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EDITORIAL

Silent threats of 21st century: microplastic contamination of agroecosystems and its implications for the food chain toxicity

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Plastic plays an essential role in various aspects of the contemporary lifestyle, primarily for its convenient use, affordability, and versatility. In response to the world's growing demand for plastic products, the plastic production has witnessed a significant growth in recent years. The global production of plastics has experienced remarkable growth as the rate of increase of global annual production is about twenty times more than 50 years ago. In 2021, it reached the highest production ever with 390.7 million tonnes(PlasticsEurope 2022). Notably, approximately 96% of the total production of plastics occurred since the year 2000. The Covid-19 pandemic resulted in a considerable rise in the plastic and single-use plastic products (SUPs) demand, elevating plastic to one of the top three most widely produced materials globally, alongside steel and cement (Kibria et al. 2023). According to the estimates, the global annual production of plastics may rise to 33 billion tonnes by 2050 (Cincinelli et al. 2019). Considering that a large proportion of the plastic products are designed for single-use purpose, it is noteworthy that in the past 50 years the volume of plastic waste has closely paralleled the increase in plastic production. The estimations suggest that around 22 million tonnes of plastics (19.4 million tonnes macroplastics and 2.6 million tonnes microplastics) were leaked into the global environment in 2019. Without the implementation of new policy measures, this amount is projected to be double by 2060 (OECD 2022).

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Leading cause of macroplastics entering the environment is the mismanagement of plastic waste, which accounted for 86% of total plastic leakage in 2019, while biosolids provenient from wastewater treatment plants serve as the major source of microplastics (MPs) release (OECD 2022). Numerous communities among developing economies face limited waste management infrastructure. Waste is often burned either in residential settings or in open dump-sites without effective emission control measures. This practice exacerbates environmental pollution by releasing greenhouse gases (GHGs), particulate matter (including MPs), and hazardous chemicals (including dioxins and other persistent organic pollutants). Due to its widespread use and ubiquitous presence in all compartments of environment, scientists refer to the current epoch as 'plastic age', akin to the bronze and iron ages. Some suggest that fossilized plastic layers will serve as key markers denoting the onset of Anthropocene Era.

Tiny particles of plastic also known as MPs, typically measuring less than 5 mm in size, are one of the globally significant environmental concerns of this century. MPs have been acknowledged as serious threat to both ecological and human health globally, given their pervasive distribution in aquatic and terrestrial environments. MPs comprise of variety of polymers mainly polyvinyl chloride, polystyrene, polyethylene, polyethylene terephthalate, and polypropylene and exist in various shapes including beads, fibres, fragments, or films. These enter the environment either directly as primary MPs originating from industrial applications (i.e., microbeads found in personal care products and cosmetics, as well as precursors for further products), or as secondary MPs resulting from the break down of bigger plastic items or macroplastics. In the environment, the MPs undergo further fragmentation and weathering, eventually breaking down into nano-plastics (NPs) (size $<$ 1 mm), thus increasing the probability of exposure and subsequently increasing the risks to both ecosystems and human health. MPs have pervasively contaminated many ecosystems globally, including

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but not limited to marine environments and deepest oceans (Waller et al. 2017), highest mountains (Zhang et al. 2019) and even polar ice caps (Kelly et al. 2020). Because of their small sizes these can be taken up by organisms and plants in the food chain. MPs are reported from human placenta and blood (Ragusa et al. 2021), fish and mussels (Murphy et al. 2017), zooplanktons (Besseling et al. 2015) and fruits or vegetables (Oliveri Conti et al. 2020). These findings raise the questions of potential toxicity of food chains due to bioaccumulation and biomagnification of MPs across different trophic levels. Although MPs are a big concern in today's world, there is only one indicator (14.1.1b) under Goal 14 of Sustainable Development Goals (SDGs), which is specifically related to the reduction of the impacts from MPs. The detrimental effects of plastic debris through mechanisms such as ingestion or entanglement have been documented in over 550 marine species (Kühn et al. 2015). To date, extensive research has been conducted yielding substantial evidence regarding the prevalence, fate, uptake, and impacts of MPs on marine ecosystems. Contrastingly, the exploration of toxicity levels across various trophic levels, particularly within terrestrial ecosystems, remains comparatively limited. This highlights a critical gap in the current knowledge of MPs pollution and its ecological implications.

