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Review article

Accumulation of Microplastics in Agroecosystems and Its Effects on Terrestrial Plants: A Short Review

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Abstract

Microplastics are currently a major global threat as they enter the ecosystem in large quantities daily and are able to persist in the environment for a long period of time. Current research focuses mainly on aquatic and related ecosystems; however, little information is available on the sources, possible accumulation, and pathways of microplastics in agroecosystems. It was previously thought that plastic particles could not be taken up or accumulate in plant bodies, but with modern technology, it has been observed that plastic particles are able to penetrate plants at the micro and nanoscales through transpiration pull forces, and in some cases through the leaves with foliar application. The purpose of the study was to identify potential sources of microplastics, their ways of entry into agroecosystems as well as into plants, and the effects of microplastics on the physiological processes of plants. We highlighted the harmful effects of these pollutants on agricultural ecosystems. Microplastics causes pore space blockages on root surfaces and oxidative damage. Moreover, they inhibit nutrient and water uptake, decrease germination capability, and have negative effects on product quality.

1. Introduction

Microplastics are minute plastic particles that are less than 5 mm in size [1]. They are found on almost every continent, and in environments ranging from the deep sea to mountains [2]. Salinity and drought remain the most alarming issues [3]. However, microplastic pollution has now become a global phenomenon and in recent times it has emerged as the second most striking issue in the environment and ecosystem [4]. Not only marine ecosystems but also freshwater and terrestrial ecosystems are getting contaminated with microplastics at an alarming rate [5]. From 1950 to 2015, the total waste generation of primary and secondary plastic was 6300 metric tons [5]. Sixty percent (4900 metric tons) of this huge amount of plastic was discarded in nature, and has accumulated in terrestrial and water bodies [5]. Arable lands have become an inalterable and key sink of

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microplastic particles [6]. Microplastic pollution in terrestrial ecosystems is quite unexplored compared to aquatic or marine ecosystem pollution [7]. Plants are the primary producers in terrestrial ecosystems [8, 9]. Microplastic pollution changes soil ecosystem which has a massive impact on plant life [10]. So, this review enquired into the effects of microplastics on plants in terrestrial ecosystems. Microplastic pollution heavily affects plant root systems, germination capacity, photosynthesis and quality of plant products. Microplastics facilitate cytotoxicity and oxidative damage, both of which are very destructive to plants. This study also provides information on the sources and accumulation of microplastics in nature as well as in agroecosystems. Eventually, this paper will provide a better understanding of microplastic pollution in terrestrial ecosystems. Some researchers have discussed terrestrial microplastic pollution. Boyle and Örmeci [11] studied the accumulation, characteristics and aftermaths of plastic pollution in both freshwater and terrestrial ecosystems. Kumari *et al*. [12] described the probable origins of microplastics, their interaction with agroecosystems, and also suggested some reclamation techniques. Both microplastic and nanoplastic behavior and interaction with soil biota and their degradation were studied by Ng *et al*. [13]. In another study, possible hazards created by microplastics and nanoplastics in current agricultural practices and their effects on plant were discussed by Azeem *et al*. [6].

In this paper, all the relevant information was gathered in order to understand how microplastics affect plant performance. It seems that a lot of studies need to be conducted to grasp the exact effects of microplastics on terrestrial plants. The objective of this paper was to analyze plant performance under microplastic pollution and provide knowledge which will hopefully lead to improvements in agricultural production. This study will help policymakers taking initiatives to minimize microplastic contamination.

2. Sources of Microplastics

Plastic particles, especially microplastics, have adverse effects on soil and the environment. Dynamic microplastic sources are city dust, tires, synthetic textiles, road markings, marine coatings, personal care products, and plastic pallets (Figure 1) [12]. Microplastics are released into the environment by degradation and decomposition processes [14]. A large amount of plastic is used in packaging and it is increasing day by day [15]. Statistics show that about 9 billion or more polyethylene bags are produced annually, and that waste is nonrenewable [16]. Major sources of microplastic and nanoplastic include wastewater treatment processes, microbeads, clothing fibers, plastic debris, cleaning and care products [17]. Every day, 300 million tons of plastic particles are released into the environment by wastewater treatment [18]. A study showed that about 90% of microplastics accumulate in sludge [19] and sludge is applied to soil as a fertilizer [20]. Greenhouse materials, plastic mulch, and soil conditioners are the main sources of plastic particles in agriculture [12, 21]. Common indirect microplastic sources include common litter, reclaimed water used for irrigation, and applied biosolids [12].

