Chapter 29

Biodegradation of microplastics and synthetic polymers in agricultural soils

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29.1 Introduction

29.1.1 Plastic pollution

The demand for plastics worldwide remains at 245 million tons every year (Andrady, 2011). Ever since the advent of "Bakelite," large quantities of weightless, resistant and durable plastics have been manufactured globally and they contribute to 10% of the municipal waste generated. One third of the commercially produced plastic resins are utilized as packaging material by replacing other customary materials such as paper and glass. Their accumulation in the natural habitat is assessed to be 155−265 million tons by the year 2060, in which 13.2% of them could be composed of microplastics (Cox et al., 2019). This has emerged as a global environmental concern due to its problematic resistance to degradation.

29.1.2 What are microplastics and synthetic polymers?

The onset of plastic age has led to the accumulation of unrecyclable waste under a wide range of environments from water bodies to terrestrial ecosystems. The artificial chemical substances that have numerous molecules with covalent bonds are called synthetic fibers and microplastics are fragments of plastics that originated from large plastics that pollute the environment. Microplastics have the risk of mixing with the biota and eventually entering the food chain (Rillig, 2012). They are small particles of plastics in the size range of 1−500 μm with variable origin and composition, and they are not immediately obvious to the naked eye. Hence, the continuance of the ecosystem requires mandatory dissociation and processing of microplastics.

29.1.3 Biodegradation

Degradation can be defined as the chemical change that decreases the integrity of the polymer by reducing its molecular weight. It is usually classified into photodegradation (light), thermal degradation (high temperature), biodegradation (microorganism), thermooxidative degradation (slow oxidation), and hydrolysis (water). The chemical breakdown of the substance or changes in physical, chemical, and mechanical properties of the material by microorganisms like bacteria, fungi, and yeast is called generally biodegradation. Enzymatic reactions are the leading factors in the process of biodegradation. Commonly, an expulsion of extracellular enzymes will be appended to the chains of plastic or polymeric substances and cleave the ties between the molecules called surface erosion. Due to the biodegradation process, the

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employed microbes will determine the substances to produce CO_2, H_2O, and other metabolites. Plastics and synthetic polymers have been introduced into the agroecosystems in different forms, for example, pesticides, pipe materials (polyvinylchloride (PVC)), plastic mulches, plant packaging material such as polyethylene (PE), polystyrene (PS), and polypropylene (PP) sewage sludge as fertilizer, and reuse of wastewater (treated in industries). The large plastics and fiber materials are degraded by the natural effects of hydrolysis, heat, UV, and abiotic effects. Generally, the plastics are degraded to the plastic films and polymeric fibers under the process of biodegradation by microorganisms. Microbes like bacteria, fungi, and yeast are involved in the process of enzymatic degradation.

Polyethylene terephthalate, the most common source of packaging material, is degraded by *Ideonella sakaiensis*, a bacterium which releases the PETase and METase enzymes to break the strong covalent bonds of the polymers to make them weaker in the form of Environmental Protection Agency (EPA) and glycol. The organic pollutants of gasoline, diesel, polycyclic aromatic hydrocarbons (naphthalene, phenalene), polybrominated biphenyls, carbamate insecticides, and herbicides are commonly present in the soil (Burgess, 2013). Anaerobic microbes utilize the pollutants as the only source of carbon and energy. Depolymerization (polymer to monomer) and biodegradation reactions have been exploited at this level. The terminal stage of biodegradation is mineralization which ends up in the formation of CH_4, CO_2, water, N_2, and salts (Fig. 29.1).

The large plastic and fiber materials under the effect of abiotic hydrolysis, fragmentation, heat, and UV form microplastics (plastic beads, pesticide chemicals, fibers, and films). Microplastic degradation is carried out by the enzymatic process of microorganisms and is involved in the production of green gases.

