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Impact of Agricultural Plastic Waste on the Environment

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Abstract

Plastics have become ubiquitous ever since their introduction into our environment in the 1950s. it is currently extensively used in our day-to-day life. Various properties of plastic, its functionality, and relatively low cost make them a preferred choice for the creation of a wide range of products. Today it is very difficult to imagine life without the use of plastic products in one or the other form. Even agriculture cannot be excluded from the use of plastic products. Various modern agricultural practices employ a wide range of plastic products like mulches, irrigation pipes, etc., to help improve productivity. Although initially the use of plastic was intended to make life easy for humans but gradually due to its extensive use it has started becoming a problem for the environment. The properties that make plastics so useful, concomitantly create problems for the environment when they reach the end of their intended lives. Due to the use of diverse polymers and additives blended into plastic sorting and recycling becomes more difficult also being a man-made polymer, it can only be degraded by very few microorganisms. This results in plastic remaining persistent in the environment for many decades once they enter it. As the world's demand for plastics increases, leakage into the environment also increases thereby hindering efforts to mitigate environmental contamination. Once they enter the environment plastic can cause harm in several different ways. The adverse effect of large plastic polymers is very well documented in various studies conducted on the marine environment but when these large polymers degrade their impact becomes more adverse as it starts not only individuals at the cellular level but also potentially the entire ecosystem. Thus the current review is intended to stimulate a discussion on making use of plastic products in agriculture only where they are very essentially required keeping in mind their hazardous effect on human health as well as the environment. It also aims at transforming the agricultural production system and achieving sustainable food security without compromising the health of the ecosystem.

Keywords: *Plastic, agriculture waste, microplastic, ecosystem, health hazard.*

Introduction

Plastics are synthetic organic polymers that are widely used in human lives having different applications ranging from water bottles, clothing, food packaging, medical supplies, electronic goods, construction materials, etc. ever since their invention plastics have progressively been incorporated into the living environment. The first synthetic material was invented in the year 1855 and by 1963 we were already living in the "Age of Plastics".Initially, although plastic was assumed to be harmless and inert, over the year' the accumulation of plastic and its dumping into the environment has led to several problems associated with it. From 1950 to 2018, about 6.3 billion tonnes of plastics have been produced worldwide of which 9% and 12% have been recycled and incinerated, respectively [41]. The constant increase in human population and consistent demand for plastics and plastic products are the major reasons responsible for the continuous increase in the production of plastics, the generation of plastic waste, and its accompanying environmental pollution. In the past few decades, plastics with their wide range of

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Table 1: Different types of plastic polymers being used currently in agriculture

S.No.	Main Plastic Polymers	Less Frequently used Plastic Polymers	Biodegradable Polymers
1.	Polyethylene (PE) Low-density PE (LDPE) High-density PE (HDPE)	Polycarbonate (PC)	Polylactic acid (PLA)
2.	Polypropylene (PP)	Polymethylmethacrylate (PMMA)	Polyhydroxyalkanoates (PHA)
3.	Expanded polystyrene (EPS)	Thermoplastic polyurethane (TPU)	Polybutylene succinate (PBS)
4.	Ethylene-vinyl acetate copolymer (EVA)	Polyamide (Nylon)	Starch blends
5.	Polyvinylchloride (PVC)	Acrylonitrile butadiene styrene (ABS)	Polybutylene adipate terephthalate (PBAT)
6.	Polyethylene terephthalate (PET)		Polycaprolactone (PCL)

properties, chemical composition, and applications have become an indispensable and versatile product in our environment. Polythene or polyethylene, the most important form of plastic, is a polymer of ethylene gas (CH_2=CH_2) which is commonly used in our day-to-day life like grocery bags, shampoo bottles, bulletproof vests, etc. Several kinds of polythenes are known with most having the general chemical formula $(C_2H_4)nH_2$. There are various categories of polyethylene low-density polyethylene (LDPE), medium-density polythene (MDPE), high-density polyethylene (HDPE), and very low-density polyethylene (VLDPE)[32]. Among these LDPE is commonly used for making grocery bags, food wrapping material, power cable sheathing, and laboratory containers as it is excellently resistant to dilute and concentrated acids, ketones, and vegetable oils. The versatile nature of LPDE makes it a major cause of pollution to our environment [39].