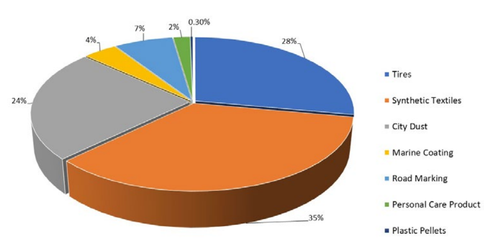

Figure 1. Sources of microplastics in the environment

3. Microplastics in Agricultural Ecosystems

It has been assumed that about 95% of MPs that come from sewage treatment plants are mixed with biosolids [22]. It was observed that the primary sources of MPs are necessary materials used on a daily basis, synthetic textiles and tires [23]. Moreover, the toxic and harmful elements are released from such plastics by the decomposition processes [24]. Microplastics have accumulated on agricultural land by tillage operations year after year. The MPs can be mixed and deposited for a long time without changing their formation [25]. It was observed that biosolids contribute remarkably to MPs pollution in agroecosystems, i.e. by 430000 tons in Europe and 300000 tons in North America [12]. Weathered by solar ultraviolet radiation and increased oxygen availability and temperature, MPs migrate through the soil vertically and horizontally [26]. They spread further through the actions of springtails and earthworms as well. MPs can easily mix with fresh water as well as irrigation water released from sewage treatment plants and in this way, can enter into agricultural soils [27]. At the time of making compost, compost contaminated with plastics is applied for crop production and thus added to soil. It can dominate top soils [28]. The problem is very concerning as it takes about 20-500 years for microplastic substances and structures to degrade [29]. Cheap and readily available plastic bags can easily be deposited in the soil because people throw them onto land indiscriminately. Almost all pesticide bags or herbicide containers are made of plastic and after use their final destination becomes the soil [30]. The polythene sheets used to pack seeds or propagating materials, which are of low cost and ready availability, can be a significant important source [25]. More information on the origin and fate of primary and secondary microplastics is described in Figure 2.

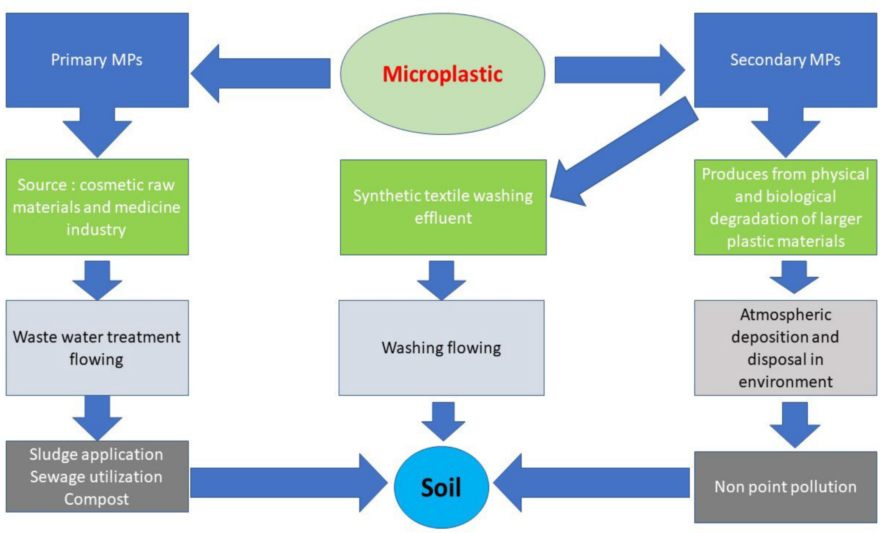

Figure 2. Schematic representation of microplastic types, sources, and sinks in the agroecosystem