29.2 Microplastics

29.2.1 Sources and types of microplastics

Microplastics have administered their impression in various ecosystems that have languished due to these contaminants. The appearance of these compounds, extensively studied in marine, terrestrial, agricultural, and soil-based environments must lead to an understanding of the varied origins of these aggregates. Sources of microplastics are classified as primary (directly manufactured such as cosmetic microbeads) and secondary (fragmented from larger plastic particles) microplastics. Their presence is not limited to water bodies only but agriculture lands too, enhancing the risk of

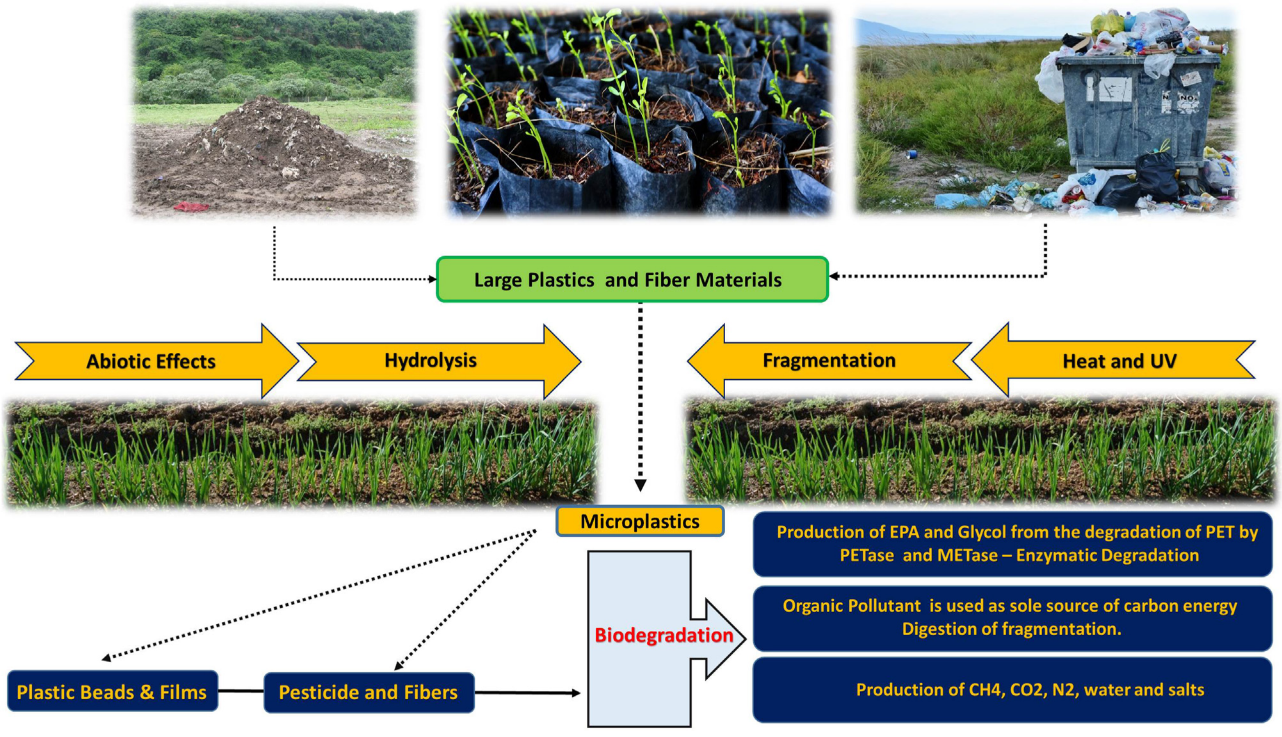

FIGURE 29.1 Overview of biodegradation of micrplastics and synthetic polymers.

contaminants in the food (Auta et al., 2017). Studies have also shown their occurrence in cosmetics and external applicants (Leslie, 2014). Types of microplastics, classified according to the polymer types are components of polyethylene, polyamide, polystyrene, chlorinated, and chlorosulfonated polyethylene (Fries et al., 2013).

29.2.2 The biological consequences and impacts of microplastics on agricultural soils

The agricultural pesticides have carcinogenic, mutagenic, teratogenic, and immunotoxin properties. The soil microbiological and physicochemical characteristics are tremendously affected by the microplastics, synthetic polymers, and agricultural pesticides. Agricultural soil has graced an obvious target for microplastic accumulation, considering their vulnerability to sludge disposal via water treatment plants. And the increasing practice of sludge as a fertilizer owes to the decline of these agroecosystems (Corradini et al., 2019). The behavior of synthetic fibers in these wastewaters adds to the booming resources of microplastic contaminants. Further, these agro-ecosystems have a remodeling in nonessential heavy metal precipitates like cadmium. The adsorption and desorption kinetics of these heavy metals have also been confirmed to be altered by microplastics through the EDS investigation of soil cadmium contents (Zhang et al., 2020).

