Challenges and Issues of Modern Science, 3 (2024). ISSN: 3083-5704
URL: https://cims.fti.dp.ua/j/article/view/244
PURL: https://purl.org/cims/2403.034

Microplastics in agricultural soils: sources and microbial remediation approaches

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Purpose. The purpose of this study was theoretical analysis of the sources of microplastics in agricultural soils, its impact on agroecosystems and microbial remediation approaches to remove microplastics from the soil. **Design / Method / Approach**. Given the complex and multifaceted nature of the research topic, a complex of general scientific methods was used to achieve the research goal: analytical, synthetic, hermeneutic, pragmatic, generalization. **Findings**. The sources of microplastics in agricultural soils are plastics used to cover fertilizers, pesticides and seeds, film for mulching, use of wastewater for irrigation, sludge from wastewater treatment as fertilizers that can lead to the occurrence of environmental risks for the functioning of agroecosystems and human health. Microbial remediation is a promising direction for the removal of microplastics from agricultural soils. **Theoretical Implications**. Generalized information on the sources of microplastics in agricultural soils, the consequences for agroecosystems of this type of pollution, as well as microbial remediation approaches for the removal of microplastics are presented, which expands the understanding of microplastics as a pollutant of agroecosystems. **Practical Implications**. The given information will contribute to the growth of research into the level of contamination of agricultural soils with microplastics, in particular, in Ukraine, and the formation of biofilms of soil microorganisms-biodegraders on the surface of microplastics (with attention to sulfate-reducing bacteria), including influence of various toxicants on these processes. **Originality / Value**. The theoretical and practical issues of contamination of agricultural soils with microplastics are summarized with emphasis on biofilm formation as an important stage of microbial remediation. **Research Limitations / Future Research**. In Ukraine, the level of contamination of agricultural soils with microplastics, the impact of toxicants on the biofilm formation by soil microorganisms-biodegraders on the surface of microplastics (with attention to sulfate-reducing bacteria) have not been determined and further research on this issue is needed. **Paper Type**. Review.

Keywords:

microplastics, agricultural soils, agroecosystems contamination, microbial remediation, biofilm formation

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The problem of the accumulation of microplastics in the environment attracts the researchers' attention from various fields of knowledge and is relevant both for different countries of the world (Sa'adu & Farsang, 2023) and for Ukraine (Yurchenko et al., 2021; Fortuna & Borysovska, 2021). Microplastics consist of plastic particles less than 5 mm in size and is formed as a result of the action of physical, chemical and biological factors on plastic products used in everyday life and practical human activities (Duis & Coors, 2016). A significant amount of microplastics is found in various environments, including soil (Guo et al., 2020). Microplastics are a pollutant and pose a potential threat to human health (Ghosh et al., 2023). Microorganisms form biofilms on the surface of microplastics (Moyal et al., 2023; Tkachuk & Zelena, 2023; Rajcoomar et al., 2024; Tkachuk & Zelena, 2024) and contribute to its degradation, which is considered a promising approach to soil bioremediation (Nauendorf et al. al., 2016; Thapliyal et al., 2024).

The need to generalize the theoretical and practical issues of contamination of agricultural soils with microplastics with attention to the formation of biofilm as an important stage of microbial remediation determined the need for this study, that defined the sources of microplastics in agricultural soils, its impact on agroecosystems and microbial remediation approaches to remove microplastics from the soil.

Methodology

Given the complex and multifaceted nature of the research topic, a complex of general scientific methods was used to achieve the research goal: analytical, synthetic, hermeneutic, pragmatic, generalization. The use of analytical and synthetic methods made it possible to determine the sources of contamination of agricultural soils with microplastics. The use of the hermeneutic method made it possible to analyze the impact of microplastics on the soil, in particular, the soil microbiota, the formation of biofilms for the process of microbial remediation. Conclusions, recommendations and proposals are based on practical generalization.

Microplastics in agricultural soils

Plastics are used in agricultural production as a coating for fertilizers, pesticides (Rusyn et al., 2021) and for the seed coatings (Langlet et al., 2024). And although researchers note the high efficiency of this approach for crop production (Rusyn et al., 2021), the danger of the formation of microplastics in the soil is not taken into account. The contribution of coated fertilizers as sources of microplastics in agricultural soils was 3% (Sa'adu & Farsang, 2023). The issue of replacing artificial microplastics in seed coatings used in agriculture is under consideration (Langlet et al., 2024). The Center for International Environmental Law found that due to the use of microplastics to cover fertilizers, toxic pesticides become even more toxic when used in agriculture. This combination of chemicals negatively affects soil structure, climate, food quality, and ecological systems as a whole (Center…, 2022).

