Overview of microplastics in agricultural settings

Viveka Öling-Wärnå

Interreg
Aurora
Co-funded by the European Union

Viveka Öling-Wärnå, Novia University of Applied Sciences
Overview of microplastics in agriculture settings

Novia University of Applied Sciences, Wolffskavägen 31, 65200 Vasa, Finland

Cover image by Ceclia Palmborg

Novia Publikation och produktion, serie R: Rapporter 6/2025
ISBN: 978-952-7526-55-2 (Online)
ISSN: 1799-4179

Abstract

In recent years, the environmental pollution caused by plastics and microplastics has received a lot of attention. Microplastics in agricultural settings primarily reach soil through agricultural practices, organic fertilizers (sewage sludge, digestate or compost), and atmospheric deposition. This report compiles the results of current research about the abundancy of microplastics in agricultural soils after fertilization with sewage sludge and briefly summarized possible effects of microplastics on soil processes, plant growth and soil organisms. Detection of microplastic particles is challenging and some important points from the first test standard for microplastics are highlighted in the report. National and EU regulations on plastic pollution in sewage sludge and digestate from biowaste are also addressed, and measures to reduce microplastic pollution in organic fertilizers are proposed. This report was prepared as part of the Boost Nordic Biogas project, financed by the European Union via Interreg Aurora.

Key words: microplastics, agriculture soil, sewage sludge, environmental pollution, organic fertilizers

Abstrakt

Under de senaste åren har miljöföroreningarna som orsakas av plast och mikroplaster fått stor uppmärksamhet. Mikroplaster i jordbruksmiljöer når främst marken genom jordbruksmetoder, organiska gödselmedel (avloppsslam, rötrest eller kompost) och atmosfäriskt nedfall. Denna rapport ger en översikt över aktuell forskning om förekomsten av mikroplaster i jordbruksmark efter gödsling med avloppsslam och sammanfattar kortfattat möjliga effekter av mikroplaster på markprocesser, växttillväxt och markorganismer. Detektion av mikroplastpartiklar är utmanande och några viktiga punkter från den första teststandarden för mikroplast lyfts fram i rapporten. Nationella och EU-bestämmelser om plastföroreningar i avloppsslam och rötrester från bioavfall tas också upp, och åtgärder för att minska mikroplastförorening i organiska gödselmedel föreslås. Denna rapport har tagits fram som en del av projektet Boost Nordic Biogas, finansierat av Europeiska unionen via Interreg Aurora.

Nyckelord: mikroplaster, jordbruksmark, avloppsslam, miljöföroreningar, organiska gödselmedel

Preface

In this report, the latest scientific research in the field of microplastics in agriculture setting is explored, including a summary of the first microplastics testing standard ISO 24187:2023. Additionally, a short overview of the regulations concerning microplastics in organic fertilizers is provided and steps for reducing microplastic contamination in digestate are compiled in the end.

The literature overview has been done in the framework of the Interreg Aurora funded Boost Nordic Biogas project. The target groups in this project and in our previous project Bothnia Nutrient Recycling (Interreg Botnia-Atlantica) have raised a concern about what happens to the microplastic particles found in both sewage sludge and digestate, and how the soil health and ecosystem are affected by these particles. With this report, we hope to provide insight into these problems and increase the target group's knowledge about microplastics in agricultural settings.

This work was financed by the European Union via the interregional fund Interreg Aurora (Boost Nordic Biogas NYPS-id 20357975). National co-funders in Finland were Novia University of Applied Sciences and Regional Council of Lapland. Boost Nordic Biogas project partners are Novia University of Applied Sciences (lead partner), Ab Stormossen Oy, BioFuel Region, Swedish University of Agricultural Sciences, and SINTEF Narvik.

The project team members Nina Åkerback (Novia University of Applied Sciences) and Cecilia Palmborg (Swedish University of Agricultural Sciences) are acknowledged for valuable feedback on the final version of this report.

Viveka Öling-Wärnå

Project researcher, PhD, Novia University of Applied Sciences

26 May 2025

Table of Contents

Overview of microplastics in agricultural settings

Introduction

In recent years, the environmental pollution caused by larger plastics and microplastics has attracted widespread attention. Microplastics in the environment was first proposed by Thompson RC *et al.* (2004) for plastic waste in the marine environment. Microplastics in the marine environment have since then been extensively studied, while studies preformed in the soil environment has started relatively late. The first to suggest that microplastics can have a harmful effect also in soil was Rillig (2012) .

Microplastics can occur in the environment either as primary or secondary microplastics. Small plastic particles that are manufactured for several purposes (e.g. for industrial use, in cosmetic products) can enter the environment directly and are called primary microplastics. Secondary microplastics are broken down from larger-sized pieces of plastic (e.g. food wrapping, agricultural films, tires, and synthetic textiles) by physical, chemical and biological processes, sun light and high temperature. (Auta, Emenike and Fauziah, 2017)

European Chemicals Agency (ECHA) and the US Environmental Protection Agency (EPA) define microplastics as plastic particles under 5 mm in size (EPA, 2024; ECHA, no date). Due to their small size and the fact that they are slowly degradable, microplastics are found everywhere in nature. Studies show a global spread of microplastics from remote areas of Siberia to tropical coral reefs (Materić *et al.*, 2022; Bian *et al.*, 2024). Moreover, microplastic particles have been found in for example fish, fruit and vegetables, beer and tap water, and in human and animal tissues (Kosuth, Mason and Wattenberg, 2018; Oliveri Conti *et al.*, 2020; Ragusa *et al.*, 2021; Thiele *et al.*, 2021; Bhowmik, Saha and Saha, 2024).

Although agricultural soils have been pointed out as major sinks of microplastics in terrestrial land, high levels of microplastic have also been reported in soils across various land due to unintentional plastic sources. For example, mangrove soils in Brazil have been reported to contain 555 to 31 087 microplastics (MPs)/kg in the 30 cm topsoil (Paes *et al.*, 2022), soils from parks and recreational areas in Amsterdam in the Netherlands have been found to contain 4 825.31 (± 6 513.85) MPs/kg soil (Cohen *et al.*, 2021) and soil samples taken from roadside in the metropolitan area of Seoul, South Korea, contained 4 987 MPs/kg soil (Yoon, Kim and Kim, 2024). These examples underscore the extensive and widespread microplastic contamination on terrestrial land.

