Microplastics in agricultural soils on the coastal plain of Hangzhou Bay, east China: Multiple sources other than plastic mulching film. *Journal of Hazardous Materials*, – 388. – 121814 p.

Liu, H., Yang, X., Liu, G., Liang, C., Xue, S., Chen, H., ... & Geissen, V. (2017). Response of soil dissolved organic matter to microplastic addition in Chinese loess soil. *Chemosphere*, – 185. – P. 907–917.

Sanaullah, M., Blagodatskaya, E., Chabbi, A., Rumpel, C., & Kuzyakov, Y. (2011). Drought effects on microbial biomass and enzyme activities in the rhizosphere of grasses depend on plant community composition. *Applied Soil Ecolog*y, – 48(1). – P. 38–44.

Manning, P., van der Plas, F., Soliveres, S., Allan, E., Maestre, F. T., Mace, G., ... & Fischer, M. (2018). Redefining ecosystem multifunctionality. *Nature Ecology & Evolution*, – 2(3). – P. 427–436.

Van der Plas, F., Manning, P., Allan, E., Scherer-Lorenzen, M., Verheyen, K., Wirth, C., ... & Fischer, M. (2016). Jack-of-all-trades effects drive biodiversity–ecosystem multifunctionality relationships in European forests. *Nature Communications*, – 7(1). – 11109 p.

O'Connor, D., Pan, S., Shen, Z., Song, Y., Jin, Y., Wu, W. M., & Hou, D. (2019). Microplastics undergo accelerated vertical migration in sand soil due to small size and wet-dry cycles. *Environmental Pollution*, – 249. – P. 527–534.

Chae, Y., & An, Y. J. (2018). Current research trends on plastic pollution and ecological impacts on the soil ecosystem: A review. *Environmental Pollution*, – 240. – P. 387–395.

Bläsing, M., & Amelung, W. (2018). Plastics in soil: Analytical methods and possible sources. *Science of The Total Environmen*t, – 612. – P. 422–435.

Rillig, M. C., Lehmann, A., de Souza Machado, A. A., & Yang, G. (2019). Microplastic effects on plants. *New Phytologist*, – 223(3). – P. 1066–1070.

de Souza Machado, A. A., Lau, C. W., Kloas, W., Bergmann, J., Bachelier, J. B., Faltin, E., ... & Rillig, M. C. (2019). Microplastics can change soil properties and affect plant performance. *Environmental Science & Technology*, – 53(10). – P. 6044–6052.

Li, L., Luo, Y., Li, R., Zhou, Q., Peijnenburg, W. J., Yin, N., ... & Zhang, S. (2020). Effective uptake of submicrometre plastics by crop plants via a crack-entry mode. *Nature Sustainability*, – 3(11). – P. 929–937.

Jiang, X., Chen, H., Liao, Y., Ye, Z., Li, M., & Klobučar, G. (2019). Ecotoxicity and genotoxicity of polystyrene microplastics on higher plant Vicia faba. *Environmental Pollution*, – 250. – P. 831–838.

Pignattelli, S., Broccoli, A., & Renzi, M. (2020). Physiological responses of garden cress (L. sativum) to different types of microplastics. *Science of The Total Environment*, – 727. – 138609 p.

Rillig, M. C., & Bonkowski, M. (2018). Microplastic and soil protists: A call for research. Environmental Pollution, – 241. – P. 1128–1131.

Zhu, F., Zhu, C., Wang, C., & Gu, C. (2019). Occurrence and ecological impacts of microplastics in soil systems: A review. *Bulletin of Environmental Contamination and Toxicology*, – 102(6). – P. 741–749.

Xu, B., Liu, F., Cryder, Z., Huang, D., Lu, Z., He, Y., ... & Xu, J. (2020). Microplastics in the soil environment: Occurrence, risks, interactions and fate–A review. *Critical Reviews in Environmental Science and Technology*, – 50(21). – P. 2175–2222.

Liu, M., Lu, S., Song, Y., Lei, L., Hu, J., Lv, W., ... & He, D. (2018). Microplastic and mesoplastic pollution in farmland soils in suburbs of Shanghai, China. *Environmental Pollution*, – 242. – P. 855–862.

Hurley, R. R., & Nizzetto, L. (2018). Fate and occurrence of micro(nano)plastics in soils: Knowledge gaps and possible risks. *Current Opinion in Environmental Science & Health*, – 1. – P. 6–11.

Guo, J. J., Huang, X. P., Xiang, L., Wang, Y. Z., Li, Y. W., Li, H., ... & Wong, M. H. (2020). Source, migration and toxicology of microplastics in soil. *Environment International*, – 137. – 105263 p.

submitted 04.04.2026;
accepted for publication 18.04.2026;
published 30.06.2026

Contact: agbanwucaleb4@gmail.com