Another source of microplastics in agricultural soils is mulch film (Long et al., 2023). At the same time, it was shown that the most common microplastic was polyurethane, and polyethylene accounted for 2.7% of microplastics (Long et al., 2023).

A different source of pollution of agroecosystems by microplastics is their irrigation with wastewater, which contains a significant amount of these microparticles (Ullah et al., 2021). The presence of microplastics in wastewater is noted by a number of authors (Habib et al., 2020; Ragoobur et al., 2021), the source of which, among other things, is hygiene products, in particular, wet wipes (Ó Briain et al., 2020; Lee et al., 2021). The use of sewage sludge as a biofertilizer for degraded soils (Marin & Rusănescu, 2023) is also a source of microplastic contamination of agricultural soils, as such sludge also contains microplastics (Arab et al., 2024). The contribution of sediment as a source of microplastics in agricultural soils was 16% (Sa'adu & Farsang, 2023).

In Europe, microplastics from biosolids (2.3–15.8 t/ha) tend to accumulate in the top 100 mm of agricultural soil (Ng et al., 2018). Accumulation of microplastics in soils deteriorates soil ecosystems, in particular, disrupts the composition of microbiota, which creates the necessary conditions for healthy plant growth, changes the concentration of chemical compounds, reduces the enzymatic activity of soils, affects water holding capacity, bulk density, texture, pH (Ullah et al., 2021). When consuming contaminated agricultural products, there is a threat of microplastics entering the human body (Ullah et al., 2021). The researchers noted that the calculated microplastic concentrations had a low non-carcinogenic and carcinogenic risk to the farming community (Sharmin et al., 2024). In addition, the colonization of the surface of microplastics by pathogenic microbiota due to fecal contamination (for example, from sewage or organic fertilizers and feces) is of concern as a route of transmission of human pathogens in the food chain (Quilliam et al., 2023). Soil microplastics, due to their significant sorption potential, can influence the degradation processes of pesticides and their level of toxicity (Bao et al., 2024). It was also shown that the accumulation of microplastics in the soil significantly promoted nitrous oxide, carbon dioxide and methane emissions, which is potentially dangerous for climate change (Chen et al., 2023).

In Ukraine, the level of contamination of agricultural soils with microplastics has not been determined, although all the sources of microplastics mentioned above have an impact on them, so there is a need for further research on this issue.

Microbial remediation as an approach to cleaning soils from microplastics

There are several technologies for removing microplastics from the environment, and biological methods appear to be the most promising and environmentally friendly (Gao et al., 2022). Some groups of microorganisms are characterized by the ability to biodegrade microplastics and are promising agents for cleaning environments from it (Othman et al., 2021). Representatives of the genus *Bacillus* are actively researched as effective biodegraders of plastics (Tkachuk & Zelena, 2021). Microbial remediation is the use of microorganisms, in particular, in the form of biofilms, an eco-friendly technology for removing pollutants from various environments (Mani, 2020; Biswal & Malik, 2022). An important role in the formation of biofilm is played by glycoconjugates (glycoproteins and glycolipids) produced by microorganisms, with the participation of combinations of which disinfection of various types of pollutants is carried out - microbial glycobiotechnology (Bhatt et al., 2021).

Researchers have analyzed soil microbiota under the influence of various types of microplastics (Qian et al., 2018; Ren et al., 2020). However, microbial communities on microplastics are unique and are called microplastisphere/plastisphere (Zettler et al., 2013). Microplastics are considered as one type of soil pollutant (Guo et al., 2020), so special attention is paid to the bacterial diversity of biofilms on it. Thus, the dominance of *Proteobacteria* (37%), *Actinobacteriota* (33%), *Patescibacteria* (9%) microorganisms was established on the surface of polypropylene and polystyrene during exposure for 8 weeks in soil from an agricultural field (from a depth of 0-20 cm), which was cultivated using principles of ecological agriculture (Kublik et al., 2022). The dominance of *Methylophaga*, *Saccharimonadales*, *Sphingomonas* on the surface of microplastics of low-density polyethylene, polystyrene, polyethylene terephthalate (exposure of 15 and 30 days in non-mulched soil of greenhouses with a previous one-week cultivation) was revealed (Chen et al., 2022). Usually, microplastics change the number of bacterial communities by affecting their metabolism, but polyethylene and polypropylene in the form of microplastics did not affect the number or structure of soil microbes (Pang et al., 2023). However, there is evidence that over time (90 days) a decrease in the total microbial number and the number of sulfate-reducing bacteria, as well as the formation of a microbial biofilm, was observed on polypropylene, compared to quartz sand (Tkachuk & Zelena, 2024). The authors emphasize the need to involve sulfate-reducing bacteria (SRB) - recognized microbial degraders - in the study of plastic degradation issues (Tkachuk & Zelena, 2024). SRB was detected in vitro as part of the microbial community capable of biodegrading polypropylene (Cacciari et al., 1993). An increase in the number of SRB (*Desulfohalotomaculum*) was also found in vitro on the surface of polypropylene samples (Malakhova et al., 2023).