Microplastics sources and abundancy in agricultural soil

Plastic materials find widespread application in agriculture because of their adaptability, durability, and low production costs. Mulching films and greenhouses help to enhance crop yield and quality. Agricultural plastic (both fossil and bio-based) can degrade into smaller fragments over time. Especially very thin films (8-50 µm) can be difficult to recover completely and can become a source of microplastics in agricultural land. Soils also encounter unintentional plastic contamination from sources like organic fertilizers (sewage sludge or compost), polymer-coated fertilizers[1], irrigation water, littering, and atmospheric deposition (Kumar *et al.*, 2020; Tian *et al.*, 2022) (Fig. 1). For example, in China, agricultural soils under intensive plastic-greenhouse vegetable production have shown high microplastic levels (7 100–42 960 MPs/kg soil), linked to frequent cropping, irrigation from nearby water bodies, and use of inorganic and organic amendments (including sewage sludge) (Zhang and Liu, 2018). Atmospheric deposition of microplastics can also be significant, especially in industrial and urban areas. A study from Paris showed a higher atmospheric fallout of microplastics at the urban site 110 (±96) particles/m^2/day on average than at the suburban site 53 (±38) particles/m^2/day (Dris *et al.*, 2016). In central London the deposition of microplastics has been reported to 575–1 008 MPs/m^2/day (Wright *et al.*, 2020). Microplastics in the air come mostly from wear and tear from rubber tires, synthetic textile fibres, and city dust (Kole *et al.*, 2017).

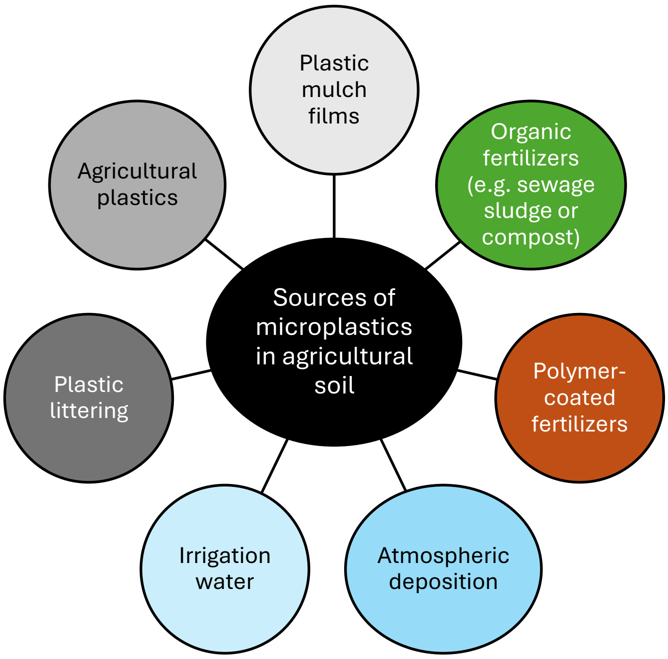

Figure 1. Diagram illustrating various sources of microplastic particles into agricultural soils.

[1] European market of polymer-coated fertilizers is mainly located to France, Germany, Italy, Netherlands, Russia, Spain, Ukraine, and United Kingdom (Research and Markets, 2024).

Microplastics in sewage sludge

Microplastics are abundant in wastewater, and the sources are mainly microbeads in industry and in personal care products, fibres from laundering of synthetic clothes, tyres, and road wear particles from urban runoff. Wastewater treatment plants (WWTPs) demonstrate a high removal efficiency of microplastics from incoming wastewater, with removal rates reaching approximately 99% (Carr *et al.*, 2011; Murphy *et al.*, 2016; Lares *et al.*, 2018). However, a major part of the microplastics (~80%) end up in the sludge and the rest is recycled back into the process with reject water (Talvitie *et al.*, 2017; Öling-Wärnå, Åkerback and Engblom, 2023). According to literature reviews, the amount of microplastics in sewage sludge varies a lot, mostly due to temporal variations and the treatment methods used at the WWTP. Concentrations as 450–113 000 and 1 000–170 900 MPs/kg dry weight (dw) in sewage sludge have been reported in review studies (Iyare, Ouki and Bond, 2020; Rolsky *et al.*, 2020). Seasonal variation of microplastic concentrations in sludge have also been described, with increased microplastic concentrations after periods of rainfall[2] and after higher levels of sun exposure[3] (Rolsky *et al.*, 2020; Sol *et al.*, 2020; Öling-Wärnå, Åkerback and Engblom, 2023). Furthermore, a recent study showed that biosolids (i.e., sewage sludge) from larger WWTPs (service populations of > 100 000 people) contained higher numbers of microplastics (2 810–4 940 MPs/kg dw) compared to lower numbers (900–1 730 MPs/kg dw) detected in biosolids from treatments plants with service populations < 10 000 people (Ruffell *et al.*, 2025).

In a study from the U.K. authors estimated the number of plastic particles in the 10 million tonnes of sewage sludge produced annually in the EU to be around 7.2 trillion to 149 trillion per year (Iyare, Ouki and Bond, 2020). Likewise in China, the average number of microplastics have been estimated to 156 trillion particles released into the environment through sewage sludge annually (Li *et al.*, 2018). In Finland, Selonen *et al.*(2023) have estimated that approximately 1.4 to 12 trillion plastic particles end up in agricultural soil with sewage sludge each year. Based on estimates that 62 000 tons of dry sludge end up in agricultural soil in Finland (Vilpanen and Seppälä, 2021) and that the sludge contains 23 000 to 187 000 MPs/kg (Talvitie *et al.*, 2017; Lares *et al.*, 2018). This is a higher load of microplastics per year than Selonen *et al.*(2023) estimated to end up in agricultural land from mulch film and agricultural plastics over a period of several years of use.

---

[2] Due to microplastic entrance into the sewage system when they are washed from the ground.
[3] Sun exposure helps fragmentation and degradation of plastics.

Microplastics in soils from farmlands with sewage sludge application

One aim of this report was to provide an overview over the extent of microplastic pollution in agriculture soils, with the focus on potential input from recycled waste products such as sewage sludge and digestate. Table 1 summarizes the findings from several studies that have measured microplastics content in soils following sewage sludge fertilization. Microplastics numbers in the soil samples varied from 3.7 (±11.9) to 12 866 (±4450) MPs/kg of dry soil. Microplastic particles were also reported in control soils (non biosolids-amended soils), but in lower range 3(±2) to 1 466 MPs/kg (Table 1). The abundance of microplastic particles in soil can vary depending on the type of biosolids used, application rate, sampling technique and microplastic extraction, as well as the climate conditions (Adhikari *et al.*, 2024). The lack of standard procedures for sampling and analysis of biological matrices also make is difficult to compare the study results. Published studies use particle numbers per fresh or dry weight soil, others use plastic weight per dry weight soil, or some use particle number per area. (Johansen *et al.*, 2024) Therefore, comparing microplastic concentration across different studies is challenging.

However, study results show that microplastic concentrations are correlated with increased rate of biosolids applied (Corradini *et al.*, 2019; Zhang *et al.*, 2020) and that continuous amendment with sewage sludge-based fertilizers may lead to accumulation of microplastics and promote their migration into the deeper layer of soils and eventually reach groundwater (Zhang *et al.*, 2020; Weber, Santowski and Chifflard, 2022). Even 34 years after ended sewage sludge application microplastics have been found in the soil to a higher extent than from nearby soil without history of sewage sludge treatment (Weber, Santowski and Chifflard, 2022).

