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Occurrence and characterization of microplastics in agricultural soils of eastern Poland

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ABSTRACT

Microplastics enter agricultural soils through sewage sludge, atmospheric deposition, and irrigation. Their accumulation in the soil profile may alter soil physicochemical properties and crop physiology, and, through the food chain, may lead to human exposure to these particles posing a potential health risk. This pilot study aimed to assess the occurrence of potential microplastics in agricultural soils of the Lubelskie Voivodeship (Poland), with particular attention to the morphological characteristics and chemical identity of a subset of them. Six composite soil samples, collected in accordance with ISO 18400-102, were dried, homogenized, and subjected to alkaline-oxidative digestion (KOH/H_2O_2) to remove organic matter, followed by filtration through GF/F glass-fibre filters. The extracted particles were examined using an infrared microscope and classified into four morphological categories. In total, 108 particles were morphologically identified as potential microplastics using an infrared microscope, and their abundance ranged from 107 to 294 particles kg^{-1} dry soil (mean 197 ± 62 particles kg^{-1}). Irregular fragments predominated (57.4%), while fibres, compact/rounded particles, and flat, film-like particles occurred at lower and comparable frequencies (12.0–16.7%), with the proportion of each shape category varying between soil batches. Chemical identification by FTIR spectroscopy, performed on a subset of 27 particles (25.0% of the total), large enough for ATR measurement, confirmed the presence of polyethylene, poly(vinyl chloride), polypropylene, and polyethylene terephthalate. The results indicate the presence of potential microplastics in all analyzed samples, and highlight the need for further research, based on a larger number of samples, into their effects on soil quality, environmental safety, and human health.

Keywords: microplastic, soil, FTIR spectroscopy, environmental risk, particle morphology.

INTRODUCTION

Microplastics are synthetic, water-insoluble solid particles measuring less than 5 mm (Koelmans et al., 2022). Primary microplastics are purposefully manufactured for use in cosmetics, pharmaceuticals, and cleaning products (Kukkola et al., 2024; Giustra et al., 2024), while secondary microplastics form through the fragmentation of larger plastics via physical, chemical, or biological processes (Osman et al., 2023). Their growing presence reflects rising global plastic production and consumption, resulting in widespread occurrence across ecosystems (Zhang et al., 2024). The high chemical and mechanical stability of plastics, which is a key advantage in practical applications, simultaneously creates a fundamental environmental problem related to their disposal. The long decomposition times of polymeric materials, combined with limited recycling options and high recycling costs, cause plastic waste tends to accumulate in landfills, leading to environmental contamination (Wang et al., 2017). Polymer waste deposited in landfills is a source of secondary microplastics, which form as a result of degradation processes. Key degradation mechanisms include physical fragmentation caused by mechanical shear forces, photodegradation under UV

radiation, which breaks C-C bonds and forms free radicals, as well as chemical oxidation, hydrolysis, and microbial biodegradation (Jenner et al., 2022; Ahmadi et al., 2026). All plastics are susceptible to these processes; however, the intensity and characteristics of degradation depend heavily by both the polymer's molecular structure and the environmental conditions present.

Environmental contamination by microplastic particles is a complex phenomenon arising from the many pathways through which pollutants enter soil and terrestrial ecosystems. According to estimates by Horton et al. (2017), the quantity of plastic entering terrestrial ecosystems annually exceeds that reaching marine environments by a factor of 4 to 23. Contamination levels vary widely by land use, industrial soils reach 300–67,500 mg/kg (Fuller and Gautam, 2016), while forest soils range from 7100–42960 particles/kg (Zhang and Liu, 2018), showing that even forests are not exempt from accumulation. Major anthropogenic sources include sewage sludge fertilizers (Willén et al., 2017; Weithmann et al., 2018), degrading mulch films, wind-transported atmospheric deposition (Allen et al., 2019), and irrigation with untreated wastewater (Uddin et al., 2025). These combined inputs progressively contaminate agricultural soils. Further anthropogenic sources include municipal and industrial landfills. In addition, uncontrolled industrial spills and wastewater from both municipal and industrial sources release significant amounts of microplastics and polymer additives from consumer products into the environment (Chae and An, 2018; Figure 1). An equally significant source is the secondary fragmentation of polymeric materials during their use. For example, the mechanical abrasion of car tires during vehicle operation generates rubber microparticles that are subsequently transported from road surfaces with stormwater runoff into terrestrial and aquatic ecosystems. Moreover, direct littering, inefficient waste management infrastructure, and improper disposal contribute to the progressive increase in microplastic concentrations in soil (Chae and An, 2018).

Wastewater treatment plants remove larger plastic debris effectively but cannot fully eliminate microplastics (Vinay et al., 2026). U.S. municipal wastewater alone is estimated to release 3–23 billion particles daily (Mason et al., 2016), while European agricultural soils receive up to 42,000 tonnes yearly via sewage sludge fertilizer (Lofty et al., 2022). A key problem is that conventional sludge treatment processes, such as lime stabilization, anaerobic digestion, and drying, fail to remove these contaminants (Mahon et al., 2017). Direct irrigation with untreated wastewater, still practiced in some regions, poses an equally serious concern (Weithmann et al., 2018).