The main soil pollutants are toxic metals/metalloids, organic pollutants, antibiotics, pesticides (Raffa & Chiampo, 2021; Li et al., 2022). Regarding the combined effect of microplastics and pesticides, additional research is needed to understand their further ecological fate and the ecological risks of the interaction (Peña et al., 2023). Under the influence of heavy metals and arsenic, inhibition of biofilm formation by soil saprotrophic microorganisms *Bacillus megaterium* var. *phosphaticum*, *B. mucilaginosus*, *Pectobacterium carotovorum* and *Escherichia coli* on the surface of plastic plate (Bybin et al., 2021). Due to the effect of microplastics of polystyrene and polytetrafluoroethylene and arsenic on the soil microorganisms of the rhizosphere of rice, a decrease in the number of Proteobacteria, an increase in the number of *Chloroflexi* and *Acidobacteria* in the soil, and inhibition of the activity of soil urease, acid phosphatase, protease, dehydrogenase, peroxidase was noted (Dong et al., 2021). The use of rhizosphere microorganisms to remove microplastics from the soil is called rhizoremediation, which is considered one of the promising strategies for bioremediation of soils contaminated with microplastics (Thapliyal et al., 2024).

Additives to plastic, such as dyes, flame retardants, stabilizers, plasticizers have a negative effect on soil microorganisms (Zaborowska et al., 2020), which can increase the inhibitory effect of pollutants on the formation of biofilms on microplastics. As a result, both the processes of formation of microbial biofilms on microplastics and its biodegradation would be disrupted, and therefore the time of preservation of the material in the soil will increase. Bacterial bioremediation of plastics (particularly polyester) can increase biofilm levels, as shown by manipulating levels of cyclic-di-HMP (Howard & McCarthy, 2023). Genetic manipulation of microorganisms allows obtaining strains with high bioremediation indicators (Thapliyal et al., 2024).

Since the processes of degradation of microplastics and the release of plastic oligomers, monomers and additives, in particular, phthalates and bisphenols, are slow, the consequences of exposure to microplastics for the environment are long-term (Zhang et al., 2023). The use of short-term laboratory studies of the toxicity of microplastics against pure cultures of microorganisms and one type of microplastics are detached from real environmental conditions (Zhang et al., 2023). The above determines the need for long-term field research. Previous studies took into account the properties of microplastics (particle size and type), as well as the type of soil (texture and components), but the issue of the influence of the soil environment (dry, flooded, etc.) on microbial communities was not covered, which requires additional research (Pang et al., 2023).

Therefore, microbial remediation of soils contaminated with microplastics is considered an environmentally safe bioremediation approach, the mandatory stage of which is the formation of microbial biofilms on the surface of microplastics. Further research should be focused on determining the impact of toxicants (in particular, pesticides present in agroecosystems) on the biofilm formation of soil microorganisms-biodegraders on the surface of microplastics (with attention to sulfate-reducing bacteria) with an assessment of their ability to biodegrade.

Conclusions

Therefore, the sources of microplastics in agricultural soils are plastics used to cover fertilizers, pesticides and seeds, film for mulching, use of wastewater for irrigation, sludge from wastewater treatment as fertilizers. The increase in the amount of microplastics in the soil affects its physico-chemical parameters, soil biota, the behavior of pesticides, which can lead to the occurrence of environmental risks both for the functioning of agroecosystems and for human health. In addition, the accumulation of microplastics in agricultural soils is alarming in view of the increase in greenhouse gas emissions and the risks of climate warming. The use of microbial remediation is a promising direction for the removal of microplastics from agricultural soils.

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