Table 1. Abundance (mean microplastic particles / kg dry soil), characteristics and sources of microplastics in agricultural soils amended with sewage sludge.

Location	Abundance	Abundance in control soil*	Prevalent size and shape	Prevalent type	Identification method	Prevalent source (and application load)	Reference
Sweden, Lanna, Västerås (2 agricultural fields)	Lanna 89(±13) MPs/kg; Västerås 32(±11) MPs/kg;	3(±2) MPs/kg	100 µm, 300 µm; fragments, fibres, flakes	n.d.	Visual inspection	Sewage sludge (Lanna, 8.6 ton dw /ha/year, in total 20 years); (Västerås, 1.3 ton dw/ha/ year, in total 18 years)	Nilsson, 2017[4]
Denmark, Sjaelland, Jylland (7 agricultural fields)	12 866 (±4 450) MPs/kg	1 466 MPs/kg	10-500 µm, 500-5 000 µm	Acrylic, PES	Visual inspection, ATR-FTIR, µFTIR	Sewage sludge (2003-2012), corresponding to ~40 years of normal phosphorus load)	(Klemmensen *et al.*, 2023) CRUCIAL study
Germany, Schleswig-Holstein (15 agricultural fields)	3.7(±11.9) MPs/kg; (range 0-218 MPs/kg)		1–5 mm; fragments, fibres, foil, platelets	PE, PP, nylon, PA	Visual inspection, FTIR	Sewage sludge (12-37 tons/ha), biogas fermentation residue (270 tons/ha), liquid manure (105-150 tons/ha), and cattle, horse, pig manure (10-638 tons/ha)	(Harms *et al.*, 2021)
Germany, Hesse (2 agricultural fields)	Field A: 9.10-31.80 MPs/kg; Field B 3.35-9.82 MPs/kg		0.3-4.91 mm; fragments, pellets, filaments, films	PE, PET, PP, PS, rubbers	Visual inspection, FTIR	Sewage sludge (A:~120-200 tons/ha for 13 years.) (B: ~2.5-5 tons/ha for 17 years). Soil samples taken 34 years after the last sludge application.	(Weber, Santowski and Chifflard, 2022)
Spain, Valencia (16 agricultural fields)	2 130(±950) light density MPs/kg; 3 060(±1 680) heavy density MPs/kg	930(±740) light density MPs/kg; 1 100(±570) heavy density MPs/kg	150-250 µm; fragments, fibres	PP, PVC	µFTIR	Sewage sludge (20-22 tons dw/ha)	(Van Den Berg *et al.*, 2020)
USA, Washington state (1 agricultural field)	383, 500, and 361 MPs/kg	117 MPs/kg	<1 mm; films, pellets, fibres	PU, PET, PA, PE	Visual inspection, FTIR	Sewage sludge digestate (4.8, 6.9, and 9.0 tons/ha)	(Adhikari *et al.*, 2024)
Chile, Mellipilla county (31 agricultural fields)	3 500 MPs/kg** (range 600 – 10 400 MPs/kg)		<2 mm; fibres, fragments, films, pellets	n.d.	Visual inspection	Sewage sludge (200 ton dw/ha)	(Corradini *et al.*, 2019)
China, Zhongyong County (3 agricultural fields)	545.9(±45.7) MPs/kg; 87.6(±9.3) MPs/kg	5.0(±0.4) MPs/kg	< 0.2 – 5 mm; flakes, fibres, films	PE, PP, PET, PP/PE, PB, EVA	Visual inspection, µFTIR	Sewage sludge compost (~30 ton/ha and 15 ton/ha)	(Zhang *et al.*, 2020)
China, Jiangsu province (1 agricultural field)	68.6(±21.5) - 149.2(±52.5) MPs/kg	40.2(±15.6) MPs/kg	0.021-4.996 mm; fibres, fragments, films, granules, and spheres	PES, PP, PAN, PE, PA, PS	Visual inspection, ATR-FTIR, µFTIR	Sewage sludge, dry heat-treated municipal sludge (16.2 tons/ha; heat-treated 3.3 tons / ha. Applied twice each year)	(Yang *et al.*, 2021)

EVA ethylene vinyl acetate copolymer, MPs microplastics, n.d. not determined, PA polyamide, PAN polyacrylonitrile, PB polybutylene, PE polyethylene, PES polyester, PET polyethylene terephthalate, PP polypropylene, PS polystyrene, PU polyurethane, PVC polyvinylchloride. *Control soil, non biosolids-amended soil, ** Median microplastic particles / kg dry soil.

---

[4] Nilsson, J. (2017). Förekomst av mikroplast i åkermark gödslad med avloppsslam. Kvantifiering och mätmetodik. Master thesis. Department of Biology and Environmental Sciences. University of Gothenburg.

Microplastics in biowaste compost

Biowaste compost is also commonly used as organic fertilizer and may be a neglected source of microplastics in agricultural soil. Only a limited number of scientific studies have been published about microplastic content in biowaste composts so far. Highest concentrations of microplastics have been found in composts from household waste or commercial food waste, likely originating from degradation of larger plastic items like bags and containers utilized for packaging. A significant amount of food waste from industrial and commercial settings can remain in its package for various reasons (e.g. passed expiration date, quality issues). At the waste recipient, this necessitates a form of depackaging, either through mechanical processes or human labor, both of which are prone to produce inconsistent and suboptimal separation efficiencies. (Porterfield *et al.*, 2023)

In a review study, microplastic particles in homogenize food waste varied widely from 36 to 1 400 (±150) MPs/kg dry material. Although the study with lowest number of particles had focused on larger particles (1-5 mm) and the study reporting higher numbers had examined only smaller particles (0.1-2 mm). Microplastics in biowaste compost from grocery stores could be as high as 300 000 MPs/kg dry material, found in a study from the United States. Composts from only green waste or energy crop digesters have also very variable numbers of plastic particles, ranging from 12 (±8) to 82 800 (±17400) MPs/kg. (Porterfield *et al.*, 2023) This indicates that packaging from food waste is not the only possible source of plastics in biowaste composts.

In a recently published study from New Zealand, biodegradable plastics (PLA and PBAT[5]) were detected in mature finished compost, suggesting that composting processes at commercial facilities have not been sufficient to complete biodegradation of these compostable plastic types (Ruffell *et al.*, 2025). At the moment there is limited evidence to support the complete degradation of biodegradable plastics in soil (Liao and Chen, 2021). Especially in countries with colder climate conditions the degradation of biodegradable plastics in soil seem to be even slower according to research done by the Finnish Environment Institute (Selonen *et al.*, 2023).