Once introduced into soil, microplastics undergo various chemical, physical, and biological processes that determine their distribution. They accumulate in surface layers, are translocated vertically, and are subject to erosion and leaching into groundwater. Nizzetto et al. (2016) demonstrated that a significant portion of plastics is retained in the surface soil layer, whereas particles smaller than 0.2 mm show significantly greater mobility. Soil fauna plays an important role in this distribution, with earthworms transporting

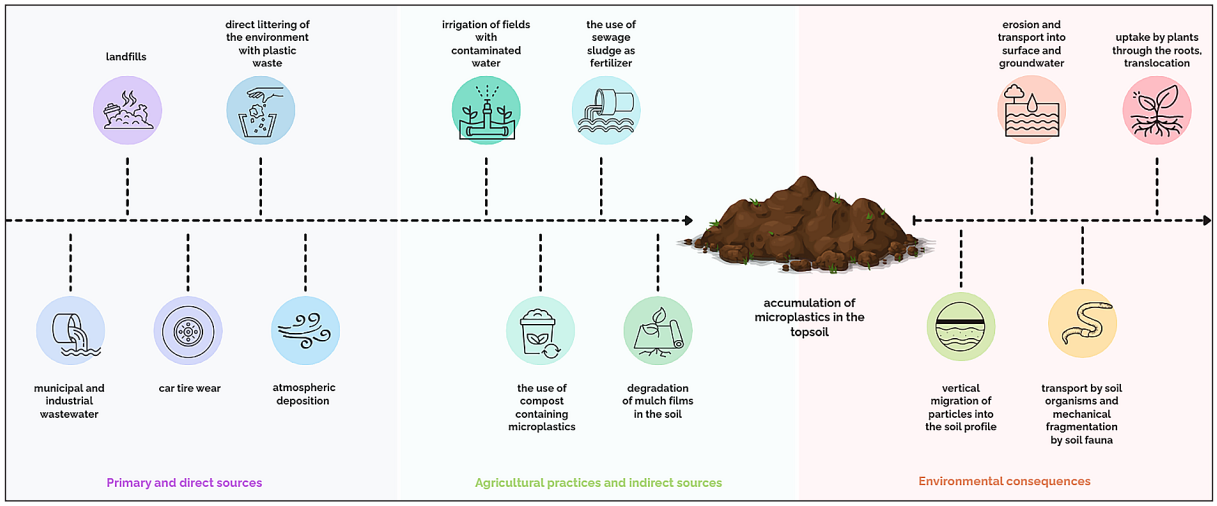

Figure 1. Sources and pathways of microplastic migration into agricultural soil

polymer particles as they burrow through the soil (Rillig et al., 2017), facilitating their migration to deeper layers. Burrowing mammals such as moles may further contribute to the mechanical abrasion of microplastic fragments into nanoplastic fractions and their transport within the soil ecosystem. In addition, soil fauna may ingest microplastics, which undergo further fragmentation in the digestive tract, generating smaller particles that highlight the complexity of the mechanisms controlling the fate of microplastics in soil.

The aim of this study was to assess microplastic particle contamination in selected agricultural soils in Poland (Lubelskie Voivodeship). The isolated particles were morphologically characterized: irregular fragments, fibers, rounded/compact particles, and film-like particles. The chemical composition of selected particles was then identified using FT-IR Spectroscopy.

MATERIALS AND METHODS

Sample collection and preparation

Soil samples were collected from six agricultural fields in Lubelskie Voivodeship, eastern Poland, near the villages of Woskrzenice Duże (52.040° N, 23.271° E), Hrud (52.098° N, 23.140° E), Bubel-Łukowiska (52.233° N, 23.184° E), Bordziłówka Stara (52.129° N, 22.985° E), Rogoźnica Kolonia (52.019° N, 22.847° E) and Swory (52.077° N, 22.929° E) between May 18, 2026, and June 12, 2026, under sunny, rain-free conditions with air temperatures ranging from 18 to 24 °C. There is not yet a single standardized sampling methodology for microplastics in soil. Samples were collected by combining material from smaller subplots into single composite samples (ISO 18400-102). One composite sample was collected from each field, consisting of 10 subsamples distributed evenly in a zigzag pattern across the entire field area, at least 10 m from roads. The subsamples were collected from the 0–5 cm layer. After thoroughly mixing the collected material on a clean stainless steel surface, a representative portion of approximately 100 g of fresh soil was taken (dry mass 85.2–95.3 g, Table 1) for further analysis. Glass containers and plastic-free equipment were used for sampling, in order to minimize the risk of contamination. The person collecting the samples wore cotton clothing. The tools were cleaned between fields using a brush and filtered water, and then dried without the use of synthetic-fiber towels. A total of six soil samples were dried at 40 °C (ISO 11464) and homogenized by hand. To remove organic matter, the samples were subjected to alkaline-oxidative digestion with a 10% KOH solution (Warchem Sp. z o.o., Poland) and 30% H_2O_2 (Warchem Sp. z o.o., Poland), shaken for 48 h (Expondo, Poland) at 300 rpm, with reagents replenished during the process. Next, samples underwent filtration using GF/F glass fiber filters (2.5 µm, Fisher Scientific) prior to storage in glass Petri dishes.