Environmental pollution by plastic wastes is now recognized widely as a major environmental burden, especially in the aquatic environment where the biophysical breakdown of plastics is a very slow and time taking process that has very high detrimental effects on marine life, and very limited options for the removal of plastic waste. The various types of plastic polymers that are currently being used in various agricultural products are represented in table 1.

The major use of plastic in agriculture includes surface mulching films, containers, polymer-coated controlled-release fertilizers, and nets/ lines used in fisheries and aquacultural operations. In general, based on their physical properties, agricultural plastics can be grouped into three main categories:

• **Flexible Products** – such as mulch films, tunnel and greenhouse films/nets, bags/sacks, silage films, non-woven textile protective “fleeces” and fishing netting and lines;

• **Semi-Flexible Products** – such as tubes and driplines, tree guards/shelters; ropes; and

• **Rigid Products** – such as bottles, baskets, cages, and fishing floats.

Irrespective of their intended use, plastics cause harm when they leak into the environment[9]. This arises during their manufacture, use, and at the end of their intended life. Ecosystem harm caused by plastic may be:

Indirect: through diffuse emissions of GHGs during manufacture and transportation, or

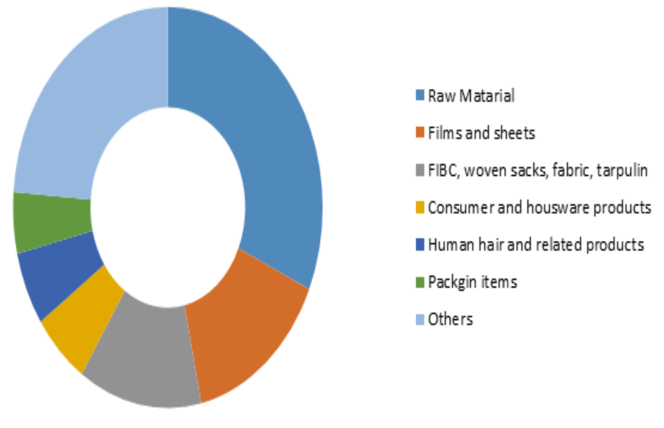
Direct: such as localized impacts on soil function and the health of grazing animals.

Since plastics are mostly made from petroleum-derived precursors, they often contribute to significant greenhouse gas emissions. Recent estimates suggest that global GHG emissions in 2019 attributed to plastics were approximately around 86 gigatonnes of carbon dioxide equivalents (CO_2-eq) and it is expected to rise to 1.34 Gt CO_2 eq by 2030 and 2.8 Gt CO_2 eq by 2050 if plastics consumption and use continue to increase at current rates [14]. Since plastics used in agricultural production is approximately 3.5 percent of global plastic production, it has been estimated that annual GHG generation will be 47 Mt CO_2 eq by 2030 and 98 Mt CO_2 eq by 2050.

The effect of agricultural plastic waste on the environment is that agricultural lands are highly affected by them. Since approximately around 93 percent of all global agricultural activities take place on land, agricultural soils are likely to be the principal receptors for damaged, degraded, or discarded agricultural plastics. Scientific knowledge about the dispersal and ultimate fate of plastic in these terrestrial environments and ecosystems is, however, limited compared with other pollutants and oceanic environments [16]. Moreover, it has been estimated that agricultural soils tend to receive greater quantities of microplastics than oceans [25]. The open burning of plastics releases a range of contaminants into the atmosphere that shas potential harm to human health and the environment. These contaminants include polychlorinated dibenzodioxins and dibenzofurans (PCDD/Fs), both of which are considered persistent organic pollutants in the environment [37]. Fires on dumpsites are also a source of atmospheric contaminants including PCDD/Fs [40]. Where agricultural plastics are disposed of at dumpsites, they provide a ready energy source to exacerbate fires. The dispersal of plastics in aquatic environments is complex due to the connectivity of fresh and saltwater courses, the flow of ocean currents, and their interface with land-based sources. Microplastics have been detected in all aquatic environments, from surface waters to oceanic sediments at depths of up to 3 km [4]. The primary source of agricultural plastics in these environments are discarded nets, floats, and lines from aquaculture structures and fishing vessels; however, significant input from land-based sources is known to occur, primarily as a result of inadequate waste containment and disposal [22]. Notably, ingestion of microplastics by zooplankton is thought to affect the density of excreted faeces, which reduces its rate of sedimentation, hence affecting the cycling of nutrients and carbon in deep oceans [35]. There are between 640 000 and 1.5 million tonnes of ALDFG abandoned lost or otherwise discarded fishing gear [10], accounting for up to 50 percent of the total plastic load from fisheries. Figure 1 represents how plastic waste generated in the terrestrial ecosystem not only pollutes the terrestrial ecosystem but it also enters the aquatic ecosystem thereby polluting it as well and posing a severe threat to marine life.

