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MICROPLASTIC DISTRIBUTION IN SOIL - A REVIEW

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Abstract

Plastics are now found in all-natural environments, including soil, in a wide variety of sizes and shapes. Plastic products have brought benefits to society in terms of economic activity and quality of life. Unfortunately, it has also become one of the major toxic pollutants of present time. Being composed of toxic chemicals and most importantly nonbiodegradable substances, plastic pollutes soil, water and air. Due to various degradation processes plastic is broken down to particles smaller than 5 mm, also known as microplastics. Microplastics are emerging contaminants, composed of different type of plastic (polyethylene - PE, polypropylene - PP, polyethylene terephthalate - PET, polystyrene - PS, polyvinyl chloride - PVC, polyurethane – PE etc.) that enter in natural ecosystems from a variety of sources, including, but not limited to cosmetics, clothing, and industrial processes. The effects of microplastics in terrestrial systems remain largely unexplored. This paper aims to review the occurrence and characteristics of microplastic pollution in soil and especially agroecosystems.

***Key words**: agriculture, microplastics, soil.*

INTRODUCTION

The annual global plastic production increased from 1.7 million tons in 1950 to 322 million tons in 2016 (Ju et al., 2019). The increase is caused by the use of different types of plastics such as polyethylene and polypropylene, as packaging in different fields and industries (Liu et al., 2019; Ionescu and Roman, 2015). Plastics in the environment degraded due to ultraviolet radiation, physical forces and hydrolysis in form of minuscule plastic fragments (<5 mm) known as microplastics (GESAMP, 2015), which will also degrade further (< 100 nm) to form nanoplastic (Ng et al., 2018). Unfortunately, little attention has been paid to nanoplastics despite the fact that these particles are more likely to pass biological membranes and affect the functioning of cells, including photosynthesis (Da Costa, 2016; Qi et al., 2018). Chemical properties of microplastics (PE, PP, PS, PVC, etc) show that they are relatively stable and their degradation processes are extremely slow, although they suffer physical changes, it can potentially persist long time in the environment (He et al., 2018).

Microplastic can accumulate in soil (Rillig and Bonkowski, 2018), water (Li et al., 2018; Wang et al., 2016; Isobe et al., 2017), air (Prata, 2018) when is inappropriately dumped or mismanaged. A number of studies have demonstrated the occurrence of microplastics in water environments including oceans (Kanhai et al., 2017), seas (Barboza and Gimenez, 2015), rivers (Mani et al., 2015), and freshwater lakes (Eriksen et al., 2013). The existence of microplastics accumulation in sediments (Alomar, 2016), also in organisms (Wright, et al. 2013; Kim and An, 2019) has been widely documented in order to determine their negative effect.

Microplastics can enter into the soil by a variety of ways including the application of sewage sludge or from the residues of plastic mulching films (Rusu et al., 2015). The evidence for microplastics accumulation in soils is increasing, for instance, approximately 700 plastic particles per kg soil were found in European agricultural land (Barnes et al., 2009; Briassoulis and Dejean, 2010). A large number of agricultural sites are covered with plastic film to retain soil moisture and some of this material is discarded in soils in an unregulated manner, without intention. Plastic has also been used in agriculture in Romania (Figure 1) for studying the effects of changing environmental conditions (light quality and intensity mainly) on some physiological indicators of different types of plants (Asănică et al., 2017). Therefore, there is a need to evaluate the environmental risk of microplastics in agricultural soil ecosystems for their rational management, since soil is one the most important resources in Romania (Mihalache et al., 2015). Thus, the objective of this review paper is to present the current literature concerning the occurrence, identification and toxicological consequences of microplastic pollution of agricultural soil.

OCCURRENCE OF MICROPLASTIC IN AGRICULTURAL SOILS

A number of sources and pathways can be identified based on the type of plastic particles found in the agroecosystems. These sources can be divided in primary microplastics sources - intentionally manufactured microplastics leaking and secondary microplastics sources - such as plastic breakdown into microplastics prior to reaching the environment.