The impact of microplastics in agricultural soil

The risks with microplastics in agricultural soil are not well-known and have been studied for a shorter time than the marine environment. The microplastic impact can be related to physical interactions of the particles and / or to chemical exposures. Microplastics are complex materials that contains many chemical substances and

[5] Polylactic acid (PLA), polybutylene adipate-*co*-terephthalate (PBAT).

additives (e.g. plasticizers, stabilizers, and flame retardants) that potentially can leak into the surrounding environment. Some of the additives are known to cause cancer, mutations, and disrupting reproduction. Microplastics can also bind hydrophobic organic substances and work as a transport carriers of harmful substances. (Naturvårdsverket, 2019)

It is still unclear how microplastics affect soil properties. Studies have shown that microplastics in soil can affect several below ground processes, such as decrease microbial activity, decrease pH, increase soil aggregates, enhance the conductivity of water and accelerate soil water evaporation. Not much is known about how plants respond to the presence of microplastics. Laboratory experiments, however, have shown plant root traits, plant leaf traits, and total biomass to be altered when microplastics are presents in soil. For example, in the presence of microplastics inhibition of growth and photosynthetic efficiency in tomatoes, soybeans, and rice have been reported. The specific effects appear to be influenced by the type, size, and concentration of the microplastics, as well as the crop type and growth stage. (Yan and Yang, 2023; Nath *et al.*, 2024) There is also findings suggesting that microplastics in soil can cause harm to soil organisms such as earthworms, nematodes, and springtails (e.g. negative impact on their growth and reproduction) (Yan and Yang, 2023). Earthworms from two sludge compost-amended fields have been found to contain 1.8 (±1.6) and 0.4 (±0.7) MPs / individual, while earthworms collected from a field without compost application contained no microplastics (Zhang *et al.*, 2020). Soil animals can act as a route for microplastics to enter terrestrial food chain when other animals ingest them.

Microplastics and nanoplastics (1 to 1 000 nm) have as well been found to transfer into plants (e.g. carrot, radish, onion, lettuce, tomato). Roots are the primary pathway for plastic particles to enter plants. Generally, particles under 3 µm have been shown to penetrate plant tissues, with impact on plant growth, causing oxidative stress (that can lead to DNA damage), and disturbing nutrient balance (Lazăr *et al.*, 2024). In a study from Italy microplastic particles have been found in apple, pear, broccoli, lettuce, carrot, and potato purchased from fruit markets and grocery stores. The highest level of microplastics were found in apples (Oliveri Conti *et al.*, 2020). The uptake of microplastics by plants and their entry into the food chain can lead to potential health issues in humans, including oxidative stress, immunological disorders, and a higher risk of cancer (Prata *et al.*, 2020), but little is known about this so far.

It should be noted that the laboratory experiments to date have mostly used commercially manufactured microplastic particles (e.g. microbeads), which are not representative for the microplastics particles typically found in soil. Microplastics in agricultural soil are commonly fibres, films, pellets, and fragments. Additionally, the concentrations of microplastics used in laboratory experiments have often been higher than what have been observed in the environment. The potential negative impacts of environmentally relevant levels of microplastics in agricultural soils remain unclear. It is important to obtain more data from long-term studies preformed under natural outdoor conditions and with realistic concentrations. (Boots, Russell and Green, 2019; Yan and Yang, 2023) E.g. field experiment CRUCIAL in Denmark, with long-term sewage sludge and composted household waste application, did not suggest a negative impact on soil health (Johansen *et al.*, 2024). Further investigations on the impact of microplastics on plants, soil organisms, and physiochemical properties are needed to ensure the health of our soils, ecosystems, and groundwater.

The first standard for microplastic analysis

Determining the exact number, size, and shape of plastic particles provides a thorough understanding of the presence of microplastics in environmental samples and is valuable for further risk assessment. The first internationally recognized microplastic testing standard ISO 24187 was published in October 2023 (ISO 24187, 2023). The standard is titled "Principles for the analysis of microplastics present in the environment" and can be applied to environmental matrices, but also to other sample types such as food and drinking water.

The analysis of plastics and microplastics is a new field in the areas of environmental analysis. One problem is that the scientific publications have not applied a uniform analysis, which makes it difficult to compare the results. Hopefully, this standard can promote the harmonization of microplastic analysis.

The standard includes a table that categorizes the microplastic particles into seven size ranges together with average particle size, mass and number of particles per 14.13 mg for each class (Table 2). Microplastic particles in sizes between 1 mm to 5 mm are classified as "large microplastics" in the standard, but this is not generally a practice. EU and US chemical and environmental agencies define microplastics as all plastic particles smaller than 5 mm (ECHA, EPA).

Table 2. Particle size classification according to ISO 24187, table modified from ISO 24187.

Particle size (µm)	Avg. particle size (µm)	Mass (mg)*	Number of particles in 14.13 mg
1 to < 5	3	1.4×10^{-8}	1.0×10^{9}
5 to < 10	7.5	2.2×10^{-7}	6.4×10^{7}
10 to < 50	30	1.4×10^{-5}	1.0×10^{6}
50 to < 100	75	2.2×10^{-4}	6.4×10^{4}
100 to < 500	300	0.014	1 000
500 to < 1 000	750	0.22	64
1 000 to 5 000**	3 000	14	1

*Mass is an estimation of average-sized (3 000 µm) spherical particle with a density of 1. **Particles in this size are classified as "large microplastics".

Detection techniques for analysis of microplastic particles

For the identification of which particles are of plastic, the standard lists several analytical methods rather than one single approach. For example, spectroscopy methods are suggested such as Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy. A wide variety of plastic polymers can be detected and identified with FTIR and Raman and can give a total number of particles. Additional techniques are suggested in the standard, but the above mentioned are commonly used in scientific research (Rolsky *et al.*, 2020; Casella *et al.*, 2023). Visual sorting of larger particles using microscopy or hot needle test are also mentioned in the standard, but it is pointed out that the results can be subjective and depending on the expertise of the person preforming the test. Usually, visual sorting is used in combination with a spectroscopy method for confirmation that the sorted particles are of synthetic plastic.

The standard highlights the importance of selecting the most suitable microplastic testing method based on the objective of the analysis. For example, is the main aim to determine polymer types present in the sample or only particle numbers as total and by size range or is mass fraction of microplastic in relation to sample quantity the most interesting.

Sampling and sample preparation for microplastics analysis

Regarding sampling and sample preparation for microplastics analysis following suggestions are mentioned in the standard.

- Sample volume needs to be large enough to examine a sufficient number of particles to reach the limit of detection for the selected analysis technique. Less expected number of particles in the sample → larger volume needed.
- For the filtration processes the particle size classes shown in Table 1 should be used. The filter material should be plastic-free (e.g. stainless steel, silica, alumina).