Observation and identification of particles

Filters containing extracted particles were examined using an AIM-9000 infrared microscope (Shimadzu, Japan). The preliminarily identified particles were classified by shape into four groups: irregular fragments (angular, with jagged edges), fibers (thread-like, with a high length-to-width ratio), compact particles resembling oval or rounded shapes, without sharp corners, and flat, film-like/foliaceous particles (thin, with a large surface area, appearing translucent in the image). Chemical identification of individual selected particles (n = 27, 25.0% of all isolated particles), whose size allowed for measurement in ATR mode, was carried out using FTIR with an IRTracer-100 spectrophotometer (Shimadzu, Japan). The selected particles represented different morphological types observed among the isolated particles, where their dimensions allowed for reliable spectral acquisition. Consequently, the FT-IR-identified subset should be considered a chemically characterized fraction of the morphologically classified particles rather than a statistically representative sample of all 108 particles. The morphological classification was therefore performed for the complete set of isolated particles, whereas chemical identification was restricted to particles for which reliable ATR measurements could be obtained. The spectra obtained were subsequently matched against a LabSolutions library (Version 2.27, 2012–2021, Shimadzu Corp., Shimadzu, Japan). A spectral similarity of ≥70% was used as the initial criterion for considering a library match, with obtained similarity values ranging from 71% to 96%. However, polymer identification was not based solely on the numerical similarity score. Each proposed identification was additionally verified by manual comparison of the experimental spectrum with the reference

spectrum, with particular attention paid to the presence and position of characteristic absorption bands of the proposed polymer.

Quality control

Quality control procedures were followed throughout the entire process. Sampling was carried out using only stainless steel and aluminium tools and glass containers with metal lids, and the person collecting the samples wore cotton clothing. In the laboratory, the use of plastic instruments was avoided and laboratory clothing made from non-synthetic materials was worn. Tools were cleaned between fields and dried without the use of synthetic-fibre towels. Procedural blank samples (n = 5) (samples subjected to the full extraction procedure without soil material) were included in the analytical series to detect any contamination. None of the blank samples contained detectable plastic particles, confirming the absence of contamination during analysis. No extraction recovery experiments with spiked soil samples and no dedicated analytical replicates were performed in this study; therefore, the recovery efficiency of the applied protocol and the analytical precision were not determined.

RESULTS AND DISCUSSION

A total of 108 particles with morphological characteristics typical of microplastics (hereafter referred to as potential microplastics) were isolated from the six soil samples analyzed. Such particles were present in all samples, and representative photographs of the larger ones, taken immediately after extraction, are shown in Figure 2.

All isolated particles underwent preliminary morphological analysis based on microscopic observation and were classified into one of four shape categories (Figure 3). The percentage share of particles in each shape category, broken down by soil batch, is presented in Table 1.

The mass of dry soil processed per sample ranged from 85.2 to 95.3 g (546.2 g in total). The abundance of particles morphologically identified as potential microplastics ranged from 107.0 particles kg^{-1} (Batch 2) to 293.8 particles kg^{-1} (Batch 1), with a mean of 197 ± 62 particles kg^{-1} of dry matter across the six samples. It should be emphasized that the values presented in Table 1 refer to particles identified on the basis of morphological characteristics (shape, appearance) under a microscope, and not to particles whose polymeric nature has been confirmed by spectroscopic methods. The proportion of each shape category varied among the batches. Irregular fragments predominated in all samples, with proportions ranging from 40.0 to 80.0%. Batch 1 stood out with the highest proportion of flat, film-like particles (25.0%); notably, this category was absent in Batches 2 and 6. Fibers were most abundant in Batches 3 and 6 (26.7% each) and least common in Batch 5 (5.3%). Across the entire analyzed sample, irregular fragments accounted for more than half of all identified particles, while the remaining three shape categories occurred at similar frequencies (ranging from 12.0 to 16.7%). Particle size was not determined individually for all particles; however, based on the microscope images and the calibrated scale bars, the isolated particles ranged from approximately 100 µm to several millimetres in their longest dimension (all below the 5 mm upper limit for microplastics). Particles selected for FT-IR analysis were of sufficient size to allow measurement in ATR mode.