An important source of primary microplastics contamination in agricultural soil is the application of sewage sludge from municipal wastewater treatment plants as a fertilizer (Mintenig et al., 2017). The microplastic in the sewage sludge is formed by synthetic fibers that fall off during laundry and indoor fibers derived from other textiles. Microplastic is not completely eliminated in the final effluent, and their route towards the sludge has been calculated to a daily deposition of 3,400,000,000 particles in the 30 tons of sludge (Magni et al., 2019). The usage of sewage sludge is common in many developed regions, with Europe processing approximately 50% of sewage sludge for agricultural use (Kelessidis and Stasinakis, 2012). *Controlled-release fertilizers* technology is using a combination of N, P and K nutrients that are encapsulated within a nutrient pill, in a coating made with a non-degrading polymer. While the technology offers a number of benefits for agriculture, it also represents an important primary source of microplastics contamination. (GESAMP, 2016).

Secondary microplastic contamination is also linked to the use of agricultural plastics, such as silage baling and plastic mulches (GESAMP, 2015). Additional plastic items used for agricultural purposes and which therefore represent potential sources of microplastic contamination in soil are containers, packaging and netting (Scarascia-Mugnozza, 2011). Plastic mulching is the use of plastic films with thicknesses between 6 μm and 20 μm on crops.

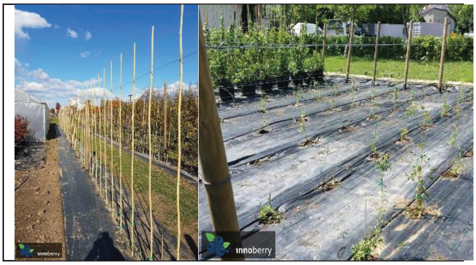

Figure 1. Plastic used in Romanian Agriculture (Asănică et al., 2017)

This technique is widely used due to the economic benefits its application offers, including increased crop yields, better crop quality, prevention of soil erosion, reduced soil transpiration, modifies soil temperature, and reduced pest pressure. Nevertheless, while the plastic mulches create the ideal microclimatic conditions to increase productivity, they also have a number of limitations. Plastic mulches are generally made of polyethylene (PE) which does not degrade well in the soil and therefore is associated with discharges of plastic residues. The use of PE also adds to the problem of recovering and recycling used mulching films (Steinmetz et al., 2016). Among the plastics used for agricultural purposes, plastics covering plastic tunnels and greenhouses have been identified as a source of microplastic litter on agricultural soil. Another secondary source is degradation of expanded polystyrene (EPS) foam which is used in packaging, building materials, or as containers. Due to its unique appearance (foam) and great flexibility, it is particularly easy to identify. Hot spots of microplastics in soil are mainly found on roadsides, as well as home gardens, industrial areas, and agricultural lands treated with plastic mulch (Liu et al., 2018).

Common polymer contaminants in/on soil are susceptible to some degree of photo- or thermooxidative degradation. The degree to which these oxidative processes can occur is highly dependent on the environmental conditions (e.g. UV exposure, temperature, soil composition, moisture, oxygen); as well as the chemical structure and crystallinity of the plastic (with oxygen diffusion and degradation occurring more readily in amorphous regions of the materials), (Ng et al., 2018). Unfortunately, if the plastic is transported into the soil, anaerobic conditions may develop in deeper layers of the soil and inhibit oxidative degradation processes, which lead to a longer time for plastic to be degraded.

Lv et al (2019) revealed the occurrence of microplastic contaminations in water, soil and animals (Figure 2) and analysed the distribution characteristics of microplastics in rice-fish co-culture ecosystems. They found an increasing trend in microplastic abundances in water, soil and animal samples from non-rice period to rice-planting period. In rice-fish co-culture paddies, microplastics level in rice-planting soils was generally higher than that in aquaculture soils and unfortunately, most of microplastics were found in digestive tracts of eels, loach and crayfish.