4. Accumulation of Plastic Particles in Plants

Current research has revealed that plastic particles are absorbed in the root hair zone and can be taken up into plants. Vascular plants serve as microplastic sinks because the plant surface is capable of absorbing MPs [31]. Recently, it was found that plants can adjust the pore size of their cell walls and uptake plastic particles [32]. When microplastics enter the soil, they undergo natural processes that change their properties and behavior, and included are microplastic weathering and a loss of physical integrity due to the combined actions of oxidants, UV radiation and mechanical stress [33]. Natural process helps microplastics to decay and this occurs faster in larger plastics that have higher surface-to-volume ratios [34]. Generally, microplastics cannot enter plant bodies directly due to their large size [35]. On the other hand, NPs are capable of entering plant tissues [6]. It was demonstrated that the tobacco plant (*Nicotiana tabacum*) cannot uptake 100 nm nano-polystyrene beads; however, 20-40 nm beads can be taken up [36]. The exudates and mucilage of plants function as the first layer of prevention that are negatively charged and protect positively charged particles uptake at the side of the outer cell wall [37]. As far as we know, no studies have clearly demonstrated the transportation and uptake of microplastics into the whole plant. More studies are needed to understand the mechanism of transpiration and uptake of microplastics. Transpiration pull in plants plays a vital role in the uptake and translocation of NPs particles [6].

NPs enter the epidermal cells of wheat roots and move into xylem tissue [38]. Plastic particles move from the root to shoot along vascular bundles by transpiration streaming [6]. NPs can be transferred to stems, leaves, and fruits by water transportation systems [39]. Using confocal microscopy and epifluorescence, it was found that plastic particles accumulated in the leaves of *Lepidium sativum* (garden cress) after 48 and 72 h of exposure to MPs [40]. Another way of entrance of plastic particles into plants is via the stomata of leaves following foliar application [41]. It is also possible that plastic particles taken up in the leaves can then move to other places via the vascular system [42]. So, it can be said that plastic particles accumulate in the flowers, leaves, fruits, and different plant parts. Microplastic uptake, translocation, and accumulation vary from plant to plant [24].

5. Impact of Microplastics on Plant

Microplastic pollution may be one of the most persistent and extensive anthropogenic alterations of earth's surface [7]. Vascular plants perform as microplastic sinks [31]. Plastic particles that are less than 5 mm in size are called microplastics [43]. There are various types of microplastics that persist in the environment, such as polyethylene (PE), polyvinyl chloride (PVC), polystyrene (PS), polypropylene (PP), polyethylene terephthalate (PET), polyamide 6 (PA6), and polyamide 66 (PA66) (Table 1). These are distributed in the environment in various form and concentrations that are explained below.

Table 1. Different types of microplastics and their densities [44]

Microplastics	Chemical Formula	Degree of Crystallinity	Density (g/cm^3)
PE	$(C_2H_4)n$	Semi-crystalline	0.92–0.97
PP	$(C_3H_6)n$	Semi-crystalline	0.88–1.23
PVC	$(C_2H_3Cl)n$	Amorphous	1.15–1.70
PS	$(C_8H_8)n$	Amorphous	1.04–1.50
PET	$(C_{10}H_8O_4)n$	Amorphous	1.30–1.50
PA6	$(C_6H_{11}NO)n$	Semi-crystalline	1.12–1.14
PA66	$(C_{12}H_{22}N_2O_2)n$	Semi-crystalline	1.13–1.38

5.1 Effect of microplastics on germination

Microplastics can cause germination failure in some plants like garden cress (*Lepidium sativum*) [40, 45], ryegrass (*Lolium perenne*) [46], chickpea (*Cicer arietinum*) [47], and in herbaceous ornamental plants such as *Trifolium repens*, *Orychophragmus violaceus*, and *Impatiens balsamina* [48], but species like rice, wheat and onion are not, or are only negligibly affected by MPs [39, 45, 49].

5.2 Cytotoxic effect of microplastics

Cytotoxic elements can damage or kill cells as they are toxic to cells. Microplastics are cytotoxic to onion (*Alium cepa*). Higher amounts of microplastic cause chromosomal aberration [47].

5.3 Effect of microplastics on plant roots

Forty nm and 1 µm PS plastics remained attached to root surface and especially to the root tips of arabidopsis (*Arabidopsis thaliana*) and wheat (*Triticum aestivum*) after the plants had been grown for 5 and 12 days, respectively, in agar media that contained PS plastic spheres (0.029 g L^{-1}) [50]. PS plastic spheres of both 100 nm and 1 µm can pile up in rice roots [51].

Microplastic particles enhance total root length by about >75.0% [52]. Root area in spring onion (*Allium fistulosum*) was increased as microplastic induced longer and finer roots [52]. Root average diameter was decreased by microplastic particles by >75.0% [52, 53].