If particles smaller than 10 µm are investigated, pressure or vacuum filtration is needed.

- The sample preparation steps should not affect the plastics in the sample. For example, if drying is performed, the temperature should generally not exceed 40 °C. Freeze-drying is more favourable. Milling or grinding samples should be avoided.
- Removal of inorganic matrix is recommended for solid samples (e.g. sludge, soil) with density separation method. (Saturated salt solutions of e.g. NaCl, $ZnCl_2$ or NaI.)
- Removal of organic matter is recommended for water and solid samples when spectroscopic detection methods are used. Removal processes could be oxidizing solutions (e.g. hydrogen peroxide or Fenton reagent), enzymatic methods or concentrated acids or bases. However, certain chemicals, agents or experimental conditions can affect the plastic particles.
- Standards that can be used from sampling are ISO 5667 series for water, sediment, and sludge samples and ISO 23611 for soil samples, but should be modified for microplastic analysis where necessary.

Data processing

Depending on the detection method different types of data are obtained, e.g. IR spectra, chromatograms, microscope images, that are interpreted to identify the microplastic content in the sample. In the standard it is emphasized that interpretation of spectrum or chromatogram data requires a person with chemical expertise. Automated reference library searches can speed up the process and allow a less biased interpretation of the results but cannot substitute the specialist. The Annex A included in the standard contains guidelines about advanced data processing.

Regulations on plastic particles in organic fertilizers

Organic compost or digestate can be used as fertilizer if they fulfil the requirements of national or EU fertilising products regulations (2019/1009). Regarding unwanted pollution such as microplastics there is no legislation in force. The existing EU regulation covers visible plastic and applies to compost and digestate as follows: The compost cannot contain macroscopic impurities > 2 mm, such as glass, metal or plastics, no more than 3 mg/kg dry matter or in total no more than 5 g/kg dry matter. From 16 July 2026, the content of impurities > 2 mm shall not be more than 2.5 g/kg dry matter, and in 2029 the limit-value will be re-assessed again. (European Parliament and European Union, 2019)

In Finland, the Finnish Food Authority is responsible for supervising fertilizer products. The new Fertilizer Act 711/2022 regulates the manufacturing, marketing, import, and export of fertilizer products. The Ministry of Agriculture and Forestry's Regulation on Fertilizer Products 964/2023, provides stipulations on the quality requirements for product categories, component material categories and their quality and processing criteria. Allowed amounts of impurities such as, glass, metal, plastics are described as following: Treated sewage sludge or digestate may until December 31, 2027, contain impurities over 2 mm in no more than 5 g/kg of dry matter in any of the following forms: glass, metal, or plastic, and the total amount of these impurities may not exceed 10 g/kg of dry matter. From January 1, 2028, compost may contain impurities of more than 2 mm not more than 2.5 g/kg of dry matter in any of the forms of glass, metal, or plastic and the total amount of these impurities may not exceed 5 g/kg of dry matter. (Finlex, 2022, 2023).

In Sweden, Revaq and SPCR, certify the quality of digestate for producers and for fertilizing products. To be able to use sludge in agriculture, Svenskt Vatten's policy requires that the treatment plant is certified according to Revaq. Revaq certification is controlled by RISE (Research Institutes of Sweden) (Svenskt Vatten, 2025). For biowaste-based products SPCR 120 is available for certification of digestate and SPCR 152 for certification of compost. The number of visible contaminants (plastic, glass, metal, composite material) in biofertilizer is determined through monthly sampling, and a rolling average is calculated based on the results from the most recent 12-month period. The threshold values for plastic differ for liquid/solid biofertilizers and compost. For liquid/solid biofertilizer, the rolling average value for contaminants (> 2 mm) must not exceed 10 cm^2/kg for liquid biofertilizer and 30 cm^2/kg for solid biofertilizer (>20% dry matter content). For compost, the total content of visible contaminant (> 2 mm) may not exceed 0.25% by weight of the dry matter. (Avfall Sverige SPCR 120, 2025; Avfall Sverige SPCR 152, 2025)

In Norway the regulations concerning the application of sludge on agricultural land are found in Lovdata. The total content of plastic, glass, and metal larger than 4 mm must not exceed 0.5% by weight of the total dry weight in the fertiliser (Lovdata, 2003).

(It should be noted that the laws and regulations referenced in this chapter may have changed or been updated since the report was written.)

EU regulations addressing microplastic pollution

The EU is addressing microplastic pollution by tackling the main sources of release. Several actions aim to achieve the Zero Pollution Action Plan's goal of reducing microplastic releases by 30% by 2030 (European Commission, 2023b). In 2023, the European Commission adopted a REACH restriction on intentionally added microplastics to products and a proposal for a regulation to prevent plastic pellet losses to the environment (EUR-lex, 2023; European Commission, 2023a). The REACH restriction refers to plastic particles with a size between 0.1 – 5 mm or 0.3 µm – 15 mm fibre-like particles with a length to diameter ratio greater than three. For example, paints, polishes and cosmetics containing microbeads or other microplastics, glitter powder, pesticides and fertilizers, and infill granules for artificial turf. The transition period is long, several years for different product groups and there are also exceptions from the ban, such as particles that are biodegradable or soluble in water or are permanently integrated or lose their microplastic nature when used (EUR-lex, 2023; TÛV Rheinland Products, 2023). These rules only apply to primary microplastics, but EU are also working on secondary microplastics. Additional regulations are likely to be proposed in the upcoming years.

Steps to reduce microplastic pollution in digestate from sludge and biowaste

Recycling of sewage sludge and biowastes provides soil with valuable nutrients and carbon, reducing landfill waste and greenhouse gases. However, in the long term, microplastics accumulation and other pollutants found in sewage sludge and biowaste can harm plants and soil organisms and change microorganisms' communities (Ruffell *et al.*, 2025). There are also risk with not utilizing digestate in agriculture, as the Swedish Environmental Protection Agency stated in a recent report (Baresel *et al.*, 2024). Mineral fertilizers have a significant environmental impact during extraction and manufacturing, contributing to the depletion of Earth's resources. Increased addition of new external fertilizers (reactive nitrogen and fossil phosphorus) instead of reusing existing nutrients contributes to problems with eutrophication. Dependence on the import of fertilizers increases risk to food supply, preparedness, and total defence during crises. In addition, without the reuse of plant nutrients, there is a risk of losing an important driving force for upstream work and monitoring of important environmental factors (Baresel *et al.*, 2024). In the next section, a list of steps has been compiled with actions that can reduce the abundance of microplastics in digestate from sewage sludge and biowaste. Steps for making the digestate safer for agricultural usage from the microplastic perspective:

1. Removal techniques of microplastics in sludge, dewatering, thermal hydrolysis and anaerobic digestion technologies have been shown to remove 61–78% of the microplastics in raw sludge (Li *et al.*, 2025). According to Tumlin and Bertholds (2020) mesophilic digestion reduces about 40% of microplastics in sludge, but it is

unclear whether the particles are totally degraded or whether they are fragmented to a size difficult to detect.