29.2.3 Effects of microplastics on soil organisms

The precarious nature of microplastics affect a wide range of organisms. The extent of the subsequent decay is evident in affected soils and the soil biota. Influenced life forms include protists, ciliates, flagellates, nematodes, isopods, and ameba, to name a few (Rillig and Bonkowski, 2018). Microplastics can reduce their movement by attaching to their external body surface and their ingestion can cause damage to the food passage, decreased responses, and poor metabolism.

29.2.3.1 Earthworms

Earthworms are a key factor in the maintenance of a healthy soil ecosystem. Microplastics can enter through dermal absorption and accidental ingestion. These invertebrates modify the soil hydraulic attributes associated with biopore formation and lead to the transport of microplastics, as proven in *Lumbricus terrestris* earthworms by the structure of burrows. They have been shown to incorporate microplastic to the soil by soil adherence, casts, egestion, and burrow formation (Rillig et al., 2017). Not just the abovementioned characteristics, but also the physiological features of earthworms like fitness, diminished growth, and intensified fatality are modified by exposure to microplastic-contaminated environments (Cao et al., 2017). According to the study conducted by Cao et al. (2017), exposure to 1% and 2% (wt./wt.) have shown lethal effects.

29.2.3.2 Nematodes

Nematodes play a key role in the soil food web with a wide range of dietary habits. The *Caenorhabditis elegans*, a well-studied nematode has been the prime model organism for the examination of microplastic influences in freshwater pelagic and benthic nematodes. While waterborne organisms like *Danio rerio* did not exhibit drastic morphological changes, nematodes like *C. elegans* revealed an inhibition of body length and reproduction rate. Further, permanent intestinal damage, due to reduced calcium levels by glutathione S-transferase enzyme accumulation causing oxidative stress in intestines, were observed in these nematodes (Lei et al., 2018). When exposed to a higher concentration of microplastic materials for a day, there are adverse effects on the adult nematode and on the offspring numbers by 4.5%−22.9% (Kim et al., 2020; Schöpfer et al., 2020).

29.2.3.3 Collembolans

Collembolan is commonly known as springtails, a micro-arthropod highly prevalent in the soil surface. Similar to earthworms, collembolans deported microplastics in soil biota. There was a noted alteration in the gut microbiome of these arthropods after microplastic exposure for 56 days. Further, the isotopic and elemental association of nontarget species like the collembolans are modified by microplastic exposure (Zhu et al., 2018). Studies have also shown reduced body weight and reproduction capacity on exposure to the microplastics.

29.2.3.4 Isopods

Crustaceans including isopods are influenced by micro plastics. Particularly modulate immune processes have observed in the terrestrial crustacean *Porcellio scaber* (Dolar et al., 2021) but there are no changes in the feeding behavior. Since the food ingestion, defecation, body mass, mortality rate, protein, carbohydrate, and triglyceride rates had little to no alteration indeed after lengthy exposure to micro plastics. Since the food ingestion, defecation, body mass, mortality rate, protein, carbohydrate, and triglyceride rates had little to no alteration indeed after lengthy exposure to microplastics (Kokalj et al., 2018).

29.2.4 Physiochemical characteristics and hidden impact of microplastics on the agricultural soils

The large amount of microplastics present in the soil is known to antagonistically influence soil biophysical and chemical properties including structure, texture, porosity, surface area, pH, and nutrient content (Tang, 2020). Interaction in soil, makes the microplastics separate within the soil patterns through the exposure to dry−wet soil cycles, soil administration, harvest, bioturbation, hence modifying the soil porosity, bulk density, water retention capacity, and overall soil composition. They also can enhance carbon, nitrogen, phosphorus, and other organic matters in loess soils of China. They also entrap and embrace toxic heavy metals in the soil, hence altering the nutrient cycle of the soil (Wang et al., 2020). Microplastics react with natural fertilizers like cow manure to create more impact on the natural emission of green gases like nitrous oxide, ammonia, carbon dioxide, methane, and microplastics taken up by plants, and the impacts are shown in Fig. 29.2. A study by Sun et al., 2020 revealed that incorporation of cow manure with microplastics, PE, and polyhydroxyalkanoate (PHA) influences methane and ammonia up to 7.9%−9.1% and 20.9%−33.9% respectively. Polyvinyl chloride is known to reduce its emissions by 6.6% and 30.4%. Importantly, the N_2O emission value is higher than the control. Cow manure is a source of nutrients for the soil and an organic fertilizer resource which is completely collapsed by the mixture of microplastics (Sun et al., 2020).

