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Micro- and Nanoplastics in Soil: Should We Be Concerned?

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Summary

Plastic accumulation, particularly micro- and nanoplastics, in the oceans has received considerable attention. Accumulation of micro- and nanoplastics in terrestrial environments, including agricultural soil, has been studied less although plastics are used routinely in agriculture. Biodegradable plastic mulches may reduce future additions of micro- and nanoplastics to agricultural soil, but more study is needed.

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USDA United States Department of Agriculture National Institute of Food and Agriculture

Micro- and nanoplastics (MPs and NPs, respectively) have received a lot of attention in recent months, and for good reason. MPs and NPs are defined as small plastic fragments that are of sizes 1-5000 microns (i.e., micrometers, 10^{-6} m, and indicated by the symbol µm) and < 1 µm, respectively [1, 2]. To provide the reader a frame of reference, the smallest objects that can be seen by the naked eye are about 100 µm, human blood cells are about 5 µm in width, and microorganisms are about 0.2-3 µm in diameter (Figure 1). Large molecules such as proteins possess diameters of 1-6 nm. MPs and NPs result from the breakdown of plastics. Of the 320 million metric tons of plastic generated globally per year (growing at 5% per year), only 6-26% is recycled and 25-28% is mishandled at its end-of-use, resulting in the release of MPs and NPs into the environment [1, 3, 4]. MPs and NPs can also be released from landfills or waste disposal/transfer facilities. Their dispersal into the environment is exacerbated by extreme weather events such as high winds, floods and hurricanes.

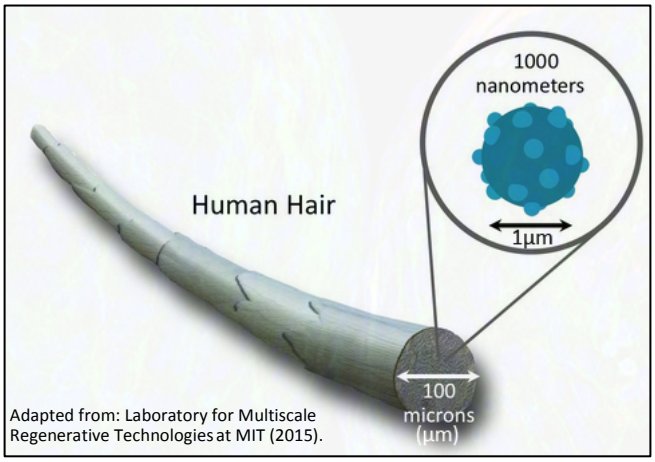

Figure 1. A human hair demonstrates the relative size of microns and nanometers.

Most of the recent reports in the scientific and popular press have focused upon the accumulation and fate of MPs and NPs in marine environments, particularly oceans. The amount of plastic in the oceans is expected to reach 250 million metric tons by 2025 [1, 3, 4]. An alarming prediction is that by 2050 the oceans will contain more plastics by mass than fish [5]. The plastic fragments floating in bodies of water will readily undergo photodegradative reaction in the presence of ultraviolet energy provided by the sun, leading to embrittlement and ultimately to the formation of MPs and NPs. The oceans are estimated to hold 5.5 trillion plastic particles, most of which are MPs and NPs [6]. Marine MPs and NPs have been reported to harm fish and other marine organisms in terms of lower reproduction, growth, and fitness, and have affected the biodiversity of microbial communities [1, 6-9].

MPs and NPs occur in soil at higher levels than in marine systems, by at least a factor of four [1, 8, 10]; but terrestrial MPs and NPs have received less attention. Recent reports suggest MPs in soil affect soil geochemistry and microorganisms [11]. Earthworms and collembolans (hexapods) exposed to MPs underwent increased mortality and reduced growth and reproductive rates [12, 13]. There are no reports to date on the impact of NPs on soils; and there is need for further investigation.