2. Pyrolysis can eliminate many contaminants in digestate, such as microplastics, per- and polyfluoroalkyl substances (PFAS), pharmaceuticals and chemicals from personal care products (PPCPs). Pyrolysis, heating dried digestate to high temperature in the absence of oxygen, can eliminate many contaminants, and the remaining biochar has several climate-smart properties. In a recent study, the microplastic removal was 91-97% for sewage sludge samples pyrolyzed at 400 °C with a 2-hours residence time. Overall removal of PFAS and PPCPs was > 99% (Keller *et al.*, 2024).
3. It is crucial to develop a normalized method and reporting units for determine microplastics in sludges, digestates and soils, which is valuable for assessment of biosolid application and new technologies related to wastewater treatment. (Rolsky *et al.*, 2020; Casella *et al.*, 2023)
4. Limit the quantity of microplastics that may be present in sludge for soil application. Especially for sludge from larger WWTPs (service populations of > 100 000 people) that have been shown to contain higher levels of microplastics (Ruffell *et al.*, 2025).
5. Upstream work and initiatives on how to reduce microplastics in the incoming materials to biogas plants. E.g. depackaging of the package food waste at source is recommended to reduce the quantities of microplastics in digestate from commercial food waste (Yang *et al.*, 2022). Public awareness and education about responsible disposal of plastics can reduce plastic waste that ends up in the soil.
6. For pre-treatment of biowaste with known plastic content, bag slicers are to prefer over shredders. Although shredders are effective in making material accessible for digestion and biogas production, bag slicers have been shown to produce less formation of plastic fragments than shredders (Steiner *et al.*, 2022). Shredders most likely increases plastic and microplastic contamination in the digestate.
7. Bioplastic bags, used for biowaste collection, need to be better suited for the end purpose of anaerobic digestion and composting. At the moment there is limited evidence to support the complete degradation of biodegradable plastics in soil (Liao and Chen, 2021) – instead can paper bags be used for biowaste collection.
8. Sieving (with e.g. 10/12 mm mesh) of composts has been shown to be an efficient method for removal of fragments > 5 mm, but less efficient for the removal of smaller fragments (1-5 mm) (Steiner *et al.*, 2022).

Hopefully, by combining regulatory measures, scientific research, proactive upstream initiatives, and consistent monitoring efforts, we can ensure the long-term health and sustainability of our agricultural soils.

References

Adhikari, K. *et al.* (2024) 'Accumulation of microplastics in soil after long-term application of biosolids and atmospheric deposition', *Science of The Total Environment*, 912, p. 168883. Available at: https://doi.org/10.1016/j.scitotenv.2023.168883.

Auta, H.S., Emenike, C.U. and Fauziah, S.H. (2017) 'Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions', *Environment International*, 102, pp. 165–176. Available at: https://doi.org/10.1016/j.envint.2017.02.013.

Avfall Sverige SPCR 120 (2025) *2025 Certifieringsregler för biogödsel SPCR 120*. Malmö: Avfall Sverige. Available at: https://www.avfallsverige.se/fakta-statistik/certifierad-atervinning/certifieringsregler-for-biogodsel/ (Accessed: 7 April 2025).

Avfall Sverige SPCR 152 (2025) *2025 Certifieringsregler för kompost SPCR 152*. Malmö: Avfall Sverige. Available at: https://www.avfallsverige.se/fakta-statistik/certifierad-atervinning/certifieringsregler-for-kompost/ (Accessed: 7 April 2025).

Baresel, C. *et al.* (2024) *Återvinning och återanvändning av resurser från avlopp*. Bromma: Naturvårdsverket. Available at: https://www.naturvardsverket.se/4a9517/globalassets/media/publikationer-pdf/7100/978-91-620-7166-0.pdf (Accessed: 21 February 2025).

Bhowmik, A., Saha, G. and Saha, S.C. (2024) 'Microplastics in Animals: The Silent Invasion', *Pollutants*, 4(4), pp. 490–497. Available at: https://doi.org/10.3390/pollutants4040033.

Bian, W. *et al.* (2024) 'Microplastic pollution in tropical coral reef ecosystems from the coastal South China Sea and their impacts on corals in situ', *Journal of Hazardous Materials*, 480, p. 135898. Available at: https://doi.org/10.1016/j.jhazmat.2024.135898.

Boots, B., Russell, C.W. and Green, D.S. (2019) 'Effects of Microplastics in Soil Ecosystems: Above and Below Ground', *Environmental Science & Technology*, 53(19), pp. 11496–11506. Available at: https://doi.org/10.1021/acs.est.9b03304.

Carr, D.L. *et al.* (2011) 'Biological Degradation of Common Pharmaceuticals and Personal Care Products in Soils with High Water Content', *Water, Air, & Soil Pollution*, 217(1–4), pp. 127–134. Available at: https://doi.org/10.1007/s11270-010-0573-z.

Casella, C. *et al.* (2023) 'Microplastics in Sewage Sludge: A review', *Environmental Science and Pollution Research*, 30(23), pp. 63382–63415. Available at: https://doi.org/10.1007/s11356-023-27151-6.

Cohen, Q.M. *et al.* (2021) 'Parks and Recreational Areas as Sinks of Plastic Debris in Urban Sites: The Case of Light-Density Microplastics in the City of Amsterdam, The Netherlands', *Environments*, 9(1), p. 5. Available at: https://doi.org/10.3390/environments9010005.

Corradini, F. *et al.* (2019) 'Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal', *Science of The Total Environment*, 671, pp. 411–420. Available at: https://doi.org/10.1016/j.scitotenv.2019.03.368.

Dris, R. *et al.* (2016) 'Synthetic fibers in atmospheric fallout: A source of microplastics in the environment?', *Marine Pollution Bulletin*, 104(1–2), pp. 290–293. Available at: https://doi.org/10.1016/j.marpolbul.2016.01.006.

ECHA (no date) *Microplastics*, *European Chmicals Agency*. Available at: https://echa.europa.eu/hot-topics/microplastics (Accessed: 21 February 2025).

EPA (2024) *Microplastics Research*, *United States Environmental Protection Agency*. Available at: https://www.epa.gov/water-research/microplastics-research.

EUR-lex (2023) *Commission Regulation (EU) 2023/2055 of 25 September 2023 amending Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as regards synthetic polymer microparticles (Text with EEA relevance)*. Available at: https://eur-lex.europa.eu/eli/reg/2023/2055/oj (Accessed: 7 April 2025).