Green gas emission has been highly influenced by the microplastics. The cow manure is a common fertilizer for farmers. Nonetheless when mixed with microplastics, it impacts the natural emission ratio of green gases like CH_4, N_2O, and NH_3.

The recent report of Chinese Academy of Sciences has revealed that the microplastics of 50 nm in size taken up by plants could penetrate through the plant roots (Li et al., 2020). Meanwhile, the spherical plastic particles about 2 μm in size with a small degree of mechanical flexibility have been identified in roots of plants and have created spaces in the root phylum. Microplastics of polystyrene material can trigger growth inhibition, genotoxicity, oxidative damage, and decreased germination rate (Guo et al., 2020).

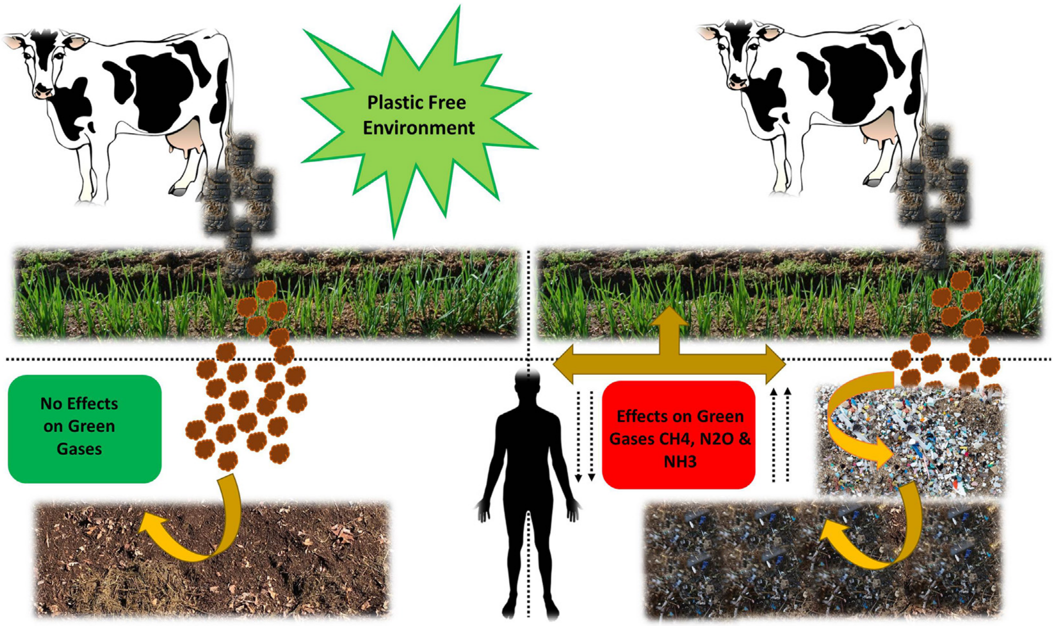

FIGURE 29.2 Microplastics: hidden impacts on agricultural soil, plant, and human.

29.2.5 Microplastic separation techniques

Microplastics are initially measured by desired analytical techniques like sampling, extraction, quantification, and quality assurance (Hanvey et al., 2017). Many researchers have suggested density separation as the best approach for the elimination of microplastics from the sediments when microplastics are highly present in the sediments. In this process, heavy salt solutions like sodium iodide and zinc chloride are used as a floating agent and proper agitation separates the solution based on their density. About 65% of microplastics are removed from the sediments (Quinn et al., 2017).

29.2.5.1 Sampling

Generally, microplastic pollution is comprehensively present in the aquatic environment rather than the soil environment. Liu et al. have revealed the presence of microplastics and mesoplastic pollution in the farmland in suburbs of Shanghai, China. The micro-Fourier transform infrared spectroscopy and density separation techniques have been used for the identification of micro and meso (large) plastics of sizes about 20 μm—5 mm and 5 mm−2 cm. The large size of microplastics is highly identified in the deep soil (Liu et al., 2018). Importantly, polypropylene and polyethene are exceedingly present in the farmlands. Examples of 78.00 and 62.50 items kg^{-1} average amount of microplastic presence have been recorded, and the percentages of polypropylene and polyethene are about 50.51% and 43.43% (Liu et al., 2018; Zhang et al., 2020).

29.2.5.1.1 Judgmental sampling

Judgmental sampling is a purposive method where the researchers and experts decide the sampling site based on their experiences. This method generally covers a large area of interest. The residents/respondents are questioned and the trial continues until a particular respondent accompanies the investigator toward any viable leads. This method is chiefly exercised to locate sampling points at the location (Adu-Boahen et al., 2020).