The occurrence of MPs in the terrestrial ecosystems, with a particular emphasis on agroecosystems is a matter of great concern. There is an increasing body of knowledge to suggest that MPs may pose a threat to the critical functions of terrestrial ecosystems. Soil health is not just an element that provides an ecological balance but also a fundamental requisite for meeting food security (SDG2). Soil is perceived to be a major sink and transporter of MPs pollution through surface runoff, enhancing the transmission of these pollutants to the aquatic ecosystems. Agroecosystems are multifunctional and provide ecological services including soil formation and preservation of soil health, food production, ecosystem regulation through organic matter and nutrient cycling, control of pests, gas exchange and carbon sequestration. Soil contamination with MPs has been increasingly documented at a global scale, raising potential concerns regarding soil health, its biodiversity and its ability in maintaining plant health. MPs affect a range of soil properties such as water-holding capacity, bulk density, and structure. Their presence in the soil can adversely affect plant performance through the increase of water evaporation, which leads to dryness of soil. These changes can then influence the soil microbial communities, potentially affecting mineralization rates and communities of root-colonizing symbionts along with changes in soil pH, which might result in change of the soil structure. The decrease in bulk density, which happens due to the presence of MPs, imposes selection pressures on soil biota, complicating their evolution and adversely impacting plants performance. In addition to soil health, the effect of MPs on plants and crops has been reported, concerning the toxicity effects on plants/crops, either due to adsorption (of MPs) and/or by internalisation of NPs. The presence of MPs has been reported in edible plants, fruits, and vegetables. The toxicity of plants with MPs and NPs is assessed by studying four core parameters of plant stress (i.e., germination, biomass, growth, and photosynthesis), which are caused by pore blockage. However, there is a lack of information on the effects of MPs on fundamental properties negatively impacting soil biota. MPs in soil due to their hydrophobic properties, serve as carriers for other contaminants to plants, they can adsorb various pollutants such as heavy metals, and facilitate their entry into plants roots, negatively impacting plant growth due to impact on their root's symbionts. MPs can enter the agroecosystems through various sources. These include biosolid/sludge application and the use of both treated or untreated wastewater for irrigation, fragmented macroplastics degradation through solid waste littering and open dumping, plastic mulching and from equipment and materials used in modern agricultural practices including polymer-coated slow-release fertilizers and pesticides, and atmospheric deposition. Among various anthropogenic sources, wastewater treatment plants are particularly significant in the direct release of heavy loads of MPs into agroecosystems, even with the presence of advanced wastewater treatment facilities. Subsequently, every day, high loads of MPs are discharged into the environment via sludge products and the utilization of treated effluents. It is estimated that around 80% of the MPs in wastewater treatment plants are captured and retained in sludge or biosolids. These biosolids are often utilized in agroecosystems as fertilizers, hence contributing significantly to the accumulation of MPs in the soil after repeated applications. The presence of MPs in surface waters have been documented largely due to the treated wastewater effluents discharge and agriculture runoff. In addition, there is a significant contribution to the influx of MPs into the agroecosystems from the surface water irrigation. Considering that most MPs found in wastewater treatment plants are retained in sewage sludge, their release into the environment through biosolids application has a considerably higher risk, when compared to direct wastewater discharge. It was estimated that annually between 2800 and 19,000 tons, 63,000-430,000 tons and 44,000-300,000 metric tons of MPs are released to agroecosystems through biosolids application in Australia, Europe, and America, respectively (Iqbal et al. 2020; Ng et al. 2018).

The evaluation of MPs in the environment involves both physical and chemical characterisation. The physical characterization encompasses techniques such as fluorescent microscopy, scanning electron microscopy (SEM), transmission electron microscope (TEM), and stereo microscopy. Chemical characterization is carried out using Fourier transform infra-red spectroscopy (FTIR), thermogravimetry (TGA), Raman spectroscopy, thermal techniques like differential scanning calorimetry (DSC), and pyrolysis gas chromatography-mass spectroscopy (py-GC-MS) (Mariano et al. 2021). When used in combination, these analytical approaches, provide a holistic and comprehensive knowledge into the thermal behaviour, physical characteristics, as well as chemical composition of MPs, thus enabling the understanding of their occurrence and distribution, environmental fate, and potential risks.

There is urgent need for regulations at different levels, to control release of MPs in the environment, particularly focusing on agroecosystems. Strict regulations with a focus on controlled production/use of SUPs, improved recycling infrastructure and promotion of sustainable alternatives such as bioplastics derived from microorganisms (polyhydroxyalkanoates) and plant-based materials (polylactic acid) is dire need of the time to address the issue. To avoid plastic toxicity in agroecosystems, there is need to establish strict limits for MPs in sewage sludge and treated wastewater used for irrigation or soil amendments, along with comprehensive MPs monitoring program for agriculture soil, waters and crops. These solutions aim to address the plastic pollution problem from multiple angles, combining policy changes, technological innovation, and shifts in consumer behavior. The most effective approach will likely involve a combination of these strategies tailored to specific contexts and needs. However, for the MPs that already entered in the agroecosystems, there is a need to expand the research on their principal input pathways, as well as their occurrence in different matrices, abundance, composition, fate, and impact, including an assessment of potential impacts on soil health/biota and residence time. Currently existing research provides only partial understanding regarding possible human health implications stemming from MPs exposure along with incomplete comprehension towards environmental effects, which include bioaccumulation across various trophic levels. Hence there is an urgent need for further investigations focused upon uptake/impacts of MPs or adsorption while exploring any consequences towards food safety/security/trophic transfer. Moreover, it is also crucial to expand the scope of research to understand the impacts of MPs on plants and soil biota, especially staple crops. To achieve the targets of environmental sustainability, it is important to manage the existing MPs in various ecosystems and reduce the use of plastics as a whole by better recycling or replacement with eco-friendly alternatives.

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