Product-wise share of plastics exports in India (2021-22)

The Indian plastic industry market is one of the leading sectors in the country. The history of the plastic industry in India dates back to 1957 with the production of polystyrene. India manufactures various products such as plastic and linoleum, houseware products, cordage, fishnets, floorcoverings, medical items, packing items, plastic films, pipes, raw materials etc. The majority of plastic products exported by India is plastic raw materials, films, sheets, woven sacks, fabrics, and tarpaulin.



Source: The Plastics Export Promotion Council of India (PLEXCONCIL)

Impact of plastic waste on the environment

Plastic waste generated in agriculture has an impact on the environment in the following three ways:
1. Physical impact
2. Chemical impact
3. Biological impact

Physical impacts

Plastic waste is considered to harm animals, plants, and soil in the following ways:

Entrapment of animals is the major harm caused to the environment as a result of the presence of plastic waste. Plastic nets, ropes, bags, and cages impede the movement of animals in aquatic and terrestrial environments by entangling them [20]. In the aquatic system, the drifting of discarded nets, pots, and traps has been termed 'ghost fishing' due to the ability of these items to continue to trap animals, leading to their unintended death [24].

Consumption of plastic waste by animals is another major issue attributed to plastic waste**.** Most animals ingest plastic, either directly (e.g. through grazing or filter feeding), or indirectly by consuming contaminated animals; thus transferring and accumulating ingested plastics up the food chain [17].

The harm caused by ingested plastics is generally a function of their size which means they exert their effects in different ways i.e. different plastic sizes ingested have a different impact on the animal body.

The effect caused by various-sized plastic on the animal body is described as under:

Macro and meso plastics: These get potentially co-ingested along with an animal's food, ingested by mistake when the plastic resembles a predator's prey or through scavenging [2]. Ingested meso and macroplastics may accumulate in an animal's gastrointestinal tract, where they can result in blockage or perforation leading to starvation and death; or cause sublethal effects, such as altered growth or reduced body condition [28].

Microplastics: Plastics less than 5 mm in size are generally referred to as microplastics. Their small size makes them highly mobile within the environment in general, and aquatic environments in particular. The uptake of microplastic particles has been observed in a wide range of aquatic and terrestrial animals [38], in plants, including vegetables [26], and drinking water [19]. Ingestion of microplastics by earthworms has been shown to increase the movement of these fragments within soil [31]. Although the physical harm microplastics may cause individual organisms is currently uncertain, it has been suggested that they can elicit inflammatory responses, and damage cells and tissues [21].

Mega and macroplastics, and films, in particular, can block out sunlight thereby impeding the flow of fluids. Liu *et al.*, 2014 [23] suggested that in terrestrial environments, plastics may impede the movement of essential elements in soil such as air, moisture, and nutrients, and the mobility of soil organisms including earthworms. Additionally, microplastics have been shown to affect soil properties, including density, aggregation, and water availability [8]. In aquatic environments, it has been found that plastic waste prevents the transmission of light into the water column thereby affecting photosynthesis by free-floating phytoplankton and those in corals [21].

Chemical impacts

Chemicals associated with plastic waste stem from two main sources:

Those adsorbed from the environment (in particular, aquatic environments): include POPs and some metals

Those introduced into plastic products during their manufacture: include a range of compounds, such as phthalates and brominated flame retardants [12, 15, 16].

Due to their high surface area to volume ratios and hydrophobic nature, plastics can absorb harmful chemicals and concentrate them [3], especially if they have become enveloped in a biofilm. When these biofilms are ingested, there is a high risk for biomagnification up trophic levels; although the extent to which these substances become bioavailable and are released systemically within individual organisms, and the harm they may cause, is likely to depend upon a range of factors. The sorption of chemicals onto plastic debris potentially affects their transport to other environments and may reduce chemical degradation [5].

