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Review

Plastics in soil: Analytical methods and possible sources

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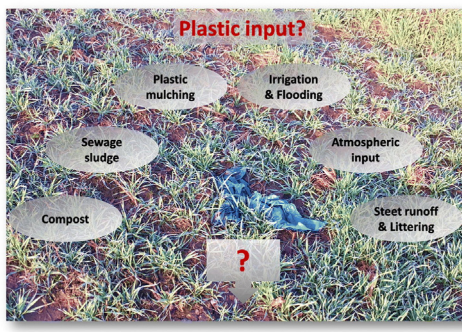
HIGHLIGHTS

- Analytical methods and possible input pathways of plastic in soil were discussed.
- Organic matter challenges plastic quantification in soil.
- Soil amendments and irrigation are likely major plastic sources in agricultural soils.
- Flooding, atmospheric input and littering can potentially pollute even remote soil.
- Leaching of small plastics from soil into groundwater cannot be excluded.

GRAPHICAL ABSTRACT



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ABSTRACT

At least 300 Mio t of plastic are produced annually, from which large parts end up in the environment, where it persists over decades, harms biota and enters the food chain. Yet, almost nothing is known about plastic pollution of soil; hence, the aims of this work are to review current knowledge on i) available methods for the quantification and identification of plastic in soil, ii) the quantity and possible input pathways of plastic into soil, (including first preliminary screening of plastic in compost), and iii) its fate in soil. Methods for plastic analyses in sediments can potentially be adjusted for application to soil; yet, the applicability of these methods for soil needs to be tested. Consequently, the current data base on soil pollution with plastic is still poor. Soils may receive plastic inputs via plastic mulching or the application of plastic containing soil amendments. In compost up to 2.38–1200 mg plastic kg^{-1} have been found so far; the plastic concentration of sewage sludge varies between 1000 and 24,000 plastic items kg^{-1}. Also irrigation with untreated and treated wastewater (1000–627,000 and 0–125,000 plastic items m^{-3}, respectively) as well as flooding with lake water (0.82–4.42 plastic items m^{-3}) or river water (0–13,751 items km^{-2}) can provide major input pathways for plastic into soil. Additional sources comprise littering along roads and trails, illegal waste dumping, road runoff as well as atmospheric input. With these input pathways, plastic concentrations in soil might reach the per mill range of soil organic carbon. Most of plastic (especially >1 μm) will presumably be retained in soil, where it persists for decades or longer. Accordingly, further research on the prevalence and fate of such synthetic polymers in soils is urgently warranted.

Contents

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1. Introduction

Since the beginning of commercial plastic production in the 1930s and 1940s, the production of the synthetic polymers rose rapidly, with an increase of 622% from 1976 to 2014 (Thompson et al., 2009). Although the recycling and energy recovery from plastic waste is rising (PlasticsEurope, 2016), large parts still reach the environment. Thompson (2006) stated that app. 10% of the produced plastic enters the oceans, and Jambeck et al. (2015) calculated that already in 2010 about 4.8–12.7 Mio t of plastic ended up in the marine environment. Similar estimates for other environmental compartments are largely lacking.

Pollution with plastic materials was recognized first in marine environments. As a consequence, a multitude of studies arose, which investigated the origin, occurrence and fate of plastic in the marine environment, i.e. in ocean water, in marine sediments and at the coast (see Lusher, 2015, for recent review). Considerably less is known about plastic in freshwater systems (Wagner et al., 2014; Eerkes-Medrano et al., 2015; Dris et al., 2015b; Horton et al., 2017), and there is only very limited knowledge on the sources, occurrence and fate of plastics in soil (Rillig, 2012; Steinmetz et al., 2016).