Identification of polymers using FTIR

To confirm the polymeric nature of the isolated particles, 27 particles (25%) were selected



Figure 2. Representative photographs of larger particles captured in the visual observation mode of the AIM-9000 infrared microscope (Shimadzu, Japan), without optical magnification and prior to infrared measurement: fiber (~3.5 × 0.8 mm), irregular fragment (~1.8 × 1.1 mm) and film-like particle (~3.9 × 2.1 mm). Scale bars: 1000 µm

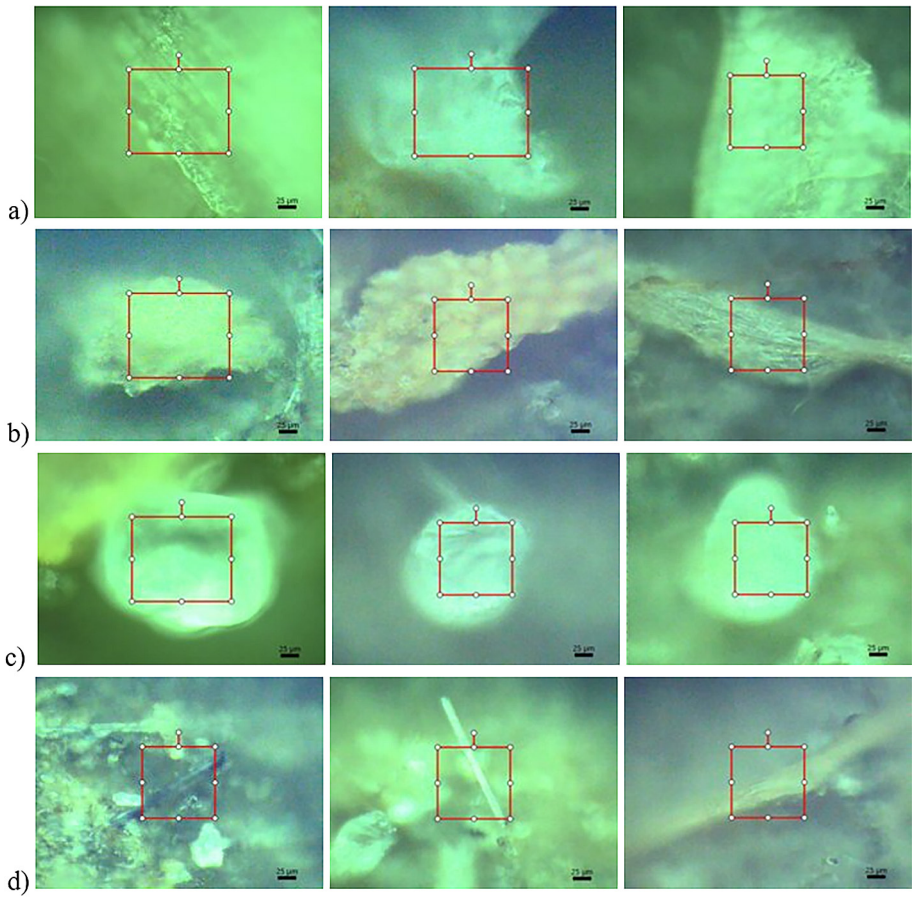

Figure 3. Representative photographs of particles illustrating the individual shape categories: (a) film-like/ foliaceous, (b) irregular shape, (c) rounded shape, (d) fiber. Red squares indicate the FTIR measurement area, not particle outlines. Scale bars: 25 µm

Table 1. Abundance and percentage share of shape categories among morphologically identified putative microplastic particles in the analyzed soil samples. Particle counts were normalized to the mass of dry soil processed per sample and are expressed as particles per kg dry soil (particles kg^{-1} d.m.). Polymer identity was confirmed by FT-IR only for a subset of 27 particles

Batch	Dry matter [g]	N	Irregular fragment	Fiber	Rounded /compact	Film-like /foliaceous	Particle [kg^{-1} d.m.]
1	95.3	28	46.4%	14.3%	14.3%	25.0%	293.8
2	93.5	10	80.0%	10.0%	10.0%	0.0%	107.0
3	85.2	15	40.0%	26.7%	13.3%	20.0%	176.1
4	93.5	21	57.1%	19.0%	14.3%	9.5%	224.6
5	91.0	19	73.7%	5.3%	15.8%	5.3%	208.8
6	87.7	15	60.0%	26.7%	13.3%	0.0%	171.0
Total	546.2	108	57.4%	16.7%	13.9%	12.0%	197.7

from the 108 morphologically classified particles, based on their size, which allowed measurement in ATR mode. The resulting spectra were compared with a database of reference polymer spectra. Among the 27 particles analyzed, at least four types of plastics were confirmed: polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), poly(vinyl chloride) (PVC). (Figure 4). The polymer identity of the remaining 81 particles was not determined.