29.2.5.1.2 Simple random sampling

Random sampling is practised in separation techniques to direct randomized control and blind experiments. Generally, this method is effectively used for the collection of terrestrial and aquatic microplastic samples, using transect lines in a few cases (Hanvey et al., 2017).

29.2.6 Microplastic identification techniques

29.2.6.1 NIR spectroscopy

Near infrared spectroscopy (NIR) spectroscopy technique is being utilized to measure elements composition with large-volume microplastics in soil. It measures microplastics by the light that is returned from the surface at wavelength 350−2500. Additionally, it provides the percentage for various wavelengths (Corradini et al., 2019).

29.2.6.2 Visual identification

The visual sorting was one of the various commonly used techniques for the identification of microplastics (using type, shape, degradation stage, and color as criteria) (Hidalgo-Ruz et al., 2012) and visually counted microplastic was spectroscopically confirmed. This microplastic percentage was differentiated with the type, color,and size. Fibers have been fabricated with a greater progress rate (75%) than particles (64%) (Lenz et al., 2015).

29.2.6.3 Chromatography

Chromatography is preferred as an analytical tool to quantify the microplastics, notably in environmental samples. It proceeds via a polymer-specific portion-related trace level with Curie-Point pyrolysis-gas chromatography-mass spectrometry coupled with thermochemolytics (Fischer and Scholz-Böttcher, 2017). To develop the disclosure of plastic contamination the quantitative analysis system pyrolysis gas chromatography-mass spectrometry was used (Ribeiro et al., 2020).

29.2.6.4 Thermogravimetric analysis

The thermogravimetric analysis technique examines the modification of sample size while the sample is subjected to temperature shift. During the heating process, gaseous composites and various chemical reactions are formed (Borrachero et al., 2008).

29.2.6.5 Vibrational spectroscopy

Raman and FTIR microspectroscopy are vibrational spectroscopies that are used for the classification of microplastics in the atmosphere. These approaches are utilized for investigating beach sediment samples and marine samples (Käppler et al., 2016).

29.2.6.6 Proton nuclear magnetic resonance spectroscopy

Proton nuclear magnetic resonance spectroscopy (H-NMR) is the technique of nuclear magnetic resonance within NMR spectroscopy used to determine the structure of hydrogen-1 nuclei within the molecules of a substance.

29.2.7 Importance of microorganisms in microplastic biodegradation

Largest scientific studies have analyzed the frequency, ingestion, portion, behavior, substance, and impression of microplastics (Yuan et al., 2020). Microorganisms are the main actors of most of the degradation of both synthetic and natural polymers. In most of the degradation processes, microbes are utilized for the conversion of smaller fragments of plastic and fiber materials. Bioremediation is an effective method for microplastic degradation (using microbes to degrade the plastic fragments).

29.2.7.1 Bacteria

Microorganisms play a vital role in microplastic and synthetic polymer degradation. The mechanism of the conversion of insoluble biopolymers to soluble polymer is the principal of the degradation of plastics and polymers. Notably, many researchers have reported the influence of microorganisms in the function of degradation. For example, polyethylene is known to be degraded using *Brevibacillus brevis*, *Rhodococcus rubber*, *Pserdomonas chlororaphis*, *Comamonas acidovorans TB-35*, and *Pseudomonas fluorescens B-22*. The urea-coated polycaprolactone-based polyurethanes are eliminated by *Closterium botulinum*. The BTA copolyester is chiefly used in the food material and agricultural packaging systems, apart from *Thermomonspora fusca* (Ghosh et al., 2013). Polyethylene microplastics are colonized by bacterial associations with a distinguished community structure along with some other taxa abounding on microplastics such as plastic-degrading bacteria and pathogens. Concurrently, the predicted functional profiles are more well-known for the microplastics in the pathways of amino acid metabolism and xenobiotics biodegradation and metabolism. These act as a discrete microbial habitat, conceivably modifying the ecological functions of soil ecosystems and those in aquatic environments compared wtih microplastics in soil (Huang et al., 2019). Plastic colonizers such as *Arcobacter*, *Escherichia*, *Colwellia*, and *Pseudomonas* species are known to be the potential candidates for microplastic degradation (Oberbeckmann & Labrenz, 2020).