Nowadays, evidence is rising that plastic is abundant in soil: Fuller and Gautam (2016), for instance, recently detected 0.03 to 6.7% of plastic in soils of an industrial area. Once plastic accumulates in soil, it becomes part of a complex mixture of organic matter and mineral substituents. Due to organic mineral interactions, soil organic matter (SOM) may become very stable and persist for up to a few hundred years (Paul et al., 1997; Six and Jastrow, 2002; Kögel-Knabner and Amelung, 2014). Yet, the origin of SOM is diverse, comprising mainly residues from plants and microorganisms at various stages of decomposition (Kögel-Knabner and Amelung, 2014; Lehmann and Kleber, 2015). This large variability of SOM constituents makes the chemical identification of plastic residues in soil to a specific challenge. Due to the vast range of functional groups in SOM, it can be difficult to identify particularly very small plastic materials on the basis of their chemical properties. Sediment analyses of plastic thus suggested to eliminate such organic impurities (e.g. Imhof et al., 2012). For soils, such approaches remain to be tested and likely optimized. Other than in at least anaerobic sediments, the oxidic nature of mineral phases may result in stronger binding of SOM moieties. Besides, some specific refractory compounds are usually more abundant in soils than in sediments, such as the compounds originating from terrestrial plants like lignins, suberins and tannins as well as their degradation products, and in several places also black carbon, the residue from incomplete biomass burning. The degree to which both organo-mineral interactions as well as these compounds interfere with plastic analyses remains to be tested. Such methodological advances, however, are urgently needed to be able to quantify the toxicity of plastic in soil via dose-response relationships as well as its fate and thus future exposure risks.

Once plastic has entered soil and environment, it threatens ecosystems by e.g., releasing toxic and endocrine substances like bisphenol A (Sajiki and Yonekubo, 2003). Furthermore plastic is a sorbent for other toxic pollutants like heavy metals and polychlorinated biphenyls (Frias et al., 2010; Ashton et al., 2010; Engler, 2012; Velzeboer et al., 2014). Especially small plastic items like microplastic (defined as <1 or <5 mm) and nanoplastic (defined as <100 or <1000 nm) endanger the environment (Teuten et al., 2007; Besseling et al., 2014; da Costa et al., 2016). Such plastic items act as carrier for pollutants when taken-up by biota (Trojan-Horse-effect; Gregory, 1996; Thompson et al., 2004; Thompson et al., 2005) and in this way adsorbed pollutants may be introduced to the food-chain (Teuten et al., 2007; Engler, 2012). A multitude of studies proved the negative effects of plastic on marine species (e.g. Gregory, 2009; Wright et al., 2013; Li et al., 2016) and for freshwater species, like fish (Sanchez et al., 2014) and birds (Holland et al., 2016). Unlike other ecosystems, there is again only very limited knowledge on ecotoxicological effects of plastic in soil. First data suggest that microplastics negatively impact on the reproduction, growth and mortality of different soil dwelling earthworms (Huerta Lwanga et al., 2016; Cao et al., 2017; Rodriguez-Seijo et al., 2017). Furthermore, beside plastic also its additives, like plasticizing agents including phthalates may harm soil dwelling organism when released from plastic. In many plastics such additives are only loosely incorporated in the polymer structure and might thus be washed out. Some of these phthalates like bis(2-ethylhexyl) phthalate were found to inhibit soil microbiological activity (Wang et al., 2016). They may exhibit carcinogenic, mutagenic and endocrine-disrupting properties (Erkekoglu and Kocer-Gumusel, 2014), and are thus considered as harmful soil contaminants (Fu and Du, 2011; J. Wang et al., 2013; Magdouli et al., 2013). Once released into the environment phthalates may be taken up by plants (Sun et al., 2015), enter the food chain and endangering human health (Hauser and Calafat, 2005). Accordingly, if the input of plastic into soil is not eliminated, negative effects on soil dwelling organism, soil fertility and human health cannot be a-priori excluded.

In principal, elimination of plastic contamination from soil might be difficult. Once introduced into the environment, plastic general turned out to be persistent, thus it accumulates in water and sediments (e.g. Barnes et al., 2009). Other persistent substances in soil, like black carbon may persist for several hundred years (e.g. Czimczik and Masiello, 2007); this might also be the case for plastic. However, the long-term fate of plastic is still largely unclear. Leaching along cracks or within large biopores as well as bioturbation through larger animals may transport stable and particulate SOM residues to deeper depths, transport