In the spectrum of the first particle (Figure 4a), a weak, overlapping band composed of four components, corresponding to C-H stretching, was observed in the 3000–2800 cm^{-1} range. An

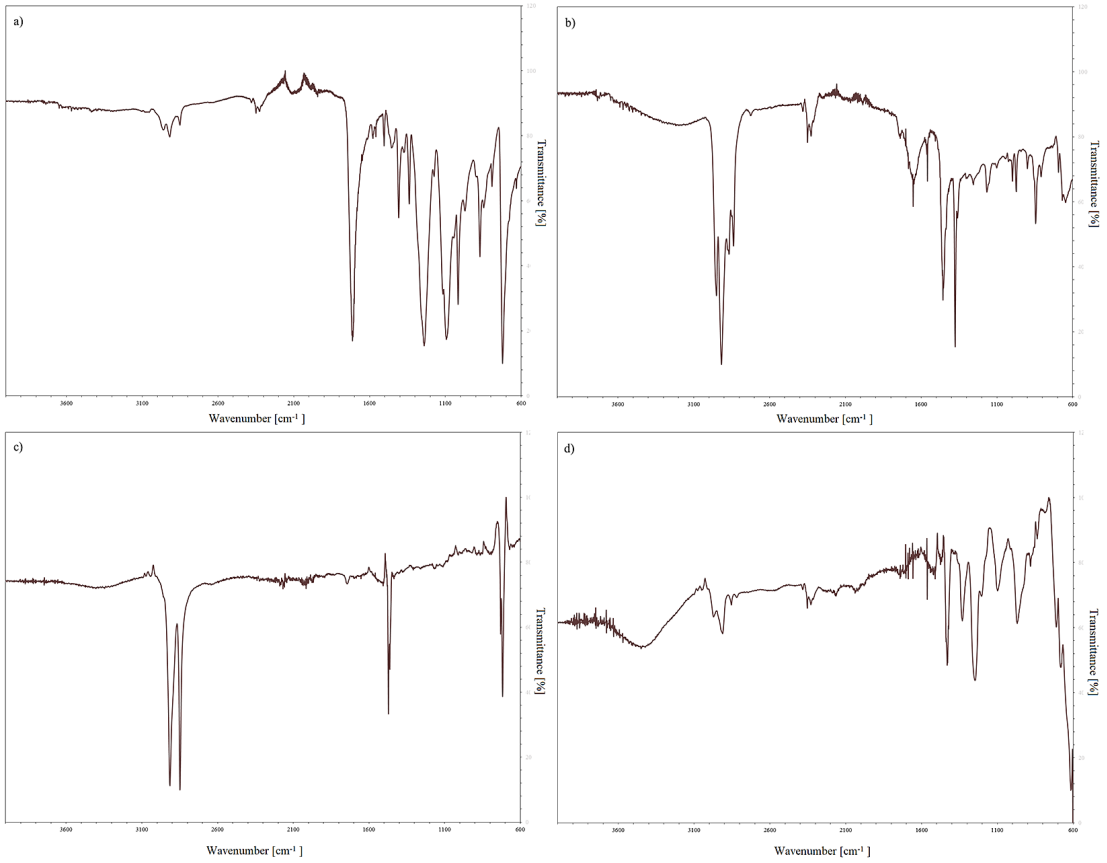

Figure 4. FTIR spectra (4000-600 cm^{-1}) of representative particles isolated from soil samples and identified by comparison with reference spectra from the spectral library (n = 27 particles analyzed): (a) PET, (b) PP, (c) PE, and (d) PVC

intense band is also visible at 1712 cm^{-1}, corresponding to the C=O carbonyl group of the ester group. Strong bands were recorded at 1240 and 1093 cm^{-1}, attributed to C-O-C stretching, as well as bands at 871 and 721 cm^{-1}, associated with skeletal vibrations of the aromatic ring. The spectrum obtained was consistent with the reference spectrum of PET.

The second particle's spectrum (Figure 4b) displayed intense C-H stretching bands (CH_2/CH_3, asymmetric and symmetric) in the 3000–2800 cm^{-1} range. The superimposed band doublet at 1375 cm^{-1}, characteristic of polypropylene, corresponds to symmetric bending of the CH_3 group, while the band at 1456 cm^{-1} was attributed to asymmetric bending of the CH_2 and CH_3 groups. In the 1250–950 cm^{-1}, C-O/C-C stretching bands were observed, and in the 950–600 cm^{-1} range, skeletal vibrations of the chain appeared. Additionally, a peak was recorded in the 3600–3200 cm^{-1} range (O-H stretching) and a band at 1652 cm^{-1} (C=O stretching), absent from the reference spectrum of pure PP. The presence of these additional bands may suggest partial oxidation of the particle surface, resulting from photodegradation of the polymer in the soil environment. The band at 2326 cm^{-1} is an artefact originating from atmospheric CO_2. Based on the characteristic band pattern, the particle was identified as PP, showing signs of environmental weathering.

The third spectrum (Figure 4c) is characterized by two dominant peaks at 2916 and 2848 cm^{-1}, corresponding to the asymmetric and symmetric stretching vibrations in the CH_2 group. Additional bands were observed at 1471 and 717 cm^{-1} attributable to C-H bending vibrations in the CH_2 group. The resulting band pattern is consistent with the reference spectrum of PE.