Biological impacts

Plastics, particularly micro- and nano plastics, can harm a wide range of organisms including animal, plant, and microbial kingdoms, through a combination of chemical and physical effects; both of which have the potential to elicit biological responses in organisms. As higher plants include almost all of the commercially important crops used as food by humans, this has potentially significant implications for agricultural productivity and global food security. There is evidence indicating that agricultural mulch films can reduce seed germination and impair root growth. High levels of plastics (>240 kg ha^{-1}) were shown to impair yields of a range of crops between 11 percent to 25 percent [11]. Unlike mega and macroplastics, which are likely to kill animals relatively quickly through entanglement and engulfment, microplastics are more likely to exert chronic, sublethal effects on animals. This affects not only individual organisms, but may also affect shoals in aquatic environments, and groups/flocks on land. Both higher and lower plants may be adversely affected by plastics. Several types of research carried out on phytoplankton in seas and oceans suggested that phytoplankton may be susceptible to the toxic effects of microplastics, with toxicity increasing as particle size decreases. Several types of research also suggest that photosynthetic activity could be impaired by microplastics (either by reducing sunlight penetration in the water column or by affecting phytoplankton metabolism). This has the potential to not only affect carbon cycling in the oceans but also the basis of almost all oceanic food chains [35]. Microplastics also affect both the composition, biomass, and metabolism of soil microbes and potentially affect the evolution of soil microbes by placing new selective pressures on communities [30]. This leads to hindrance in the ability of microorganisms to recycle nutrients and thus affects soil productivity.

Degradation of plastic in the environment

The degradation of plastic in the environment is a very slow process and it remains as such in its dumped form in the ecosystem. However, over the years various environmental factors lead to the degradation of plastic. The process through which the degradation of plastic occurs in the environment is classified into two broad categories:

Physical process: this involves a change in the bulk structure of the plastic material.

Chemical process: this involves changes at the molecular level i.e. breaking of various bonds and oxidation of long-chain polymers into smaller compounds. The chemical degradation of plastic may be due to microbial action, the presence of heat, light, or a combination of the three factors leading to the breakdown of the plastic. This degradation breaks the large plastic molecules into smaller the accumulation of these smaller fragments and their leeching into the soil and water pose a serious to the environment.

Degradation process of polyethylene: Polythene is the most inert polyolefins in the natural environment and its degradation is very slow because its backbone is constituted by C–C single bonds which do not readily undergo hydrolysis and which resist photo-oxidative degradation due to the lack of UV–visible chromophores. However, impurities during manufacturing and the presence of some unsaturated (C═C) bonds in the main chain or at the chain ends (typically, vinyl groups in HDPE and vinylidenes in LDPE) act as a site of oxidation and help in the degradation of polythene. These sites are readily oxidized by O_3, NO_x, or other tropospheric radicals, often to highly unstable hydroperoxides, which are then converted to more stable UV-absorbing carbonyl groups(42). In the absence of sunlight, thermal-oxidative degradation of PE does not occur at appreciable rates at temperatures below 100 °C. (43). Figure 1 represents the degradation of polyethylene representing similar product formation during both photo and thermal oxidation since the function of photooxidative degradation is to only initiate the chain reaction.

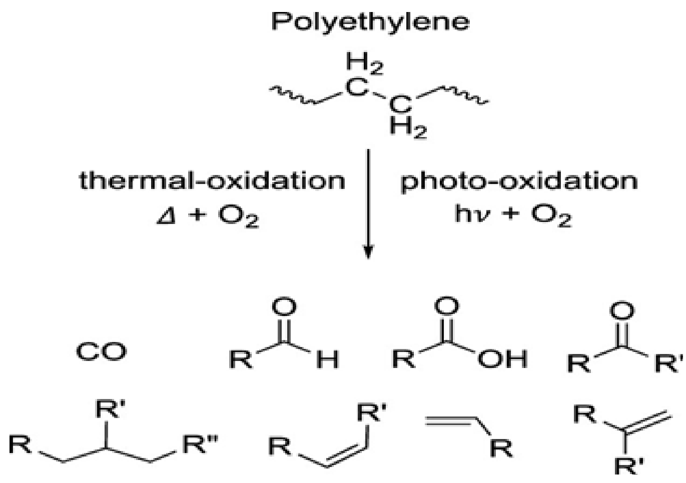


Figure 1: Products formed as a result of thermal- and photo-oxidative degradation pathways for polyethylene (R, R′, and R″ are polymer chains of variable length).