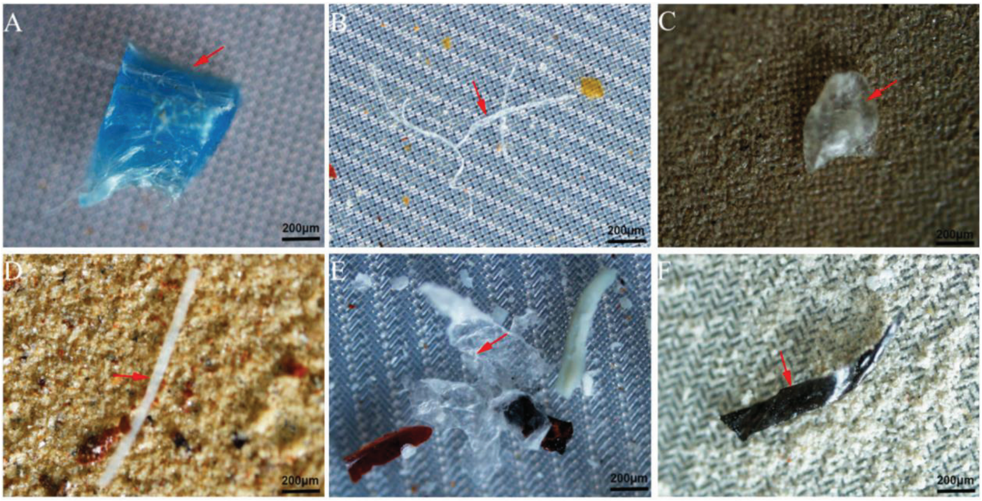

Figure 2. Microplastics in water (blue PE film and while PE fiber), soil (translucent PVC granules and white PP fiber), and aquatic animals (translucent PE film and black PE film) (Lv et al., 2019).

MICROPLASTIC IDENTIFICATION METHODS

Due to the rapid development of microplastic research, there is a lack of consistency in sampling and extraction techniques used to quantify microplastics in agricultural soil. Collected soil samples are generally recommended to be passed through a 2 mm sieve in order to remove rocks and plant leftovers. Usually, microplastic is separated from soil using difference of density. In this procedure, salt solutions of known densities are utilized to float microplastic particles out from the soil matrix. Light density plastics such as PE, PP, polyamide (PA), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), polymethyl methacrylate (PMMA), and PS particles can be extracted using a saturated NaCl solutions (density of 1.18 g cm^3) (Liu et al., 2018). For high density microplastic the optimum solution density should be 1.6-1.8 g cm^3, which could be achieved using $ZnCl_2$ or NaI as suggested by van Cauwenberghe et al. (2015). Another separation technique is using electrostatic behaviour of microplastics, which can facilitate their separation from multiple environments including water, sediments, and bleach sands; and with a reported recovery up to 100% for each type of plastic (Felsing et al., 2018).

The first examination of the sample is frequently performed by visual observation, which can be achieved through simple naked eye observation, or assisted by optical microscopy (Silva et al., 2018). In the latter, surface texture and structural information of the particles can be obtained, thus allowing for the identification of ambiguous particles. Characteristics like colour, shape, surface texture, and any other characteristic that may contribute for distinguishing microplastics from other particles, are used for their separation from other components of the sample (Zhang et al., 2018). Depending on their shapes and features, the microplastics can be categorized into pellets, foams, fragments, flakes, films, fibres and sponges (Zhou et al., 2018). Most pellets have hard, regular, disc-, ovoid- or cylindrical-shaped dimensions, while fragments have hard, jagged and irregular shapes.

The use of Scanning Electronic Microscope (SEM) for identification of microplastics provides extremely clear and high-magnification images of plastic particles, facilitating the discrimination of microplastics from organic particles. SEM can be suitable for accurate detection of microplastic particles of different sizes and shapes (e.g., fibre, spherule, hexagonal, irregular polyhedron) Silva et al., (2018).

Infrared and Raman spectroscopies are the two most commonly used techniques for the characterization of microplastics (Mintenig et al., 2017). These spectroscopic techniques required low sample amounts with minimal sample preparation and they are also indicated for the discrimination of plastics and natural particles for soil samples (Corradini, et al. 2019). Concerning their spatial resolution, Raman spectroscopy is able to assess microplastic samples higher than 1 mm while infrared spectroscopy only could identify microparticles higher than 10-20 mm. Pyrolysis -Gas-Chromatography-Mass Spectrometry (Py-GC-MS) is a destructive technique that has also been described for the characterization of microplastics in terms of identification of polymer type, by analysing their thermal degradation products. This technique eliminates the need of pre-treatment of sample since it directly examines the solid polymer sample. In addition, only a small quantity of sample is analysed in one measurement (5-200 μg). A similar hyphenated technique can be used, Thermogravimetric analysis coupled with spectroscopic method Fourier-Transform-Infrared (TGA-FT-IR) which measures the mass variation of microplastic over time as the temperature changes and also the thermal degradation products by FT-IR. This technique uses a sample weight of 2-20 mg (Majewsky et al., 2016).