The last spectrum (Figure 4d) shows a broad band in the range 3600–3100 cm^{-1} and a double peak at 2966 and 2912 cm^{-1} (C-H stretching). Bands were recorded at 1431/1327 cm^{-1} (CH_2 bending/wagging), and 1246/968 cm^{-1} (C-H bending/wagging). A distinct decrease in transmittance was observed towards lower wavenumbers, consistent with the C-Cl stretching band lying below the measured spectral range. The recorded band pattern confirms the presence of PVC.

The quality of the recorded spectra varied, some particles yielded spectra characterized by a high signal-to-noise ratio and clearly resolved bands, allowing unambiguous matching to a library of reference spectra, while others were characterized by lower signal quality, which limited the certainty of identification. In one case, the spectrum did not show bands characteristic of synthetic polymers, and the particle was excluded from the group of confirmed synthetic polymers. The results indicate that classifying particles based solely on microscopic observation does not allow unequivocal confirmation of their polymeric nature. This limitation underscores the need for careful interpretation of visual identification results and supports the use of spectroscopic methods as a confirmatory step for establishing composition of particles in microplastic studies. At the same time, the presence of particles with morphological characteristics consistent with microplastics in all analyzed samples is consistent with reports from other agricultural soils. These findings confirm the need for further research involving unambiguous identification of polymers and determination of microplastic contamination in the soil environment.

Microplastics in agricultural soils

The abundance of particles morphologically identified as potential microplastics in this study (107–294 particles kg^{-1} d.m.; mean 197 ± 62 particles kg^{-1}) is at the lower end of the values reported for agricultural soils. Comparably low abundances were found in farmland soils in the suburbs of Shanghai, China (78.00 ± 12.91 and 62.50 ± 12.97 items kg^{-1} in shallow and deep soil, respectively; Liu et al., 2018), and the lower part of the range reported for soils in Hebei Province, China, subject to long-term organic fertilizer application (90-910 particles kg^{-1}, mean 368.88 ± 207.97; Guo et al., 2024). Higher abundances were reported for agricultural soils in southwestern Poland, where sandy soils contained 383 ± 188 particles kg^{-1} and finer-textured soils 933 ± 682 to 1540 ± 912 particles kg^{-1} (Medyńska-Juraszek and Szczepańska, 2023), and for farmland near a wastewater treatment plant in Tehran, Iran with mean 439.5 particles kg^{-1} (Ghadirli et al., 2023). Much higher values were found in agricultural soils in Xiangtan (mean 4377 particles kg^{-1}; Ye et al., 2024) and Chengdu, China (1333–15067 particles kg^{-1}; Liao et al., 2023). Piehl et al. (2018), who identified macroplastic and microplastic particles on farmland by ATR-FTIR, expressed their results per hectare (206 particles ha^{-1} extrapolated), which precludes direct comparison with mass-based abundances.

Direct comparison of these values is, however, limited by differences in sampling depth, the lower size limit of detected particles, the extraction procedure, and the method of identification. Samples in the present study were taken from the 0–5 cm layer, whereas, for example, Medyńska-Juraszek and Szczepańska (2023) sampled the 0–25 cm layer, which may influence the reported abundances, as particle concentrations can vary with depth. In addition, particles in the present study were identified mainly visually, with chemical confirmation by ATR-FTIR for a subset of 27 particles that were large enough for ATR measurement. Abundances based on visual identification may be overestimated because not all particles are polymers. The abundances are also influenced by land use and inputs: the highest values in the cited studies were associated with proximity to wastewater treatment plants (Ghadirli et al., 2023), organic fertilizer application (Guo et al., 2024), and soil texture (Medyńska-Juraszek and Szczepańska, 2023). The relatively low abundances found here should therefore be interpreted with caution, as they may reflect the sampled land use and the methodological limitations of the study (a small number of samples, the shallow sampling depth, and the lower size limit of the applied method), and as the fields were not characterized in terms of fertilization history or soil texture. The polymers identified here (PE, PP, PET, and PVC) are among the most frequently reported in agricultural soils (Merino-Guzmán and Jofré-Fernández, 2025).

The impact of microplastics on crops

The present study did not assess the effects of microplastics on crop plants; the following section summarizes evidence from the literature that provides context for the presence of microplastics in agricultural soils. The presence of microplastics in agricultural soils may pose risks to crop production, affecting plant physiology both directly and indirectly by disrupting soil properties and the microbiome (Figure 5). Direct mechanisms of microplastic phytotoxicity include the physical blockage of seed pores and root cells, which impedes the uptake of water and minerals. Azeem et al. (2021)