Degradation of Polyethylene Terephthalate (PET): The chemical structure of polyethylene terephthalate (PET) consists of alternating ethylene glycolate and terephthalate subunits, linked via ester bonds therefore under ambient conditions photooxidation is a common process(45). When PET is landfilled or sinks below the regions that are penetrated by sunlight photodegradation cannot occur, there slow thermal oxidative degradation and hydrolysis may occur together, or sequentially. The chemical products resulting from the degradation of PET are represented in figure 2.

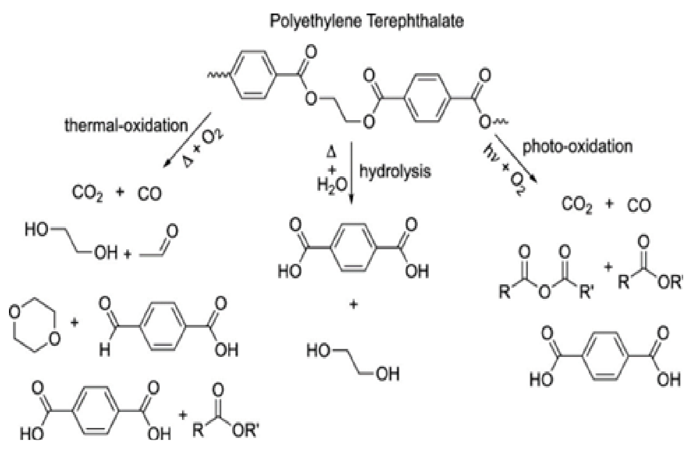


Figure 2: Products of the three common degradation routes in the environmental degradation of polyethylene terephthalate (R and R′ are polymer chains of variable length).

Plastic waste management and recycling

Since it is clear that plastic waste is a very serious threat to our ecosystem thus waste management plays a very crucial role in reducing the toxic effects of plastic waste on the environment. There is a need for systematic plastic waste collection, treatment, and disposal for the global reduction of plastic litters and ocean pollution[18]. Inadequate management of landfills makes way for harmful chemicals in plastic wastes to leach into the environment, polluting the soil, air, and underground water. Proper wastewater management will prevent microplastics from entering the environment from landfills. Most treated wastewater are discharged into rivers or oceans, thereby adding another pollutant and causing water pollution. Therefore, there is a need to ban such practices.

The use of bioplastic must be promoted. Bioplastics are a plastic produced from cellulose that is made of wood pulp by a British chemist in the 1850s. Now, bioplastics can be produced from different biodegradable and non-biodegradable materials including weeds, hemp, plant oil, potato starch, cellulose, corn starch, etc [29]. Bioplastics are environmentally friendly since they require fewer fossil fuels during production in comparison to other types of plastic. In the production of bioplastics, substitutes for fossil fuel resources like wood, cellulose, sugar, and starch are used. This has made bioplastic production more sustainable and environmentally friendly in comparison to conventional plastic production. The production of bioplastics decreases the consumption of non-renewable energy and reduces the emission of greenhouse gases [13].

Previously efforts were being made to protect the environment from plastic litter, but now the focus has shifted to biodegrading the plastic with the help of various microorganisms and recovering value from polythene [7,34,36]. In biodegradation, strong carbon bonds are broken down through microbial actions that reduce the strength of polythene (as molecular weight decreases) and hence polythene gets degraded [27]. This is achieved in two ways: aerobic as well as anaerobic.

In aerobic degradation oxygen acts as an electron acceptor and the final products are carbon dioxide and water [33].

Anaerobic biodegradation occurs in absence of oxygen and therefore microorganisms use nitrate, sulphate and iron as electron acceptor [6].

Several reported examples of plastic-degrading bacteria and fungi are *Bacillus cereus, Pseudomonas aeruginosa, Phanerochaetechrysosporium, Aspergillus versicolor, Streptococcus aureus,* and many more.