European Commission (2023a) *Proposal for a Regulation on preventing pellet losses to reduce microplastic pollution*. Available at: https://environment.ec.europa.eu/publications/proposal-regulation-preventing-pellet-losses_en (Accessed: 7 April 2025).

European Commission (2023b) *Protecting environment and health: Commission adopts measures to restrict intentionally added microplastics*. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_23_4581 (Accessed: 7 April 2025).

European Parliament and European Union (2019) *Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R1009&from=EN (Accessed: 21 September 2022).

Finlex (2022) *Lag om gödselmedel 711/2022*. Available at: https://www.finlex.fi/sv/lagstiftning/2022/711 (Accessed: 1 April 2025).

Finlex (2023) *Jord- och skogsbruksministeriets förordning om gödselprodukter 964/2023*. Available at: https://www.finlex.fi/fi/lainsaadanto/2023/964?language=swe (Accessed: 7 April 2025).

Harms, I.K. *et al.* (2021) 'Amount, distribution and composition of large microplastics in typical agricultural soils in Northern Germany', *Science of The Total Environment*, 758, p. 143615. Available at: https://doi.org/10.1016/j.scitotenv.2020.143615.

ISO 24187 (2023) 'Principles for the analysis of microplastics present in the environment'.

Iyare, P.U., Ouki, S.K. and Bond, T. (2020) 'Microplastics removal in wastewater treatment plants: a critical review', *Environmental Science: Water Research & Technology*, 6(10), pp. 2664–2675. Available at: https://doi.org/10.1039/D0EW00397B.

Johansen, J.L. *et al.* (2024) 'Extent and effects of microplastic pollution in soil with focus on recycling of sewage sludge and composted household waste and experiences from the long-term field experiment CRUCIAL', *TrAC Trends in Analytical Chemistry*, 171, p. 117474. Available at: https://doi.org/10.1016/j.trac.2023.117474.

Keller, A.A. *et al.* (2024) 'Elimination of microplastics, PFAS, and PPCPs from biosolids via pyrolysis to produce biochar: Feasibility and techno-economic analysis', *Science of The Total Environment*, 947, p. 174773. Available at: https://doi.org/10.1016/j.scitotenv.2024.174773.

Klemmensen, N. *et al.* (2023) *Forskning og vidensdannelse omkring mikroplastik i spildevandsslam udspredt på landbrugsjorde*. Miljøstyrelsen. Available at: https://www2.mst.dk/Udgiv/publikationer/2023/03/978-87-7038-496-4.pdf.

Kole, P.J. *et al.* (2017) 'Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment', *International Journal of Environmental Research and Public Health*, 14(10), p. 1265. Available at: https://doi.org/10.3390/ijerph14101265.

Kosuth, M., Mason, S.A. and Wattenberg, E.V. (2018) 'Anthropogenic contamination of tap water, beer, and sea salt', *PLOS ONE*. Edited by Z. Zhou, 13(4), p. e0194970. Available at: https://doi.org/10.1371/journal.pone.0194970.

Kumar, M. *et al.* (2020) 'Microplastics as pollutants in agricultural soils', *Environmental Pollution*, 265, p. 114980. Available at: https://doi.org/10.1016/j.envpol.2020.114980.

Lares, M. *et al.* (2018) 'Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology', *Water Research*, 133, pp. 236–246. Available at: https://doi.org/10.1016/j.watres.2018.01.049.

Lazăr, N.-N. *et al.* (2024) 'Micro and nano plastics in fruits and vegetables: A review', *Heliyon*, 10(6), p. e28291. Available at: https://doi.org/10.1016/j.heliyon.2024.e28291.

Li, H. *et al.* (2025) 'Removal of microplastics in sludge during intensive treatment processes in a wastewater treatment plant in China', *Journal of Cleaner Production*, 496, p. 145113. Available at: https://doi.org/10.1016/j.jclepro.2025.145113.

Li, X. *et al.* (2018) 'Microplastics in sewage sludge from the wastewater treatment plants in China', *Water Research*, 142, pp. 75–85. Available at: https://doi.org/10.1016/j.watres.2018.05.034.

Liao, J. and Chen, Q. (2021) 'Biodegradable plastics in the air and soil environment: Low degradation rate and high microplastics formation', *Journal of Hazardous Materials*, 418, p. 126329. Available at: https://doi.org/10.1016/j.jhazmat.2021.126329.

Lovdata (2003) *Forskrift om gjødselvarer mv. av organisk opphav*. Available at: https://lovdata.no/dokument/SFO/forskrift/2003-07-04-951#:~:text=Form%C3%A5let%20med%20denne%20forskriften%20er,kan%20utnyttes%20som%20en%20ressurs. (Accessed: 7 April 2025).

Materić, D. *et al.* (2022) 'Presence of nanoplastics in rural and remote surface waters', *Environmental Research Letters*, 17(5), p. 054036. Available at: https://doi.org/10.1088/1748-9326/ac68f7.

Murphy, F. *et al.* (2016) 'Wastewater Treatment Works (WwTW) as a Source of Microplastics in the Aquatic Environment', *Environmental Science & Technology*, 50(11), pp. 5800–5808. Available at: https://doi.org/10.1021/acs.est.5b05416.

Nath, S. *et al.* (2024) 'Microplastics and nanoplastics in soil: Sources, impacts, and solutions for soil health and environmental sustainability', *Journal of Environmental Quality*, 53(6), pp. 1048–1072. Available at: https://doi.org/10.1002/jeq2.20625.

Naturvårdsverket (2019) *Mikroplaster i miljön år 2019*. Redovisning av ett regeringsuppdrag. Stockholm. Available at: https://www.naturvardsverket.se/4ac3ba/globalassets/amnen/plast/dokument/ru2019-05-28uppdrag-mikroplaster.pdf (Accessed: 1 April 2025).

Oliveri Conti, G. *et al.* (2020) 'Micro- and nano-plastics in edible fruit and vegetables. The first diet risks assessment for the general population', *Environmental Research*, 187, p. 109677. Available at: https://doi.org/10.1016/j.envres.2020.109677.

Paes, E.D.S. *et al.* (2022) 'Widespread microplastic pollution in mangrove soils of Todos os Santos Bay, northern Brazil', *Environmental Research*, 210, p. 112952. Available at: https://doi.org/10.1016/j.envres.2022.112952.

Porterfield, K.K. *et al.* (2023) 'Microplastics in composts, digestates, and food wastes: A review', *Journal of Environmental Quality*, 52(2), pp. 225–240. Available at: https://doi.org/10.1002/jeq2.20450.

Prata, J.C. *et al.* (2020) 'Environmental exposure to microplastics: An overview on possible human health effects', *Science of The Total Environment*, 702, p. 134455. Available at: https://doi.org/10.1016/j.scitotenv.2019.134455.

Ragusa, A. *et al.* (2021) 'Plasticenta: First evidence of microplastics in human placenta', *Environment International*, 146, p. 106274. Available at: https://doi.org/10.1016/j.envint.2020.106274.