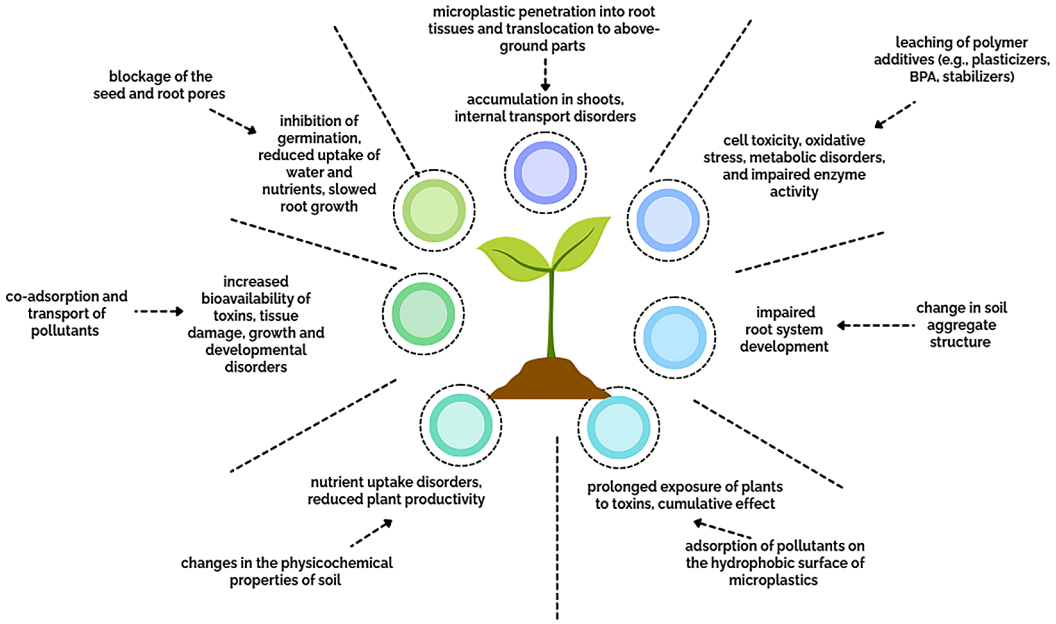

Figure 5. Mechanisms of microplastic action on crop plants, reported in the literature

found that smaller polymer particles can penetrate root tissues much more easily than larger particles and subsequently translocate to above-ground shoots. De Silva et al. (2022) further showed that the presence of polyethylene microplastics can affect lentil seed germination by inhibiting metabolic activity in the early stages, which may result from physical pore blockage. Similar observations were made by Wang et al. (2021), who revealed that the dry weight of soybeans was reduced after the addition of various concentrations of microplastics compared with the control and, additionally, after the seventh day, an inhibition of root length was observed, which was positively correlated with concentration. Indirect mechanisms, primarily related to changes in soil properties, significantly influence how microplastics affect plants.

Microplastic particles can alter soil physicochemical properties, leading to a decrease in density, disruption of aggregation, changes in water-holding capacity, and alterations in enzymatic activity. Additionally, microplastics can adsorb or act as transport vectors for contaminants, including heavy metals such as cadmium (Martin and Turner, 2019), lead, chromium, and zinc (Godoy et al., 2019), and pesticides (Peña et al., 2023), thereby increasing their bioavailability in soil and potentially in plant tissues. Gasperi et al. (2018) further noted that fibrous microplastics can also act as vectors for atmospheric pollutants, broadening the range of contaminants with which microplastics interact in the environment.

Beyond their direct and indirect effects on crops, microplastics function as vectors for chemical pollutants released both during manufacturing and subsequent degradation. During plastic production, numerous additives are used, such as plasticizers, flame retardants, and residual monomers, which may be released into the soil (de Souza Machado et al., 2018). Their release has been shown to intensify as the material degrades, particularly under conditions of high soil biological activity. Furthermore, the hydrophobic surface of microplastics promotes the sorption of other environmental contaminants, such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and organochlorine pesticides (Horton et al., 2017). The accumulation of microplastics in agricultural soils and their ability to migrate into groundwater pose risks to food safety and the quality of water resources. This threat is further exacerbated by the use of sewage sludge and compost containing microplastics, which leads to their long-term accumulation in terrestrial ecosystems and increases the potential exposure of living organisms, including humans, to these contaminants.

Potential health risks resulting from exposure to microplastics

Human exposure and health effects were not assessed in this study. The evidence below comes from previous experimental (in vitro and

in vivo) and review studies and is presented as background for interpreting the significance of microplastic occurrence in agricultural soils. Agricultural soil is a major source of terrestrial microplastics, and their ability to penetrate crop tissues creates a direct route of human exposure through the food chain. Once absorbed, these particles have been reported to cross biological barriers and accumulate in internal organs, including the placenta (Weingrill et al., 2023; Oliveira et al., 2025), brain, kidneys, liver (Garcia et al., 2024; Erdely et al., 2025), and heart (Dzierżyński et al., 2025). In vitro and in vivo studies indicate that microplastics can affect multiple body systems, inducing oxidative stress, inflammation, and cellular damage (Figure 6) (Prattichizzo et al., 2024). Alongside the particles themselves, released chemicals such as plasticizers, PCBs, and heavy metals may trigger chronic inflammation, contributing to gastrointestinal, pulmonary, reproductive, cardiovascular, and neurotoxic effects (Lei et al., 2024). Irregular edges and large surface area can cause physical damage such as internal abrasions, epithelial atrophy and desquamation, perforation, and even obstruction of the intestine (Ding et al., 2023). The gut microbiome can further break microplastics into smaller fragments, damaging the intestine by disrupting immune function and microbial balance (Teng et al., 2022). Additives used in plastic manufacturing (such as bisphenol A, phthalates, styrene) have been associated with allergic, carcinogenic, and toxic effects (Patil et al., 2022). Due to its large surface area, the gut readily adsorbs microplastics, triggering intestinal irritation, macrophage activation, and cytokine release (Bouwmeester et al., 2015). These particles also transport carcinogens such as BPA and phthalates, elevating cancer and immune disorder risks (Segovia-Mendoza et al., 2020). In addition to risks to the liver and digestive system, 90-day polystyrene exposure impaired cardiac function in rats via oxidative stress, apoptosis, pyroptosis, and inflammation (Wei et al. 2021).