Table 2: List of various microorganisms responsible for the biodegradation of various plastic compounds

S. No	Polymer degraded	Species	Degradation efficiency	References
1	Polystyrene	*Pseudomonas* sp.	>10% weight loss	[46]
		Curvularia sp.	Microscopic examination showed adherence and penetrance to the polymer	[47]
		Enterobacter sp. *Citrobacter sedlakii*	0.8% weight loss	[48]
2	Polypropylene	*Vibrio Aspergillus niger*	60% weight loss	[49]
		Bacillus cereus	12% weight loss	[50]
3	Polyethylene terephthalate	*Ideonella-sakaiensis*	Almost complete degradation achieved	[51]
		Saccharomonosporaviridis	13.5% weight loss for PET-GF and 27.0% for PET-S	[52]
		Thermomonosporacurvata	At 50°C, hydrolysis rate 3.3 × 10^{-3} min^{-1}	[53]
4	Polyvinyl chloride	*Pseudomonas citronellolis Bacillus flexus*	19% after 30 days of incubation	[54]

Efforts must be made to educate people on the potential environmental and public health effect of pollution by plastic waste. There is a need for people to be aware of the chemical constituents of plastic products and their health effects. Educational curriculums at different levels must include ways of plastic pollution reduction and waste management systems as information resources.

References

[1.] Alabi OA, Ologbonjaye KI, Awosolu O, Alalade OE (2019) Public and Environmental Health Effects of Plastic Wastes Disposal: A Review. *Journal of Toxicology and Risk Assessment* 5:021

[2.] Andrades, R., dos Santos, R.A., Martins, A.S., Teles, D. & Santos, R.G. 2019. Scavenging as a pathway for plastic ingestion by marine animals. *Environmental Pollution* 248: 159–165.

[3.] Andrady, A.L. 2011. Microplastics in the marine environment. Marine Pollution Bulletin, 62(8): 1596–1605.

[4.] Barrett, J., Chase, Z., Zhang, J., Holl, M.M.B., Willis, K., Williams, A., Hardesty, B.D. *et al.* 2020. Microplastic Pollution in Deep-Sea Sediments From the Great Australian Bight. *Frontiers in Marine Science* 7.

[5.] Beriot, N., Zomer, P., Zornoza, R. &Geissen, V. 2020. A laboratory comparison of the interactions between three plastic mulch types and 38 active substances found in pesticides. *Peer Journal* 8: e9876.

[6.] Datta P.K., Mishra K., and Kumar M.N.V.R., (1998), Popular Plastics and Packaging, Mahindra Publishers, New Delhi, India. p.73.

[7.] David K. A. Barnes., Francois Galgani.., Richard C. Thompson., and Morton Barlaz., (2009), Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B. 364: pp 1985–1998

[8.] de Souza Machado, A.A., Lau, C.W., Kloas, W., Bergmann, J., Bachelier, J.B., Faltin, E., Becker, R. *et al.* 2019. Microplastics Can Change Soil Properties and Affect Plant Performance. *Environmental Science & Technology* 53(10): 6044–6052

[9.] Ellen MacArthur Foundation. 2020. Enabling a circular economy for chemicals with the mass balance approach: a white paper. p. 35.

[10.] FAO. 2018. The State of World Fisheries and Aquaculture - Meeting the sustainable development goals.

[11.] Gao, H., Yan, C., Liu, Q., Ding, W., Chen, B. & Li, Z. 2019. Effects of plastic mulching and plastic residue on agricultural production: A meta-analysis. *Science of The Total Environment* 651: 484–492.

[12.] GESAMP. 2015. Sources, fate, and effects of microplastics in the marine environment: A global assessment. p. 98.

[13.] Gironi F, Vincenzo P (2011) Bioplastics and petroleum-based plastics: Strengths and weaknesses. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects* 33: 1949-1959.

[14.] Hamilton, L., Feit, S., Muffett, C., Kelso, M., Rubright, S., Bernhardt, C., Schaeffer, E. *et al.* 2019. Plastic and Climate: The Hidden Costs of a Plastic Planet. p. 208.

[15.] Harding, S. 2016. Marine Debris: Understanding, Preventing and Mitigating the Significant Adverse Impacts on Marine and Coastal Biodiversity.

[16.] Horton, A., Walton, A., Spurgeon, D., Lahive, E. & Svendsen, C. 2017. Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of The Total Environment*, 586

[17.] Huerta Lwanga, E., Mendoza Vega, J., Ku Quej, V., Chi, J. de los A., Sanchez del Cid, L., Chi, C., Escalona Segura, G. *et al.* 2017. Field evidence for transfer of plastic debris along a terrestrial food chain. Scientific Reports, 7(1): 14071

[18.] Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, *et al.* (2015) Plastic waste inputs from land into the ocean. *Science* 347: 768-771.