Farmlands may be particularly vulnerable to accumulation of MPs and NPs [10]. Agricultural plastics have many valuable uses in farming (Figure 2), particularly sustainable agriculture [14],

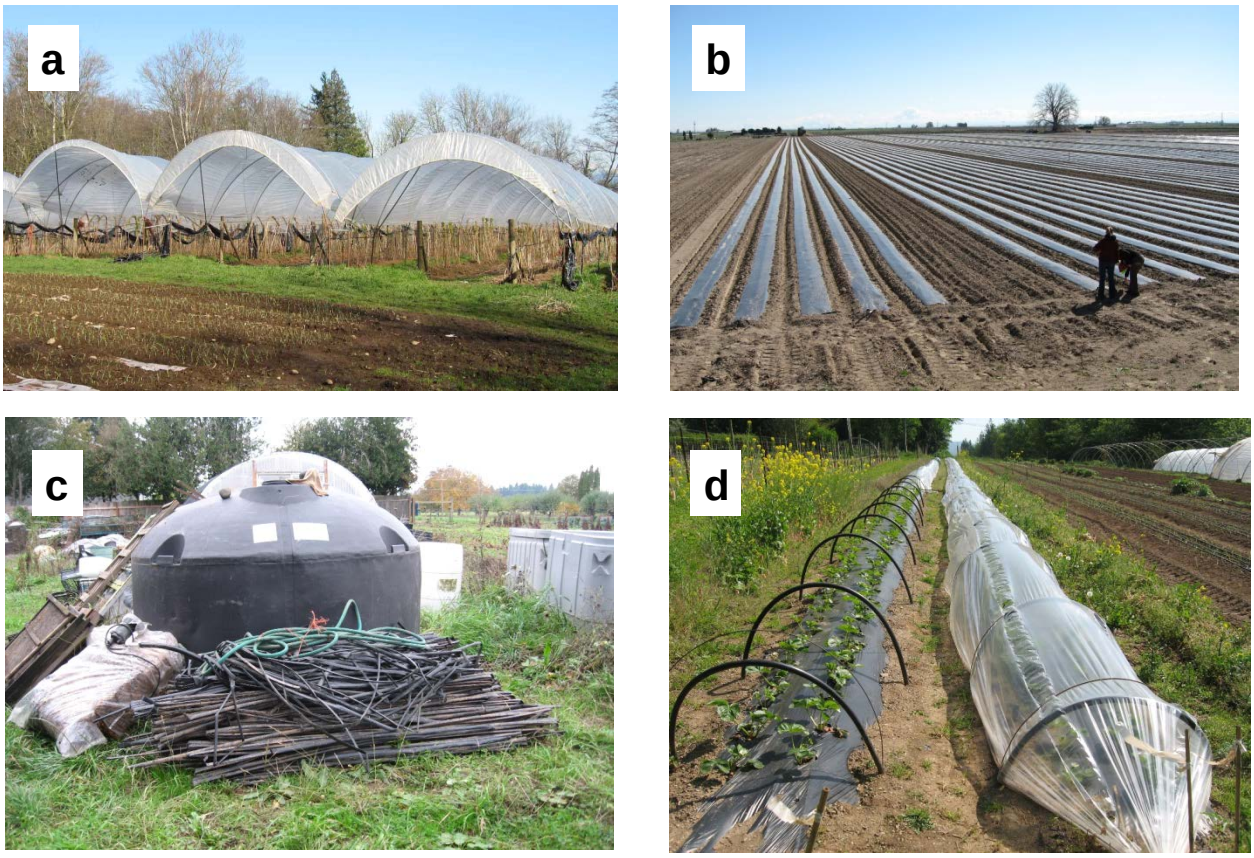

Figure 2. Use of plastics in agriculture: **(a)** *high tunnels,* **(b)** *plastic mulch film,* **(c)** *drip tape, and* **(d)** *row covers.* (C. Miles)