Rillig, M.C. (2012) 'Microplastic in Terrestrial Ecosystems and the Soil?', *Environmental Science & Technology*, 46(12), pp. 6453–6454. Available at: https://doi.org/10.1021/es302011r.

Rolsky, C. *et al.* (2020) 'Municipal sewage sludge as a source of microplastics in the environment', *Current Opinion in Environmental Science & Health*, 14, pp. 16–22. Available at: https://doi.org/10.1016/j.coesh.2019.12.001.

Ruffell, H. *et al.* (2025) 'Quantification of microplastics in biowastes including biosolids, compost, and vermicompost destined for land application', *Water Emerging Contaminants & Nanoplastics*, 4(1). Available at: https://doi.org/10.20517/wecn.2024.65.

Selonen, S. *et al.* (2023) *Mikromuovit maatalousmaassa – päästöt, vaikutukset ja vähentäminen*. Suomen Ympäristökeskus. Available at: https://helda.helsinki.fi/items/c4d99d0a-e5d9-4a40-986c-d06bc8914681 (Accessed: 31 March 2025).

Sol, D. *et al.* (2020) 'Approaching the environmental problem of microplastics: Importance of WWTP treatments', *Science of The Total Environment*, 740, p. 140016. Available at: https://doi.org/10.1016/j.scitotenv.2020.140016.

Steiner, T. *et al.* (2022) 'Microplastic Contamination of Composts and Liquid Fertilizers from Municipal Biowaste Treatment Plants: Effects of the Operating Conditions', *Waste and Biomass Valorization* [Preprint]. Available at: https://doi.org/10.1007/s12649-022-01870-2.

Svenskt Vatten (2025) *Slamanvändning och Revaq*. Available at: https://www.svensktvatten.se/vara-sakomraden/avlopp-och-miljo/slamanvandning-och-revaq/ (Accessed: 7 April 2025).

Talvitie, J. *et al.* (2017) 'How well is microlitter purified from wastewater? – A detailed study on the stepwise removal of microlitter in a tertiary level wastewater treatment plant', *Water Research*, 109, pp. 164–172. Available at: https://doi.org/10.1016/j.watres.2016.11.046.

Thiele, C.J. *et al.* (2021) 'Microplastics in fish and fishmeal: an emerging environmental challenge?', *Scientific Reports*, 11(1), p. 2045. Available at: https://doi.org/10.1038/s41598-021-81499-8.

Thompson, R.C. *et al.* (2004) 'Lost at Sea: Where Is All the Plastic?', *Science*, 304(5672), pp. 838–838. Available at: https://doi.org/10.1126/science.1094559.

Tian, L. *et al.* (2022) 'Microplastics in agricultural soils: sources, effects, and their fate', *Current Opinion in Environmental Science & Health*, 25, p. 100311. Available at: https://doi.org/10.1016/j.coesh.2021.100311.

Tumlin, S. and Bertholds, C. (2020) *Kartläggning av mikroplaster – till, inom och från avloppsreningsverk*. 2020–8. Bromma: Svenskt Vatten Uteckling. Available at: https://vav.griffel.net/filer/svu-rapport-2020-08.pdf (Accessed: 7 April 2025).

TÛV Rheinland Products (2023) *Ban on microplastics under REACH*. Available at: https://www.tuv.com/content-media-files/master-content/rs/Attachments/3499_Information_2023_10_Microplastic_EU_en.pdf (Accessed: 8 April 2025).

Van Den Berg, P. *et al.* (2020) 'Sewage sludge application as a vehicle for microplastics in eastern Spanish agricultural soils', *Environmental Pollution*, 261, p. 114198. Available at: https://doi.org/10.1016/j.envpol.2020.114198.

Vilpanen, M. and Seppälä, P. (2021) *Yhdyskuntalietteen käsittelyn ja hyödyntämisen nykytilannekatsaus vuosilta 2019–2020*. Vesilaitosyhdistyksen monistesarja nro 71. Helsinki: Finnish Water Utilities Association. Available at: https://www.vvy.fi/site/assets/files/4691/yhdyskuntalietteen_kasittelyn_ja_hyodyntamisen_nykytilannekatsaus_2021.pdf (Accessed: 14 February 2023).

Weber, C.J., Santowski, A. and Chifflard, P. (2022) 'Investigating the dispersal of macro- and microplastics on agricultural fields 30 years after sewage sludge application', *Scientific Reports*, 12(1), p. 6401. Available at: https://doi.org/10.1038/s41598-022-10294-w.

Wright, S.L. *et al.* (2020) 'Atmospheric microplastic deposition in an urban environment and an evaluation of transport', *Environment International*, 136, p. 105411. Available at: https://doi.org/10.1016/j.envint.2019.105411.

Yan, Y. and Yang, Z. (2023) 'Sources, distribution, behavior, and detection techniques of microplastics in soil: A review', *Chinea Geology*, 6(4), pp. 695–715. Available at: https://doi.org/10.31035/cg2023042.

Yang, J. *et al.* (2021) 'Microplastics in an agricultural soil following repeated application of three types of sewage sludge: A field study', *Environmental Pollution*, 289, p. 117943. Available at: https://doi.org/10.1016/j.envpol.2021.117943.

Yang, Z. *et al.* (2022) ‘Occurrence of macroplastics and microplastics in biogenic waste digestate: Effects of depackaging at source and dewatering process’, *Waste Management*, 154, pp. 252–259. Available at: https://doi.org/10.1016/j.wasman.2022.10.018.

Yoon, J.-H., Kim, B.-H. and Kim, K.-H. (2024) ‘Distribution of microplastics in soil by types of land use in metropolitan area of Seoul’, *Applied Biological Chemistry*, 67(1), p. 15. Available at: https://doi.org/10.1186/s13765-024-00869-8.

Zhang, G.S. and Liu, Y.F. (2018) ‘The distribution of microplastics in soil aggregate fractions in southwestern China’, *Science of The Total Environment*, 642, pp. 12–20. Available at: https://doi.org/10.1016/j.scitotenv.2018.06.004.

Zhang, L. *et al.* (2020) ‘An Overlooked Entry Pathway of Microplastics into Agricultural Soils from Application of Sludge-Based Fertilizers’, *Environmental Science & Technology*, 54(7), pp. 4248–4255. Available at: https://doi.org/10.1021/acs.est.9b07905.

Öling-Wärnå, V., Åkerback, N. and Engblom, S. (2023) ‘Digestate from Biowaste and Sewage Sludge as Carriers of Microplastic into the Environment: Case Study of a Thermophilic Biogas Plant in Ostrobothnia, Finland’, *Water, Air, & Soil Pollution*, 234(7), p. 432. Available at: https://doi.org/10.1007/s11270-023-06436-z.