[19.] Koelmans, A.A., Mohamed Nor, N.H., Hermsen, E., Kooi, M., Mintenig, S.M. & De France, J. 2019. Microplastics in freshwaters and drinking water: Critical review and assessment of data quality. *Water Research*, 155: 410–422

[20.] Kolenda, K., Pawlik, M., Kuśmierek, N., Smolis, A. &Kadej, M. 2021. Online media reveals a global problem of discarded containers as deadly traps for animals. Scientific Reports, 11(1): 267.

[21.] Landrigan, P.J., Stegeman, J.J., Fleming, L.E., Allemand, D., Anderson, D.M., Backer, L.C., Brucker-Davis, F. *et al.* 2020. Human Health and Ocean Pollution. *Annals of Global Health*, 86(1): 151.

[22.] Li, W.C., Tse, H.F. &Fok, L. 2016. Plastic waste in the marine environment: A review of sources, occurrence, and effects. *Science of The Total Environment*, 566–567: 333–349

[23.] Liu, E.K., He, W.Q. & Yan, C.R. 2014. `White revolution' to `white pollution'—agricultural plastic film mulch in China. Environmental Research Letters, 9(9): 091001.

[24.] Lively, J.A. & Good, T.P. 2019. Chapter 10 - Ghost Fishing. In C. Sheppard, ed. World Seas: an Environmental Evaluation (Second Edition), pp. 183–196.

[25.] Nizzetto, L., Futter, M. &Langaas, S. 2016. Are Agricultural Soils Dumps for Microplastics of Urban Origin? *Environmental Science & Technology*, 50(20): 10777–10779.

[26.] Oliveri Conti, G., Ferrante, M., Banni, M., Favara, C., Nicolosi, I., Cristaldi, A., Fiore, M. *et al.* 2020. Micro- and nano-plastics in edible fruit and vegetables. The first diet risks assessment for the general population. Environmental Research, 187: 109677.

[27.] Pruter A.T., (1987), Sources, quantities and distribution of persistent plastics in the marine environment, Marine Pollution Bulletin, 18, pp 305–310

[28.] Puskic, P.S., Lavers, J.L. & Bond, A.L. 2020. A critical review of harm associated with plastic ingestion on vertebrates. *Science of The Total Environment*, 743: 140666

[29.] Reddy RL, Reddy SV, Gupta GA (2013) Study of Bioplastics as Green and Sustainable Alternative to Plastics. *International Journal of Emerging Technology and Advanced Engineer* 3: 82-89.

[30.] Rillig, M.C., de Souza Machado, A.A., Lehmann, A. &Klümper, U. 2019. Evolutionary implications of microplastics for soil biota. *Environmental Chemistry*, 16(1): 3

[31.] Rillig, M.C., Ziersch, L. & Hempel, S. 2017. Microplastic transport in soil by earthworms. Scientific Reports, 7(1): 1362.

[32.] Rivard C., L. Moens, K. Roberts, J. Brighar, and S. Kelley, (1995), Starch esters as biodegradable plastics: Effects of ester group chain length and degree of substitution on anaerobic biodegradation, *Enzyme and Microbial Technology*, 17, pp 848-852

[33.] Seymour RB, (1989), Polymer Science Before& After 1899: Notable Developments during The Lifetime Of MaurtisDekkar, *Journal of Macromolecular Science*, 26, pp 1023-1032

[34.] Sharma P., Bhattacharyya S., Verma V., Kalyan R.K., Kumar V., Pandey K.N., and Singh M., (2013), Studies on Isolation and Identification of Active Microorganisms during Degradation of Polyethylene / Starch Film, *International Research Journal of Environment Sciences*, 2(9), pp 83-85

[35.] Shen, M., Huang, W., Chen, M., Song, B., Zeng, G. & Zhang, Y. 2020. (Micro)plastic crisis: Un-ignorable contribution to global greenhouse gas emissions and climate change. *Journal of Cleaner Production*, 254: 120138.

[36.] Singh B., (2005), Harmful effect of plastic in animals: The Indian Cow, *The Scientific and Economic Journal*, 2, pp 10-18

[37.] Stockholm Convention Secretariat. 2001. Stockholm Convention on Persistent Organic Pollutants.

[38.] Truong, N. van &beiPing, C. 2019. Plastic marine debris: sources, impacts, and management. *International Journal of Environmental Studies*, 76(6): 953–973.