because they make efficient use of nonrenewable resources and can sustain the economic viability of a farm operation. Applications include mulch films, high tunnel coverings, drip tape, row covers, silage films, packaging (e.g., for seed, seedlings, or fertilizers), among others [15, 16]. But, the majority of the plastic materials employed for these products are non-biodegradable, and polyethylene is most commonly used. The plastics become brittle due to sunlight and other weather-related effects, and form small fragments that disperse in the environment due to flowing water and wind. (See video on biodegradation of plastic mulch [17]). Often, plastic fragments become incorporated into the soil due to incomplete retrieval of the mulch film when it is being removed or recovered prior to disposal. Polyethylene mulch fragments in soil occur in concentrations as high as 60-300 kg/ha (up to 500 kg/ha reported in China) [18, 19]. Residual plastic fragments can adsorb pesticides used in crop production or plasticizers that are employed in the manufacture of the plastics that may be released during plastic breakdown, leading to heightened and toxic levels of the agents in nearby soil [7]. The long-term fate of plastic fragments in soil is unknown. Recent reports predict that plastic fragments may reside in soils for over 100 years due to the near-absence of oxygen and ultraviolet radiation from the sun [11].

Biodegradable plastics are a step in the right direction to alleviate concerns about MPs and NPs in soil. Biodegradable mulches are designed to undergo biodegradation after being tilled into the soil at the end of the harvest season (Figure 3). A benchmark is for complete mineralization of biodegradable mulches by soil microorganisms within two years [20]. A recent report demonstrates that under standardized laboratory tests (e.g., ASTM D5988 [21]), MPs of size 50-75 µm (the diameter of a human hair) are readily biodegradable [22]. But, it is unclear if these results will translate to biodegradation in natural soil systems, or to NPs in soil. English reported the accumulation of MPs in an agricultural field immediately following two cycles where BDMs that were employed for vegetable production were tilled into the soil (Figure 4) [23]. It is not yet clear if the MPs and NPs resulting from BDMs will fully degrade under natural field conditions, or if they will cause any short-term or long-term harm to the soil ecosystem during their residence time (months to years). Further research is needed to more deeply understand the short-term and long-term effect of MPs and NPs on soil ecosystems.

Figure 3. Rototilling of biodegradable mulch film into the soil after harvest of vegetable crop. (C. Miles)

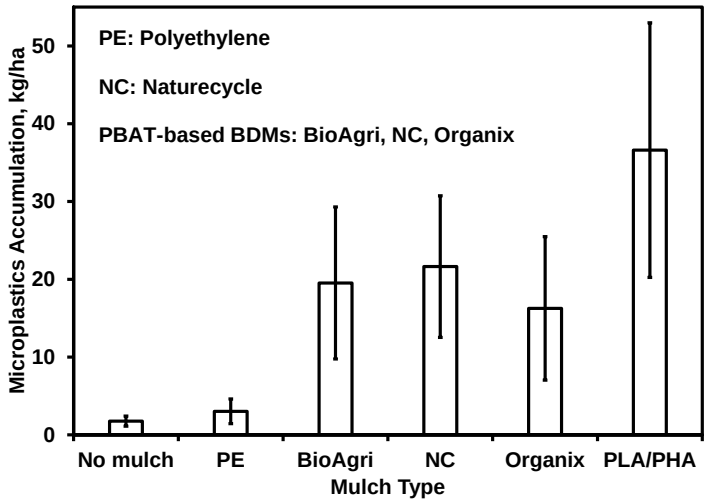

Figure 4. Accumulation of MPs (250-2000 µm) in soil after employing plastic mulches for two consecutive years in Knoxville, TN. With the exception of polyethylene (PE), mulch materials were tilled into the soil after crop harvest. BioAgri, NC (Naturecycle) and Organix are commercially available biodegradable mulches that contain polybutylene adipate terephthalate (PBAT) as their major polymeric constituent. PLA/PHA is an experimental mulch film prepared from a polylactic acid / polyhydroxyalkanoate blend. (From Reference [23] with permission.)

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