29.2.7.2 Yeast

The single-cell organism yeast rapidly breaks down plastics and polymers to degrade materials. Particularly, the phyllosphere yeasts, which are present in plant leaves, immediately degrade the biodegradable plastics from soil. The synthetic polymers and biodegradable plastics are degraded by various sorts of yeasts using enzymatic reactions. For example, cutinase-like enzymes, which are produced by *Cryptococcus* sp. strain S-2, degrade the polylactic acid and biodegradable plastics (Masaki et al., 2005).

29.2.7.3 Fungi

The biodegradation of microplastics is actively achieved by naturally occurring fungi which require minimum nutrients and are known to decrease both the quantity and intensity of the microplastic grains (Paço et al., 2017). Fungi attack substrates utilizing their enzymes and detoxify pollutants with their inherent and unique expertise and can act on nonspecific substrates. They can generate hydrophobins approaching the surface layer to affix hyphae upon hydrophobic substrates. Fungi can utilize certain substrates, essentially the individual carbons, including starch sources, in macro- and microplastics, thereby degrading them (Sánchez, 2020).

29.2.7.4 Enzymatic degradation

While most plastics are extremely biostable, there is strong evidence that these products can be enzymatically degraded by microbes. It is possible to manipulate biological agents and their lytic enzymes as a potent method for polymer degradation. The polymer based on starch is attractive for microbial incursion and the matrix material acts on hydrolytic enzymes to decrease their weight. Compared to other synthetic polymers, polymers made of starch or flax fiber display better biodegradability. Due to their abilities to dissolve and metabolize synthetic plastics, members of the metabolically diverse genus *Pseudomonas* are of special concern (Bano et al., 2017).

29.3 Synthetic polymers

Synthetic polymers are robust substances with a wide variety of mechanical, thermal, and oxidation properties that can be transformed into biomedical polymers. They are categorized into inorganics (metals and ceramics) and organics (polymers). In general, the successions of multiple aggregates of the same monomeric units with the straight-chained or branched forms derived from the petroleum products are called synthetic polymers. Commonly, the synthetic polymers have been categorized into four types in the utility point of vision such as thermoplastics, thermosets, elastomers, and synthetic fibers. Synthetic polymers have unique physicochemical and mechanical properties which results in slow degradation.

29.3.1 Inorganic and organic polymers

Inorganic polymers are composed of a carbon-free macromolecule with double covalent bond attachment in the back or main chain. They are more stable than organic polymers. They are known to melt or get soft structure at high temperatures but do not do not burn (expect polymers containing sulphurs). Mostly, the inorganic polymers are dissolved with polar solvents because they are made up of many polar units, which contribute to the high occurrence of covalent bonds. Organic polymers originate from the polycondensation reactions that generate low-molecular-weight reactive molecules. Generally, organic polymers are released from enzyme-mediated processes using microorganisms and are classified into main four categories, such as proteins, carbohydrates, nucleic acids, and lipids. Examples of biopolymers include polysaccharides, polypeptides, and polynucleotides, which are released by cell lysis. Organic polymers have higher elasticity corresponding to the inorganic polymers due to the short-chain segment as well as the stiffness of the cross-linked polymers. Structurally, inorganic polymers are pure crystalline in nature and can be categorized into phosphorus-based polymers or polyphosphazines (polyphosphonitrilic chlorides and polydiethoxyphosphazines), sulfur-based polymers or linear chain polymers (polymeric sulfur and polymeric sulfur nitride), and chalcogenide glass or network polymers.

29.3.2 Sources of synthetic polymers in agricultural soil and their impact

Microplastic integration and synthetic polymers are inevitable in agricultural and other sectors because of their strong prevalence. The agricultural soil is profoundly affected by the notable pollutants of microplastics and synthetic polymers. In the agriculture sector, microplastics and synthetic polymers have played a vital role with a strong impact on the soil. For example, beads fragments, plastic mulches, fibers, films, biodegradable plastics, and nanoplastics (Rillig et al., 2019). From the farmer's view, the concern is toward the amelioration of production with limited resources that induce the changes in the agriculture pattern. In contrast, the natural pattern is an effective way to produce healthy products as well as to minimize the use of microplastics and synthetic polymers.

The plastic materials and polymers are used in agricultural sectors to ameliorate the production as well as to deliver food security for the human health (Zumstein et al., 2018). The use of plastics in the agricultural line has introduced the chances for the accumulation of plastics. In the meantime, the use of a biodegradable polymer rather than a nondegradable polymer limits the frequency of deposition (Zumstein et al., 2018). The synthetic polymer and microplastics extraction is the initial step to exclude them from the soil.