The particles identified in this study should be interpreted in the light of this literature with caution. The polymers confirmed by FTIR (PE, PP, PET, and PVC) are among those most frequently reported in agricultural soils and are those for which additive release and sorption of contaminants have been described. The oxidation bands observed in the spectrum of one PP particle (Figure 4b) indicate surface weathering, a process that has been associated with fragmentation and changes in sorption properties. However, most of the particles isolated here were at least about a hundred micrometres in size, whereas uptake into plant tissues and passage across biological barriers have been

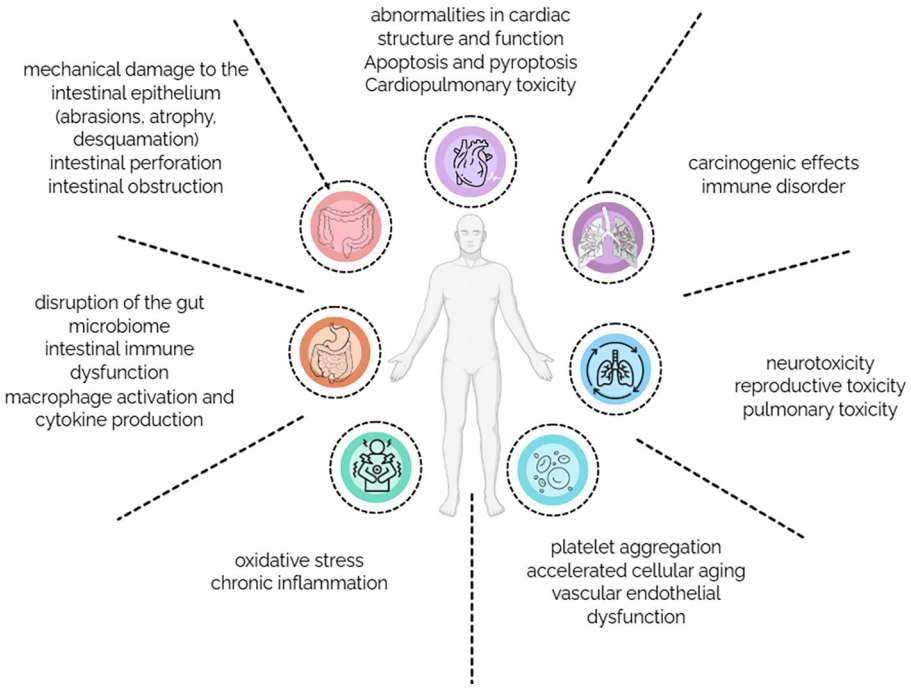

Figure 6. Schematic overview of the potential health effects of microplastic exposure in humans reported in previous studies

reported mainly for much smaller particles. The health and crop effects described above therefore cannot be inferred from the present data; they may be relevant to the smaller fraction that was not captured by the applied method or that can arise from further fragmentation of the particles found. Moreover, the abundances observed here (107–294 particles kg^{-1} d.m.) cannot be directly compared with the concentrations used in many exposure experiments. Assessing the actual risk would require data on particle size distribution, bioavailability and exposure, which lie beyond the scope of this pilot study.

CONCLUSIONS

The study confirmed the presence of particles with microplastic characteristics in all analyzed agricultural soil samples collected in the Lubelskie Voivodeship. A total of 108 particles were isolated and morphologically classified. Their abundance ranged from 107 to 294 particles kg^{-1} d.m. Morphological analysis showed that irregular fragments (57.4%) predominated over other shapes, although the proportion of individual shapes varied among soil samples. Chemical identification using FTIR spectroscopy, conducted on 27 selected particles, confirmed the presence of at least four types of synthetic polymers (PET, PP, PE, and PVC), the polymer identity of the remaining particles was not determined, so the reported abundances should be treated as an upper estimate. Given the varying spectral quality, and the limited, partial spectroscopic coverage across only six soil samples, the study is pilot in nature. Its results provide preliminary data for the studied fields and should not be extrapolated to the whole region or used for national-level generalization. Since the effects of microplastics on crops and human health were not assessed in this study, the literature data discussed in this paper serve only as context and, together with the present findings, indicate the need for further research based on a larger number of samples, including quantitative assessment of particle size and abundance, and studies of their impact on soil quality, crops, and human exposure.

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