[39.] Usha R., Sangeetha T., and Palaniswamy M., (2011), Screening of Polyethylene Degrading Microorganisms from Garbage Soil. *Libyan Agriculture Research Centre Journal International*, 2(4), pp 200-204

[40.] Weber, R., Herold, C., Hollert, H., Kamphues, J., Blepp, M. &Ballschmiter, K. 2018. Reviewing the relevance of dioxin and PCB sources for food from animal origin and the need for their inventory, control, and management. *Environmental Sciences Europe*, 30(1): 42

[41.] www.wikipedia.com

[42.] Anne M. Arnold, Zachary C. Kennedy, Joshua A. Silverstein, Jacob F. Ellis, Janine R. Hutchison. Pearlescent Mica-Doped Alginate as a Stable, Vibrant Medium for Two-Dimensional and Three-Dimensional Art. *ACS Omega* **2021,** *6* (29) , 18694-18701

[43.] Hanqing Jiang, Shengda Wang, Yanhui Wang, Yaxian Wang, Liang Li, Li Ma, Dongmei Cui, Tao Tang. Synthesis of Long-Subchain Hyperbranched Polypropylene Using Thermally Degraded Products as Precursor. *Macromolecules* 2021**,** *54* (12) , 5567-5576

[44.] Ali Chamas, Hyunjin Moon, Jiajia Zheng, Yang Qiu, Tarnuma Tabassum, Jun Hee Jang, Mahdi Abu-Omar, Susannah L. Scott, and Sangwon Suh. Degradation Rates of Plastics in the Environment. *ACS Sustainable Chemistry & Engineering* 2020 *8* (9), 3494-3511

[45.] KateřinaSkleničková, VěraVlčková, Sabina Abbrent, Sonia Bujok, Aleksandra Paruzel, LíviaKanizsová, Olga Trhlíková, Jana ŘíhováAmbrožová, Martin Halecký, Hynek Beneš. Open-Cell Aliphatic Polyurethane Foams with High Content of Polysaccharides: Structure, Degradation, and Ecotoxicity. *ACS Sustainable Chemistry & Engineering* 2021, *9* (17), 6023-6032

[46.] Mohan A. J., Sekhar V. C., Bhaskar T., Nampoothiri K. M. (2016). Microbial assisted high impact polystyrene (HIP) degradation. *Bioresour. Technol.* 213 204–207

[47.] Motta O., Proto A., De Carlo F., De Caro F., Santoro E., Brunetti L., et al. (2009). Utilization of chemically oxidized polystyrene as co-substrate by filamentous fungi. *Int. J. Hygiene Environ. Health* 212 61–66.

[48.] Mor R., Sivan A. (2008). Biofilm formation and partial biodegradation of polystyrene by the actinomycete *Rhodococcusruber*: biodegradation of polystyrene. *Biodegradation* 19 851–858.

[49.] Cacciari P., Quatrini G., Zirletta E., Mincione V., Vinciguerra P., Lupattelli P., et al. (1993). Isotactic polypropylene biodegradation by a microbial community: physicochemical characterization of metabolites produced. *Appl. Environ. Microbiol.* 59 3695–3700.

[50.] Auta H. S., Emenike C. U., Fauziah S. H. (2017). Screening for Polypropylene degradation potential of bacteria isolated from mangrove ecosystems in Penninsular Malaysia. *IJBBB* 7 245–251

[51.] Yoshida S., Hiraga K., Takehara T., Oda K. (2016). A bacterium that degrades and assimilatespoly (ethyleneterephthalate). Science 351 1196–1199.

[52.] Kawai F., Oda M., Tamashiro T., Waku T., Tanaka N., Yamamoto M., et al. (2014). A novel Ca2+-activated, thermostabilized polyesterase capable of hydrolyzing polyethylene terephthalate from Saccharomonosporaviridis AHK 190. Appl. Microbiol. Biotechnol. 98 10053–10064.

[53.] Wei R., Oeser T., Then J., Kühn N., Barth M., Zimmermann W. (2014b). Functional characterization and structural modeling of synthetic polyester-degrading hydrolases form Thermomonosporacurvata. AMB Express 4:44

[54.] Giacomucci L., Raddadi N., Soccio M., Lotti N., Fava F. (2019). Polyvinyl chloride biodegradation by Pseudomonas citronellolis and Bacillus flexus. New Biotechnol. 52 35–41