Many of the polymers, particularly commodity polymers have been highly used in agriculture (Albertsson et al., 1987) because of their superabsorbent, soil conditioning, and biosorbent nature (Milani et al., 2017). In general, the decomposition of a nonbiodegradable plastic polymer takes many years and, in particular, the deposition of polymers in the soil is harmful to the quality of the polymer. Generally, the types of polymers used in agriculture are PHA (mode of degradation is hydrolysis, induce water pollution in agriculture), polythioester (considerable waste disposal problem, the residual film left in the field after mulching induces severe problems to the soil), polyesters (nonbiodegradable fabrics), polyethylene (due to incineration produce harmful gas emissions), polypropylene (low moisture regain), polystyrene (soil compression), and polyvinyl chloride (has high chlorine content that induces the toxic pollution).

The interaction between the fine clay particles of soil and polymers introduces the process of aggregation leading to the loss of soil strength. Tian et al. (2019) have reported the consequence of polymer materials on soil structure. The humic acid and modified polymers may influence the soil aggregation. The soil organic carbon mineralization has been suppressed by the modified polymer. The stability of soil aggregates is directly proportional to the soil polymer incorporation (Tian et al., 2019). Because of the lack of oxygen supply, polymer aggregation under the soil surface has a slow biodegradation rate. Importantly, the biodegradation process under anaerobic conditions produces methane and carbon dioxide.

29.4 Key steps in the biodegradation of polymers in agriculture soil

29.4.1 Microbial colonization

The biodegradation of polymeric products has had a tremendous detrimental effect on agricultural properties. Synthetic polymers have become substrates for various heterotrophic bacteria. The process of biodegradation is initiated by the noninfectious cellular layer (biofilm) of microbes like *Ochrobactrum anthropi*, *Vibrio harveyi*, *Alcaligenes denitrificans*, *Xanthomonas maltophila*, and *Pseudomonas aeruginosa*, and the process is called colonization. The temperature, relative humidity, and carbon source (utilized from the polymers) are the necessary requisites to form this layer. More specifically, the metabolic processes of microbes have degraded plasticizer phthalate esters used in the processing and softening of PVC (Gu, 2007).

29.4.2 Enzymatic depolymerization

Microplastics are produced from the reactions of fragmentation, degradation, weathering, UV radiation, and by the microorganisms on plastic materials. Plastic products have been entering the soil since the 1940s, and will be in the atmosphere for decades. They impact natural bodies of water and cause soil contamination, including to farmland, and air pollution. Incorporating polymers in agriculture would increase production while increasing the deposition of microplastic and polymer waste. The effective way to eliminate the large volume of polymers and plastics is enzymatic microbial biodegradation process. Many enzymes perform an essential part in the biodegradation of polymers. Extracellular depolymerases can break polymers into monomers and utilize them as carbon source (Gu, 2003). For example, the proteinase k, lipase, and pronase have been used for the poly(L-lactide) degradation (Banerjee et al., 2014).

In general, the microorganisms generate extracellular enzymes that have attributes for plastic surface degradation and break their polymer chains and produce biogases like CO_2, CH_4, and water. Significantly, the proteases, hydrolases, ureases, cutinases, esterases, and laccases have been used in enzymatic biodegradation. These enzymes originate from bacterial strains, viz., *Pseudomonas*, *Streptococcus*, *Staphylococcus*, and *Bacillus*, as well as fungal species like *Pestalotiopsis*, *Penicillium*, *Phaenarochete*, *Aspergillus*, etc. *Ideonella sakaiensis* is a bacterium that has been identified in Japan landfills and is used for the poly-ethyleneterephthalate (PET) degradation using PETase enzyme. The PET is converted into mono(2-hydroxyethyl) terephthalic acid (MHET), terephthalate (TPA), and bis (2-hydroxyethyl) TPA using PETase, and later producing glycol and TPA from the conversion of MHET (Palm et al., 2019). These conversions are helpful to the other soil microbes to degrade the rest of the materials and produce CO_2 and water. The only drawback of PETase is that PET degradation can only occur when other plastics are still in existence. Researchers are focusing on the production of PETase enzyme to control the other soil pollutants. The enormous derivatives of PETase have been developed using the integration of genetic engineering. Initially, the enzyme gene sequence is screened and incorporated with several vectors like pSB1k3 and pSB1c3 and transformed into *E. coli* using recombinant DNA technology to produce a purified form of PETase enzyme for mass production.