In polymer science differential scanning calorimetry (DSC) is used to verify the purity of synthetic materials by examining the phase transitions (Silva et al., 2018). During DSC analysis, a sample is heated using a controlled temperature gradient with a defined heating rate. Using the melting point of different polymers DSC can identify the type of polymer in the sample. This technique has the advantage of straightforward operation and only very small sample amount requirements (1 to 20 mg). Also it is used complementary with FT-IR analysis. The main polymers identified in soil were PE and PP pellets, fibres, and fragments, PP flakes and films, and PS foams (Mintenig et al., 2017; Corradini et al., 2019; Ng et al., 2018) which are consisting with plastic used in agriculture (Scarascia-Mugnozza et al., 2011).

INTERACTION BETWEEN TERRESTRIAL BIOTA AND MICROPLASTIC

After extensive initial degradation, biodegradation (a process of mineralization of an organic material under aerobic and anaerobic conditions) plays an important role in the ultimate fate of plastics in soil. In soil are present plastic-degrading organisms, such as *Microbacterium awajiense, Rhodococcus jostii, Mycobacterium vanbaalenii, Streptomyces fulvissimus, Bacillus simplex and Bacillus sp*., which were identified from earthworm's (*L. terrestris*) gut (Huerta Lwanga et al., 2018). Because of less energetically expensive carbon resources, biodegradation of plastic particles would be less likely to become a relevant process (Ng et al., 2018). As ecosystem engineers, *L. terrestris* participate in important ecosystem processes like organic matter decomposition and water infiltration (Rilling et al., 2017). *L. terrestris* is known to produce long vertical burrows through which water and pollutants are transported. The uptake of microplastics by *L. terrestris* and the resulting biogenic transport into the soil may lead to the pollution of groundwater and consequent uptake by terrestrial plants (Huerta Lwanga et al., 2018). Another earthworm, *Eisenia fetida* was exposed to 0.25% and 0.5% of PS microplastic and showed no growth inhibition to these concentrations. Growth inhibition occurred at exposure to concentrations >1% (Cao et al., 2017).

Ju et al. (2019) showed that reproduction of springtail, *Folsomia candida,* was inhibited when the concentration of microplastic reached 0.1% in soil and was reduced by 70.2% at the highest concentration of 1%. Also, Kim and An (2019) observed disruptive movement of springtail *Lobella sokamensis* in soil at low concentration of plastic particles (8 mg/kg) and this behaviour created bio-pores in the soil system. The influx of plastic particles into these cavities subsequently immobilized the springtails within.

So far, the effect of microplastic on soil fertility and microbial activity were still not clear, although researches demonstrated that plastic-film residues can decrease soil porosity, air circulation, microbial biomass and activity and can probably affect soil fertility (Ng et al., 2018). Plants are not expected to intake microplastic, because of the high molecular weight or large size of the particles, which prevents their penetration through the plant cell wall.

Soil protists (amoebae, ciliates and flagellates) are highly likely to take up microplastic particles in the range of a few micrometers and smaller (Rilling et al., 2018), but there is still a need to examining longer-term effects on soil protist communities and functions.

All though plastics may be considered biochemical inert, sub-micron additives have been increasingly used in commercial thermoplastic applications. Most additives are of small molecular size and are not chemically bound to the polymer. Several sorption studies have been performed and reported based on interactions of contaminants with microplastic. Hüffer et al. (2019) examined the transport of selected organic plant-protection agents (atrazine and 4-(2,4-dichlorophenoxy) butyric acid). Yang et all. (2019) investigated the transport of glyphosate and its main metabolite, aminomethylphosphonic acid (AMPA) via earthworms in the presence of different concentrations of LDPE microplastics. Liu et al. (2019) showed that the sorption behavior of two phthalate esters, including diethyl phthalate and dibutyl phthalate onto three types of microplastics (PVC, PE and PS) is influenced by chemical properties of microplastic and pH. Also, microplastic's presence significantly inhibited the dissipation of tetracycline and antibiotic resistant gene in the soil. In addition, Sun et al. (2018) find out that when the microplastic and sophorolipid co-existed in the soil, sophorolipid could break the inhibiting barrier of the microplastic, and significantly enhance the attenuation of tetracycline / antibiotic resistant gene in the soil.

CONCLUSIONS

It is a well-known fact that microplastic is present in the environment, but the effects in terrestrial systems remain largely unexplored. This is a first step in studying the microplastics role in agricultural ecosystems. Further research is required to understand and quantify the transport of microplastic in soil, to observe the mobility of retained organic contaminants on microplastic in soil, the effect of ingested microplastic by soil fauna due to their small size, and last but not the least the accumulation in the agricultural food crops.

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