5.4 Effect of microplastics on plant photosynthesis

Microplastics have both positive and negative effects on photosynthesis, but it is still not clear. In maize (*Zea mays*) foliar application of microplastic particles like PS-NH_2 and PS-COOH for a range of time (two, five, and seven days) showed noticeable effects on the photosynthetic activity of maize leaves (24-27%) [42]. A study conducted on lettuce (*Lactuca sativa*) also showed that certain photosynthetic parameters and the chlorophyll content of plants decreased after treatment with microplastics [54]. But an experiment performed on duckweed (*Spirodela polyrhiza*) showed that 50 nm red fluorescent nanoplastics at a concentration of 10^4 particles/mL had no statistically significant effect on chlorophyll *b* content [55]. Studies have shown conflicting results, so further studies are needed [6].

5.5 Oxidative damage of microplastics

Microplastics can cause oxidative damage as they affect the antioxidant systems of plants. Several enzymatic activities are altered by various microplastics. Catalase (CAT), superoxide dismutase (SOD), peroxidase (POD), malondialdehyde (MDA) are enzymes that help plants to mitigate oxidative damage. Different types of microplastics like PS plastic at both 5 µm and 100 nm, PH-NH_2, PH-COOH can affect the activity of these enzymes.

In the case of CAT, PH-NH_2, PH-COOH, and PS (100 nm) enhanced its activity, but PS (5 µm) decreased CAT enzyme activity [42, 56]. Microplastics like PS-NH_2 and PS-COOH enhanced SOD activity by 200%, 110%, and 192% [42]. Another microplastic called PS (polystyrene) plastic (5 nm) also increased SOD enzyme activity by from byt ~59%, 131%, and 222% at 10, 50, and 100 mg L^{-1} concentrations [56]. PS-NH_2 and PS-COOH increased POD activity by 99.2%, 63.4%, and 33.4% [42]. In faba bean (*Vicia faba*), PS (100nm) increased MDA enzyme activity by ~37% at concentrations of 100 mg L^{-1} and PS (100 nm) decreased MDA enzyme activity by ~39% at concentrations of 50 mg L^{-1} [56]. In maize, after two days of exposure, MDA activity was not affected by PS-NH_2 and PS-COOH but MDA content increased by 176% after seven days of exposure to PS-NH_2 [42].

5.6 Effect of microplastics on plant product quality

Microplastics degrade the quality of many plants, like rape, cucumbers, rice, etc. In rice (Y900), polystyrene microplastics inhibited metabolites and caused quality deterioration [57]. It was found that microplastics facilitated heavy metal entry in brome rape and along with heavy metal microplastics caused loss of quality of the rape by altering malondialdehyde, sugar and vitamin C content [58].

6. Conclusions

Although research on microplastics began only a few decades ago, scientific knowledge has evolved significantly in recent years. In our article, we have discussed different types of interactions of microplastics with plants. Such interactions have various ecological effects on terrestrial ecosystems. As plastic particles are very small, they can easily be transferred to different parts of the plant. They can enter the food chain through translocation of plant parts, and can have toxic effects on various enzymatic activities. Microplastic pollution is a complex environmental problem and has many ambiguities. Till now, massive studies have been done on the occurrence and ecological effects of microplastics in marine and other aquatic ecosystems, but in the case of terrestrial ecosystems, such studies have been limited. The pollution level of soil microplastics are too limited and it is necessary to systematically monitor the distribution of microplastics through different areas. Besides, there is a lack of consistent criteria for evaluating microplastic pollution which has led to a lack of comparison of existing research data. Nowadays, stereomicroscopy, Fourier Transform Infrared spectroscopy (FTIR) and Raman spectroscopy are widely used in microplastic detection. Pyrolysis gas chromatography spectrometry (TED GC MS), thermogravimetry (TGA) and time of flight secondary ion mass spectrometry (TOF SIMS) have also been used for detection. But detectors are too costly. That is why it is essential to explore other detection tools for future work. Besides, it is also necessary to unify and standardize the analysis methods for future study. Only through the mutual cooperation of scientists can a solution be found. The amount of research into microplastics in terrestrial ecosystems should be increased. Possible solutions can be found by better coordination of research and knowledge regarding the potential risks of microplastics, their harmful effects, and their sources in modern agriculture.

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