29.4.3 Pesticide polymers on abiotic degradation

The plastics enter agricultural fields in different forms but one of the frequent paths is using pesticides on agricultural lands. The pesticides have various types of chemicals including PPCP (pharmaceuticals and personal care products) and ibuprofen. Rubasinghege et al. (2018) reported the presence of PPCP and ibuprofen in the kaolinite clay as the major mineral components of the soil (Rubasinghege et al., 2018). The presence of polymer in the agriculture soil induces bioaccumulative and endocrine disruptive activity in humans.

The so-called prooxidants (prodegradants) added in the amounts of 1%−5% cause and perpetuate free-radical chain reactions with the involvement of oxygen, which is one way to speed up polyethylene depletion (Koutny et al., 2006). These processes contribute to the photochemical oxidation of synthetic polymers, and initiate the breakdown of long polymer chains into short segments that most commonly end with functional groups (carboxyl, ketone, and alcohol). By mixing a synthetic (decomposition-resistant) polymer with a natural (biodegradation-prone) polymer in one substance, a material whose chemical structure is partly degraded under the influence of biological factors can have irreversible damage to its internal structure (Mohan, 2011). Therefore it can be concluded that if such a composition contains a large amount of a biodegradable part, it is likely that it will be completely degraded after a certain period of time. The resultant degrading products seem to be an intrinsic part of the ecosystem and do not pose a greater danger to living species. Starch is probably one of the most widely used plant biomass for polymer structure alteration. The comparatively large variety of research papers exploring the properties of starch and polyethylene mixtures confirms this (Vázquez-Morillas et al., 2016; Johansson et al., 1999; Boryniec et al., 2004; Mierzwa-Hersztek et al., 2019; Korol, 2014).

The primary PPCP contained in the soil is typically degraded by the effects of UV radiation and oxygen and later is stored in the degraded form leading to the accumulation of PPCP in plants and water which induces severe health effects and increases the environmental toxicity. The plant materials and soils are frequently induced to the sorption of chemicals like PPCP which can be eliminated using abiotic degradation method (thermal, chemical, mechanical, photodegradation). Metal iridium-doped polymers break the chemical bonds of the polymer, rendering the polymer available for fuel and energy (Yirka, 2016). The degradation of photodegradable molecules is caused by the absorption of photons and various wavelengths of light, such as infrared radiation, visible light and ultraviolet light.

29.4.4 Biotic degradation

It is identified that more than 20 bacterial genera degrade various kinds of plastics. In order to investigate their ability to degrade and metabolize a range of synthetic polymers and by-products, experiments on various activities of the genus *Pseudomonas* have been conducted (Esmaeili et al. 2013; Ribitsch et al., 2015; Roy et al., 2008). The biodegradation of polythenes has involved microbial enzymes capable of degrading lignin polymers containing oxidizable C−C bonds which include manganese peroxidases, lignin peroxidases, and laccases. Laccase-mediated oxidative cleavage of the amorphous plastic film region results in the formation of readily accessible carbonyl groups and a major reduction in the weight of the PE film. In particular, the use of customized microbial consortia demonstrated encouraging PS and PE degradation relative to the use of independent microbes (Eubeler et al., 2010; Lobelle & Cunliffe, 2011; Sivan, 2011).

29.5 Conclusion

The entire world is dominated by microplastics and synthetic polymers. Plastics have become an important commodity for everyday use. The need for synthetic polymer and plastic materials is inevitable in all sectors. Polymers are thermoelastic, water insoluble, and pose a significant environmental threat. Certainly, the introduction of artificial material into the natural settings raises the value of production in all industries, including agriculture, however the detrimental effect on agricultural land must also be acknowledged. As the degradation process leads to complete degradation and polymer mineralization, microbial degradation is easier than physical and chemical processes. In altering the physicochemical properties and degradation of plastics, the biofilm population plays an important role. The plastic-modifying enzymes described above are critical for achieving a complete biological process for the upcycling of plastic waste into biodegradable plastic, but they also involve sufficient microorganisms capable of assimilating hydrolysis materials. Targeting plastic substitution and increasing the growth of biodegradable goods (no harm to soil particles) can accelerate the production of natural materials instead of synthetics for the agricultural industry and for all. The removal of plastics from human life is a productive way to conserve soil and other living things.

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